Unique Thermal Spray Cabinet with High Enthalpy Plasma

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Abstract

KLM Royal Dutch Airlines has the oldest Maintenance, Repair and Overhaul (MRO) shop for aircraft in the world (more than 80 years old). The company's philosophy in all areas, including thermal spray, has always been to pursue the latest innovations and to maintain well-equipped facilities with state-of-the-art processes, equipment and materials for performing repairs. In the area of thermal spray, the latest procurement is a state-of-the-art unique cabinet with a high enthalpy plasma spray process. This new cabinet and new plasma spray process provides up-to-date technology for applying thermal spray coatings on aircraft engines. In this paper, experiences and the latest results obtained using this system to deposit various types of coatings used on aircraft will be reported.

Introduction

KLM started incorporating thermal spraying in their Engineering & Maintenance Division in 1969 with flame spray equipment (acetylene-oxygen). In the mid seventies the first plasma spray equipment was bought. In 1987 the first fully automated and robotized plasma spray system was acquired and in 1993 the first electric arc spray system entered the engine overhaul shop of the KLM.

In 2002 KLM initiated planning to build a complete new engine shop at Schiphol-Airport for its engine MRO market on General Electric (CF6-50, CF6-80A, CF6-80C2, CF6-80E1) and CFM-International (CFM56/7B) engines. Taking into account all the occupational and environmental laws, it was determined that this would be an excellent opportunity to introduce state-of-the-art processes, techniques and equipment. This was considered particularly important for thermal spraying because for engine repairs the company wanted to establish a centre of excellence in thermal spraying and be at the cutting-edge of this field.

Changes in the Aviation Industry

The last couple of decades have brought many changes in the aviation industry. These changes concern, among others, aviation legislation, occupational health laws, environmental laws, safety laws, European laws (CE directives), standardization (ISO, CEN, NEN, DIN, AMS, etc.), OEM manuals (e.g., new repairs, new consumables). Also, the financial situation of companies in the aviation industry has changed dramatically, caused, for example, by politics, market changes, cost of consumables (e.g., nickel prices), cost of labor and external factors like SARS, BSA, wars and terrorism.

<u>Innovations</u>

A key question for MRO facilities in this changing environment is how to survive in the current market. One of the possible ways of increasing the chances of surviving is to be innovative and introduce new ideas in the MRO market. Innovations can be focused on techniques and labor. In the case of techniques, computerized and automated processes (like: ultra high waterjet stripping, shotpeening, TIG-welding, LASER-cladding and even thermal spraying) can be considered In the case of labor, special air-conditioned working areas, separate cabinets for smokers and improved work conditions can improve the functioning of a thermal spray facility.

In the Netherlands, the latter of these two approaches is especially being promoted. Manual labor involves, for example, bench work, NDT work, high pressure cleaning, welding, chemical cleaning and, again, thermal spraying. Dutch occupational laws are encouraging industry to take the operator out of dangerous processes, where exposure to hazardous materials are possible. Dutch legislation also requires a so-called "minimalization obligation" for labor-exposure by means of the latest 'state-of-the-art' equipment.

State of the Art

As mentioned in the introduction, in 2002 KLM began planning to build a complete new engine overhaul shop at Schiphol-Airport in the Netherlands. Therefore KLM Engine Services Department started looking at new solutions and state-of-the-art thermal spray equipment. The Process, Equipment and Materials Development Department of the KLM Engineering & Maintenance Division began to prepare specifications for a unique fully automated and robotized thermal spray cabinet with features never seen before in the thermal spray industry.

All the major thermal spray companies were invited to engineer and quote on this unique specification. Two years later in 2004 a new state-of-the-art fully automated and robotized cabinet was built, including 5 different thermal spray systems: 1) a closed-loop electric arc Thermach spray system: AT400, 2) a traditional external Sulzer-Metco APS system: 9MB, 3) a traditional internal Sulzer-Metco APS system: 7MST, 4) a HP-HVOF Praxair-Tafa Inc. system: JP8000 and 5) a High Enthalpy Progressive Technology Inc. APS system: 100HE. Included in this cabinet (Fig. 1) is a 4 axes gantry-robot; an indexable turn table; a unique dust suction, filtration and recirculation system; an infra-red part temperature control system; a CO2 cooling system; a cabinet gas and temperature sensor system; and gas flow measurement by 'critical orifices'.

