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Thermal spraying — Powders —

Part 2: Comparison of coating performance and spray powder chemistry

Projection thermique — Poudres —

Partie 2: Comparaison de enduire performance et poudre chimie

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*.

This first edition of ISO 14232-2, together with ISO 14232-1:2017, cancels and replaces ISO 14232:2000, which has been technically revised.

A list of all parts in the ISO 14232 series can be found on the ISO website.

Introduction

The performance of a sprayed coating is one of the major factors for its industrial application. However, the chemical composition or chemistry of the sprayed powder is not always the key information for the actual coating application. Understanding the relationship between the chemical composition/chemistry of the sprayed powder and the resulting coating performance allows for the most effective selection of powder to obtain the required coating performance.

This document provides technical information describing the comparison of spray powder chemistry and coating performance. Spray coating performances are extremely diverse. This document examines the performances of wear resistance and corrosion resistance. Other performance categories are in preparation.

The ISO 14232 series consists of two parts. ISO 14232-1 examines the characterization of spray powders. This document is a technical report that examines how technical literature describes the application of powders.

Thermal spraying — Powders —

Part 2: Comparison of coating performance and spray powder chemistry

1 Scope

This document gives guidelines for selecting the powder chemistry or composition for obtaining an objective coating performance.

It provides comparisons of coating performance for wear resistance (Table 1) and corrosion resistance (Table 2) to spray powder chemistry/composition. The wear types shown in Table 1 are abrasive, adhesive, chemical, erosion, fretting, impact, rolling and sliding. The corrosion types shown in Table 2 are acid/alkaline/salt, atmospheric, biochemical, biological, chemical agent, chemicals in food, combustion gas, sea water, fresh water, molten metal, molten salt, non-aqueous solution, soil, steam and miscellaneous. The tables give the coating chemistries and describe the composition of spray powder of metals/alloys, ceramics and cermets. The guidelines have been produced on the basis of academic literature, in particular the *Journal of Thermal Spray Technology* and the *Proceedings of the International Thermal Spray Conference*.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

4 Comparison table of wear resistance and spray powder chemistry

Table 1 — Comparison of wear resistance and spray powder chemistry

Type of wear	Metals	Ceramics	Cermet
Abrasive	316L[75]	Al2O3[6][8][16][74][77][80][93][96]	Al2O3-Ni[77][80]
	Amorphous ferrochromes[9]	Al2O3-TiO2[24][64][99]	Al-SiC[10]
	Co-based self-fluxing alloy[100]	Al2O3-ZrO2[80]	Carbide cermet[9]
	Cobalt alloys[9]	Cr2O3[8][54][73][74][75][93][94][99]	Cr3C2-NiCr[37][42][52][55][62][73][74][75][85][99][69]
	Fe-13Cr-7Ni-4B-5W-0,2C[30]	TiO2[6][28][54][96]	Cr3C2-NiCr-SFA[67]
	Fe-40Al-0,05Zr[31]	ZrO2-Y2O3[6][54]	FeNiAlCr-TiC-Al2O3[70]

Table 1 *(continued)*

Type of wear	Metals	Ceramics	Cermet
	FeCrMoWMnBCSi[87] FeCrNi[99] Fusible[9] Inconel 625[55] Mo alloys[9] Ni-21Cr-8,3Mo-5Fe-1,2Nb-Ti[29] NiCr[51] NiCrSiB[11][50][75][99][107] Stellite 6[50] Stellite-21[42]		Ni-based cermet[92] Ni 60[60] NiCrSiB-WC-Co[99] NiWC25[60] NiWC35[60] SiC cermet[57] TiC-SFA[56] VC-WC-CoCr[74] WC cermet[61] WC-Co[1][3][5][11][15][17][22][37][48][49][63][65][66][68][69][74][75][85][99][101][104] WC-CoCr[15][42][48][49][55][58][69][73][74][84][85][99] WC-Ni[69]
Adhesive	Fe-0,8C[34] Fe-19Cr- 0,1C-1,6B[34] FeCrMoWMnBCSi[88]	Al2O3[74][98] Cr2O3[74][81][103] TiO2[28]	Al2O3-Al[97] Cr3C2-NiCr[37][74][103] FeB-BN[102] MoS2 cermet[59] VC-WC-CoCr[74] WC-Co[5][37][74][89] WC-CoCr[41][74][103]
Chemical	Inconel 625[55]	Al2O3-TiO2[64]	Cr3C2-NiCr[55][85] WC-Co[85] WC-CoCr[41][55][85]
Erosion	Fe-0,8C[34] Fe-19Cr-0,1C-1,6B[34] Fe-40Al-0,05Zr[31] FeCrMoWMnBCSi[88] Inconel 625[55] NiCrSiB[11] NiCrSiFeB[21]	Cr2O3[94] TiO2[28] ZrO2-5CaO[4] ZrO2-Y2O3[4][18][82]	Cr3C2-NiCr[52][55][62][69] Cr3C2-NiCr-SFA[67] FeNiAlCr-TiC-Al2O3[70] Ni60[60] NiWC25[60] NiWC35[60] SiC cermet[57] TiC-SFA[56] WC cermet[61] WC-Co[3][4][5][11][21][22][38][49][63][69][95] WC-CoCr[21][49][55][58][69] WC-CoFe[21] WC-Ni[69]
Fretting	CuNiIn[91]		Cr3C2-NiCr[69] WC-Co[69][89] WC-CoCr[69] WC-Ni[69]