Figure 1: The new unique state-of-the- art fully automated and robotized thermal spray cabinet of Progressive Technology Inc.

Features

The new cabinet is equipped with the latest Siemens PLC as slave computer and a Windows XP based PC as master computer. Incorporated in the PC is a Progressive Technologies Inc. CITS (Computer Integrated Thermal Spraying) software with special features like preventive maintenance and cost-of-ownership calculation. Off-line programming of parts is possible. All the incorporated thermal spray guns are monitored, controlled and recorded through the master-PC.

Dust Suction, Filtration and Recirculation System

Probably one of the most advanced parts of the cabinet is the unique dust suction, filtration and recirculation system. The cabinet is designed in such a way that there is an adjustable combined 'down flow floor air suction' and 'horizontal flow plenum air suction', which ensures almost no dust problems during spraying. In addition, all of the dust-contaminated air is sucked to the newest Donaldson-Torit cartridge filtration system (DFO-56/4). After the first cartridge filtration step, the air is pushed through a second step HEPA #14 filtration unit. After this step the air is monitored by a computer-controlled continuous particle measuring system. Then the air is pushed through a third step HEPA #14 filtration unit. Subsequently, the ultra-filtered air is divided by electrical valves to recirculation piping and exhaust piping outside the building. The recirculation percentage is computer controlled and depends on gas and temperature sensors in the cabinet. Also, the sucked air quantity is adjustable by a frequency-controlled ventilator and is PLC-monitored. Measurements of the filtered air showed that this system had a dust emission lower than 1.5 ng/m^3 of air, which is unique in the world for thermal spray systems. This means that the dust content of the recirculated or exhausted air has a value 1000 times lower than that required by the most stringent proposed chromate (VI) exposure level (see Table 1).

Table 1: EPA guidelines for chromate levels.

Limits	PEL value µg/m3	Time weighed average
Current PEL value in The Netherlands	10	15 minutes
KLM guideline	0,5	8 hour
Proposed PEL value of the Dutch Health Council [2] (risk of cancer: 4 out of 1000 employees)	2	8 hour
Proposed PEL value of the Dutch Health Council [2] (risk of cancer 4 out of 100,000 employees)	0,02	8 hour

100 HE High Enthalpy Plasma Spray gun

One of the unique processes incorporated in the cabinet is the new 100HE enthalpy plasma spray gun of Progressive Technologies Inc (Fig. 2). This gun is capable of spraying with a high feedrate (up to 200 g/min) combined with a very high deposition efficiency (DE) (up to 95%) and excellent coating qualities (porosity contents, oxide levels, tensile bond strength and density values reaching those of HVOF coatings).

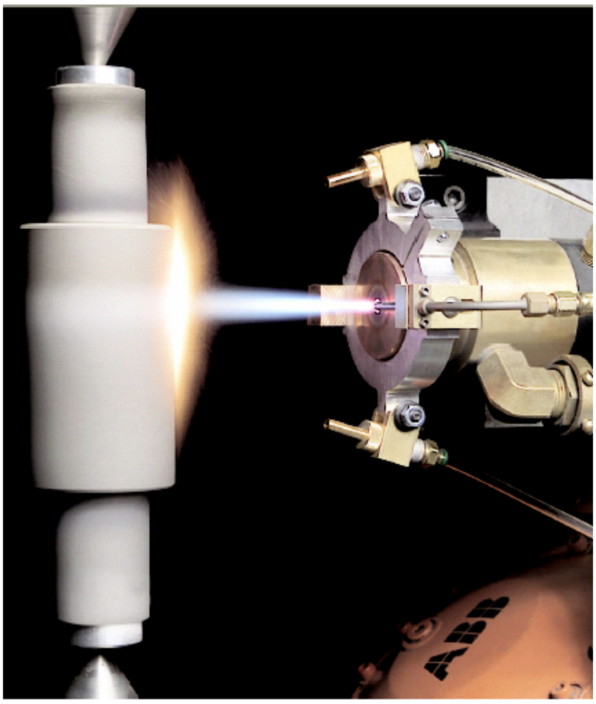

Figure 2: The new100HE high enthalpy plasma spray gun of Progressive Technologies Inc.

Experience

KLM sprayed their polyester-aluminum powder as the first powder to check out the capabilities of the new high enthalpy plasma spray system. See Fig. 3 and 4 (gas values in scfh) for the first spray results. Table 2 shows the results of a parameter DOE by PTI [3] for optimizing coating results of Polyester-Aluminum. The results of this first tested powder were very successful at KLM and KLM started spraying other powders.

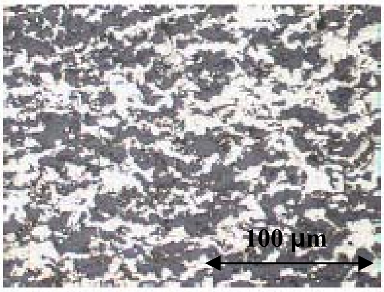

Figure 3: Spray results #1 of polyester-aluminum (powder: PAC 905-6; hardness 57 – 60 R_{15Y} ; 75% DE at 180 g/min.; spray parameters: Ar320, N2 90, H2 120, 240V, 330A)

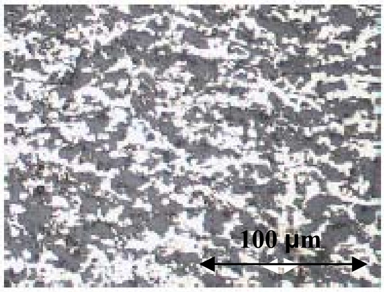

Figure 4: Spray results #2 of polyester-aluminum (powder: PAC 905-6; hardness 62 – 65 R_{15Y} ; 70% DE at 300 g/min. spray parameters: Ar300, N2 100, H2 120, 240V, 330A)

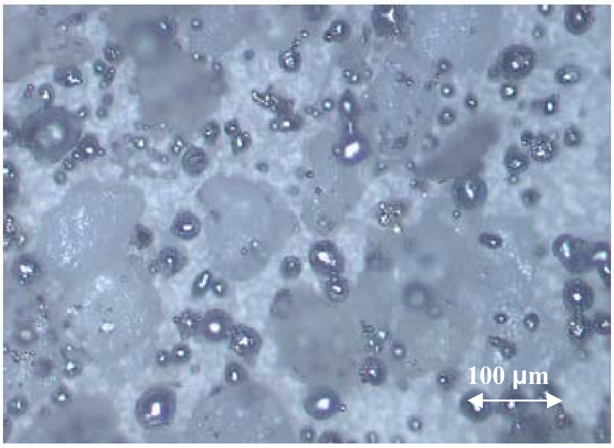

Figure 5: Spray results of polyester-aluminum (powder: PAC 905-6; image analysis results).

Table 2: DOE for polyester-aluminum powder.

Test	Nozzle	Ar	N2	H2	kw	Feed-rate	Carrier	S.O.	DE %
1	.450L ext	350	100	50	50	180	12	6"	77
2	.450L ext	350	100	70	60	180	12	6"	77
3	.450L ext	320	100	60	55	180	14	5.5"	79
4	.450L ext	320	100	50	50	180	14	5.5"	80
5	.450L ext	280	100	60	55	180	12	5.5"	74
6	.450L ext	350	100	60	55	180	12	5.5"	78
7	.450L ext	320	100	50	50	180	12	5.5"	76
8	.550 ext	350	100	50	45	180	12	7"	72
9	.550 ext	350	100	50	55	180	12	7"	70
10	.550 ext	370	100	40	45	180	12	6"	77
11	.550 ext	370	120	40	45	180	12	6"	78
12	.550 ext	320	100	40	45	180	12	6"	74
13	.550 ext	350	100	40	40	180	12	6"	78
14	.550 ext	350	100	40	40	180	12	5"	81
15	.550 ext	350	100	40	50	180	12	5"	76
16	.550 ext	350	100	30	40	180	12	5"	80
17	.550 ext	350	100	20	40	180	12	5"	80
18	.550 ext	350	100	20	40	180	12	4.5"	81
19	.550 ext	330	100	20	40	180	12	4.5"	80
20	.550 ext	360	100	20	35	180	12	4.5"	80
21	.550 ext	360	100	50	40	180	12	4.5"	80
22	.550 ext	360	100	50	35	180	12	4.5"	81
23	.450L ext	340	100	50	50	180	14	5"	83
24	.450L ext	350	100	50	60	180	14	5"	84
25	.450L ext	370	120	60	50	180	14	5"	84
26	.450 ext	370	120	60	50	180	14	5"	82
27	.450 ext	370	120	60	50	180	14	5.5"	81
28	.450 ext	390	120	60	50	180	14	5.5"	82
29	.450L ext	370	120	60	50	180	14	5"	83
30	.450L ext	370	130	60	50	180	14	5"	82
31	.450L ext	370	120	60	50	180	14	4.5"	83
32	.450L ext	370	120	55	45	120	12	5"	80
33	.450L ext	370	120	50	40	120	12	5"	78
34	.450L ext	370	120	60	60	120	14	5.5"	84
35	.450L ext	350	100	50	45	120	14	6"	82
36	.450L ext	370	100	40	45	120	14	4.5"	84
37	.450L ext	370	100	50	45	120	14	4.5"	84