Table 1 *(continued)*

Type of wear	Metals	Ceramics	Cermet
Impact	Amorphous ferrochromes[9] Cobalt alloys[9] Fe-0,8C[34] Fe-19Cr-0,1C-1,6B[34] Fusible[9] Mo alloys[9] NiCrSiFeB[21] Stellite-21[42]		Carbide cermet[9] Cr3C2-NiCr[42] WC-Co[21] WC-CoCr[21][42] WC-CoFe[21]
Rolling	AlSnCuNi[83]		WC cermet[61] WC-Co[68]
Sliding	Al-20Sn-1Cu[25] Al-20Sn-1Cu-2Ni[25] Al-20Sn-1Cu-7Si[25] Co-28Mo-17Cr-3Si[26] CoMoCrSi[90] CuWZn[79] Fe-15Cr-14Mo-15C-6B-2Y[36] Fe-40Al-0,05Zr[31] FeCrB[45] FeCrNiBC[109] FeCrWBMoMn[35] Mo-(Cu-10Sn)-(Al-12Si)[23] Ni-21Cr-8,3Mo-5Fe-1,2Nb-Ti[29] Ni-3Al[33][105] NiCr[33][105] NiCrSiB[112] Stainless steel[2] Ti[7]	Al2O3[16][74][98] Al2O3-TiO2[32][64][106][111] Al2O3-ZrO2[40] Cr2O3[2][13][32][74][103] Cr2O3-TiO2[43] ZrO2-Y2O3[18][32][78]	Al2O3-Al[97] Cr3C2-CoNiCrAlY[110] Cr3C2-NiCr[7][13][71][74][103][110] Cr3C2-NiCr-SFA[67] FeB-BN[102] MoCoB-CoCr[27] Mo-FEP-Al2O3-TiO2[20] MoS2 cermet[59] Ni60[60] NiCrWB-50Al2O3[86] Ni-TiC[79] NiWC25[60] NiWC35[60] SiC cermet[57] TiC-SFA[56] TiC-Ti[7] VC-WC-CoCr[74] WC-(W/Cr)2C-Ni[39] WC-Co[7][12][13][14][17][19][38][39][44][46][53][63][68][72][74][76][86][110] WC-CoCr[12][14][19][20][32][41][44][46][53][58][74][103][108] WC-Co-NiCrSiB[47] WC-Cr3C2-Ni[44][110] WC-Ni[20]

5 Comparison table of corrosion resistance and spray powder chemistry

Table 2 — Comparison of corrosion resistance and spray powder chemistry

Type of corrosion	Environment and effects	Materials	Ref. no.
Acid/alkaline/ salt	Galvanic	Al on Ni-20Cr	[196]
		Al2O3, Cr2O3	[129]
		Fe-based alloy	[178]
		Fe-17Cr-38Mo-4C alloy	[124]
		Inconel 625	[289]
		Inconel 690	[202]
		Many kinds of materials	[190]
		NiCrMoB	[210]
		Stainless steel	[184]
		316L	[183]
		Ternary coating system involving aluminium, zinc and magnesium	[209]
		Twin-wire electric arc spraying of zinc and aluminium coatings	[188]
	Mechanical	Al2O3, Cr2O3, Al2O3-ZrO2	[205]
	Metallographic	Al2O3-TiO2	[160], [261]
		Fe-10Cr-10Mo containing a large amount of carbon and/or boron	[121]
		Fe-based alloy	[168]
		Hastelloy C-22	[145]
		Ni-Ti composite	[169]
		WC, NiCrMo	[243]
		WC-Co	[239]
	Mechanical	Cr2O3, WC-12%Co, Ni-11%P, Al-2%Zn	[123]
	Uniform	Al, Al+Al2O3, Al+Al2O3+Zn	[174]
		Al2O3, Al2O3-Cr2O3	[295]
		Al2O3-TiO2	[270], [273]
		Al-Al2O3	[272]
		Cr3C2–20NiCr	[267]
		Fe-Cr-based Armacor C™ coating	[194]
		Fusible Ni-B-Si alloys with a variety of alloy additions (Cr, Mo, Cu, etc.)	[191]
		Inconel 625	[279]
		Ni, Ni-20Cu, Ni-20Cr, Ni-20Cr+50Al2O3, Ni-20Cr+30WC-CoCr	[161]
		Ni-20Cr	[116]
		NiCrBSi	[282]
		SM 8625, Inconel 625, SM8276, Hastelloy276, Deloro Stellite 21, Mo wire	[294]
		316L	[193]
		Ta	[271]

Table 2 *(continued)*

Type of corrosion	Environment and effects		Materials	Ref. no.
			Ti	[164], [192], [269], [278]
			TiO2	[165]
			WC-10Co4Cr, Cr3C2–25NiCr, Sanicro28	[283]
			YSZ	[167]
			Zn, Al, Zn-15Al	[266]
		Galvanic	Al-5%Mg	[171]
			Fe-10Cr-13P-7C	[127]
			Fe-based amorphous alloys	[138]
			IN 625	[139]
			Ni-50%Cr mixed with NbC, TaC, TiC, WC, Cr3C2, or VC	[125]
			Ni-based amorphous alloys	[135]
			NiCr, NiCrSiB, NiCrMoFeCuBSi, NiCrMoNb, CoNiCrMoBSi, WC-Co, CrC-NiCr	[204]
			WC-Co, WC-Co-Cr, WC-NiMoCrFeCo, WC-FeCrAl, WC-SS316L, WC-FeNiCr alloy, Cr3C2-NiCr, Cr3C2-NiCrMoNb, FeCrC-Ni	[285]
		Mechanical	TiO2	[149]
		Metallographic	Cr3C2-NiCr	[156]
			WC-CoCr	[170]
Atmospheric corrosion	Galvanic		Zn	[119], [120]
	High temperature		CrC-NiCr	[232]
			MCrAlY	[247]
			NiCrAlY	[288]
			YSZ	[128]
			YSZ, CaO-SiO2-ZrO2	[122]
		Environmental embrittlement	Cr3C2-NiCr	[148]
			Cr3C2-NiCr, WC	[154]
	Mechanical	Uniform	Al2O3, CrNi-steel, CrMo-steel	[224]
	Metallographic		Al, Zn, NiAl, NiCrBSi	[233]
	Uniform		CrMo-steel, TiC-Ni-Ti	[226]
			AlSi/Graphite, AlSi/hBN	[216]
		Environmental embrittlement	Zn	[252]
		Galvanic	Zn	[220]
		High temperature	Al, FeCrNi, FeCrNiSiB	[140]
		Metallographic	CrC-NiCr	[228]
Biochemical	Uniform		Ethylene methacrylic acid and ethylene tetrafluoroethylene	[195]
Biological	Metallographic		Ti	[177]