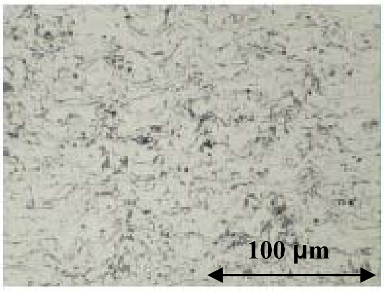

Figure 6: Spray results of Inconel718 (powder: PAC 718F; spray parameters: Ar240, N2 90, H2 40, 200V, 330A).

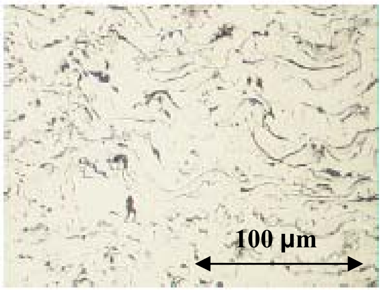

Figure 7: Spray results of Ni-Cr-Al (powder: PAC908C; spray parameters: Ar200, N2 100, H2 100, 150V, 600A).

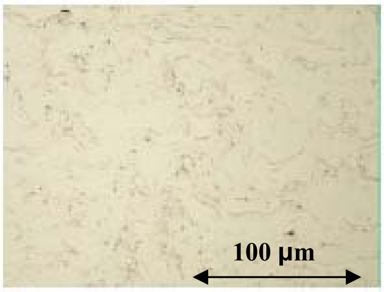

Figure 8: Results of CuNiIn (powder: PAC658C roasted; spray parameters: Ar300, N2 100, H2 40, 230V,240A).

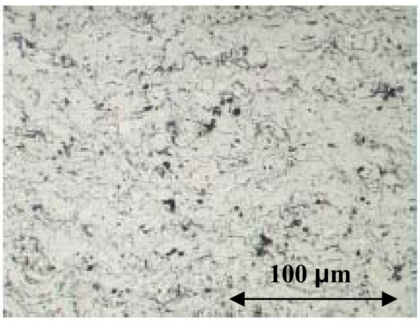

Figure 9: Results of CrC-NiCr (powder: PAC131; spray parameters: Ar200, N2 100, H2 100, 210V, 420A)

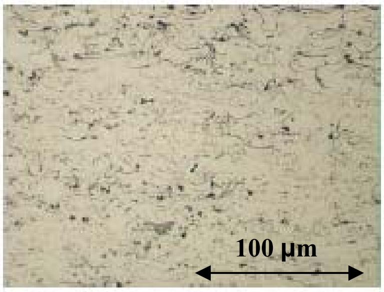

Figure 10: Sprayed coating results of T800 (powder: PAC T800; spray parameters: Ar200, N2 100, H2 150, 250V, 380A).

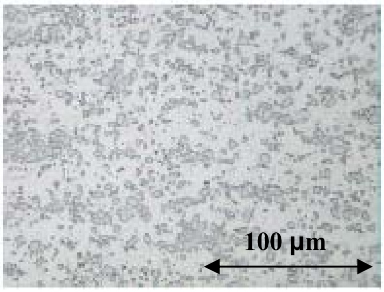

Figure 11: Spray results of WC-Co12 (powder: PAC127; spray parameters: Ar300, N2 120, H2 50, 260V, 330A).

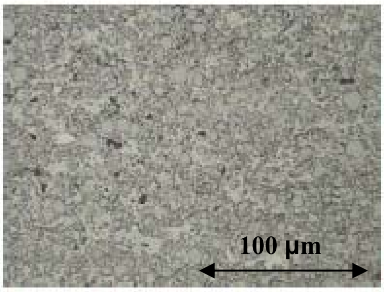

Figure12: Results of WC-Co17 (powder:PAC200; parameters: Ar350, N2 120, H2 40, He 200, 270V, 340A).

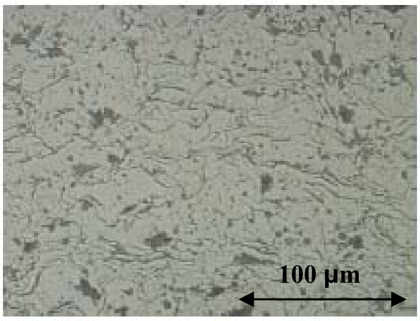

Figure 13: Sprayed coating results of ZrO_2-Y_2O_3 (powder: PAC2008P; spray parameters: Ar150, N150, H2 120, 230V, 400A).

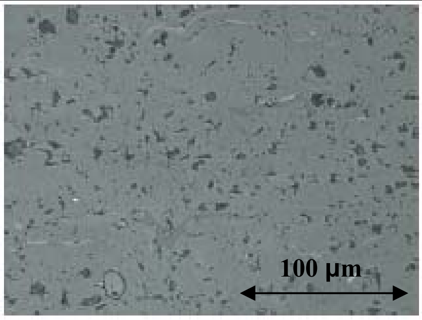

Figure 14: Spray results of Al_2O_3 (powder: PAC 701B; spray parameters: Ar150, N2 120, H2 120, 230V,410A).

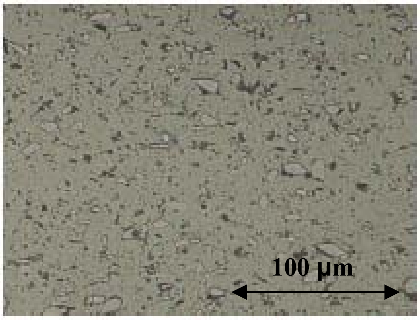

Figure 15: Sprayed coating results of A l(powder: PAC 19SP; spray parameters: Ar150, N2 150, H2 120, 230V, 410A .)

All coatings sprayed of figure 6 till 15 showed in general increased densities, lower porosities, higher tensile bond strengths, better uniformities, lower oxide contents, etc. compared to the traditional APS sprayed coatings.

Table 3: Typical application for which the new state-of-the-art thermal spray cabinet is used..

Parts:	Coatings:	Function:
LPC booster shrouds	Polyester-Al	Abradable
Combustor	NiCrAIY / Y2O3-ZrO2	TBC
HPC stator casing	NiAl / Al	Abradable
Fanmidshaft	WC / Co	Anti-wear
Turbine Mid Frame	Inconel 718	Dimensional restoration
LPT casing	CrC-NiCr	Anti-impact
Air / Oil seal	NiAl / Al2O3	Machine element clearance control coating

The most important characteristics of the 100HE high enthalpy system are the high feedrates and high DE's compared to a standard APS system. The combination of high feedrates and high DE's resulted generally in a decrease by a factor of almost 2.5 in the spray times (depending on the kind of coating, coating thicknesses and the part geometry). Turn-around-times (TATs) are very important in the aircraft MRO business because reducing the TAT reduces cost . The reduced TATs together with the powder savings derived from high DE's for the 100HE spray system resulted in a payback time for this new system of 15 months at KLM.

The new system is now being used in production for applying all known thermal spray materials used in the aviation industry for General Electric and CFM-International aircraft engines.

Summary

The KLM introduced a new state of the art fully automated and robotized thermal spray cabinet with 5 thermal spray processes and among all things unique features on dust suction and filtration. Especially the incorporated new 100HE High Enthalpy plasma spray process turned out to be a great success on DE, coating quality, TAT and hardware life. By introducing this unique cabinet KLM engine services is capable of fulfilling the future capacity demanding and has a versatile flexible spray system in house.
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Conclusion

KLM has invested in the next generation flexible, automated and robotized thermal spray cabinet including a high enthalpy plasma spray system in order to establish and maintain a center of excellence in thermal spraying. With this system, KLM will stay at the forefront of the aircraft MRO market, which was reported at the AEA (Association of European Airlines) office [1].

Acknowledgement

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References

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