Table 2 *(continued)*

Type of corrosion	Environment and effects		Materials	Ref. no.
Chemical agent	High temperature		Fe-Al, Incoloy 800H	[213]
			In 625	[254]
		Environmental embrittlement	SFA	[152]
			SFA, In 625	[153]
	Mechanical		Hastelloy C276, SUS316L	[115]
Chemicals in food	Mechanical		NiCr	[219]
Combustion gas	High temperature		304, Al	[245]
			CoNiCrAlY	[114]
			Cr-based alloy	[225]
			Cr-Ni-2,5Mo-1Si-0,5B (55 % and 58 % Cr)	[118]
			Fe-Cr-Si	[276]
			In 625	[254]
			MCrAlY, YSZ	[131]
			MoSi	[179]
			Ni-20Cr	[173]
			Ni-50Cr	[151], [211]
			NiAl, WC	[246]
			Nickel and cobalt-based self-fluxing alloys, iron-based amorphous alloy and chromium carbide cermet coatings	[176]
			Phosphoric acid sealed ceramic coatings	[182]
			Sol-gelled 8YZ	[181]
			Y2O3-ZrO2	[144]
			YSZ	[180], [234]
			YSZ, NiAl	[136]
		Environmental embrittlement	Cr3C2NiCr	[148]
			Cr3C2NiCr, WC	[154]
			SFA	[152]
			SFA, In 625	[153]
	Metallographic		Ni-5Al	[113]
Sea water	Galvanic		Al	[249]
			Al, Zn, ZnAl	[253]
			AlSn, AlSnCu	[203]
			Al-Zn	[286]
			FeCrNiMo stainless steel	[217]
			Inconel 625	[289]
			Inconel 690	[202]
			Many kinds of off-shore application	[189]
			Ni-based 16C, Co-based Stellite 6	[207]

Table 2 *(continued)*

Type of corrosion	Environment and effects		Materials	Ref. no.
			NiCr+Mo, laser alloy	[198]
			Stainless steel	[184]
			Ti	[291], [297]
			TiC+NiTi, (Ti, W)C+Ni, WC-Co, WC-CoCr, CrC-NiCr, Inconel	[200]
			WC-Co, Inconel	[215]
			WC-CoCr, NiCrSiB	[201]
			Zn, Zn-Al	[260]
			Zn, ZnAl, ZnSnAl, ZnMgAl, ZnCr5	[293]
			ZnAl	[264]
	Uniform		Al	[287]
			Al2O3+sealants	[133]
			Al-Cu, Al-Zn, Zn	[275]
			AlSi/Graphite, AlSi/hBN	[216]
			Polymer	[235]
			Ta, Ti	[126]
			Ti	[134]
			Ti	[281]
			WC-CoCr	[187]
			WC-CoCr/HVOF, Sealing	[166]
			Zn, Zn-15Al, Al, Al-5Si, Al-12Si, Cu-7Al-0,5Fe, Cu-9Al-4Ni-4Fe-1,5Mg, 60Cu-40Zn-0,7Sn-0,05Pb, 420 stainless steel, 316 stainless steel	[162]
			ZnNi-Al2O3, ZnCu-Al2O3, Zn-Al-Al2O3	[284]
		Environmental embrittlement	Al	[130]
			Zn	[197]
		Galvanic	Al, Al+Al2O3, Al+Al2O3+Zn	[292]
			WC-Co, Ni	[137]
			WC-Co, WC-Co-Cr, WC-NiMoCrFeCo, WC-FeCrAl, WC-SS316L, WC-FeNiCr alloy, Cr3C2-NiCr, Cr3C2-NiCrMoNb, Fe-CrC-Ni	[285]
			WC-CoCr, WC-NiCr, WC-CoCrMo, WC-CrMoNi	[208]
			Zn, Al, Zn15Al, Al5Mg	[199]
			Zn, Al	[242]
			Zn	[220]
		High temperature	Al, FeCrNi, FeCrNiSiB	[140]
		Mechanical	PEEK	[230]
			TiO2	[149]
			WC-Co, WC-CoCr, Cr2O3, NiCrSiB	[212]
		Metallographic	Cr3C2-NiCr	[156], [228]
			WC-CoCr	[251]

Table 2 *(continued)*

Type of corrosion	Environment and effects		Materials	Ref. no.
			WC-NiCr, CrC-NiCr, TiC-NiCr	[229]
			ZnAl	[132]
	Metallographic		316L	[238]
			316L, Hastelloy C	[236]
			Al, Zn, NiAl, NiCrBSi	[233]
			Fe-based	[257]
			Hasrelloy C	[240]
			Inconel 625	[237]
			NiCrMoNb	[241]
			NiCrWBSi	[143]
			316	[263]
			Ti	[158]
			WC-CoCr	[244]
			WC-CoCr, WC-Co	[146]
		Galvanic	WC-Co	[227]
		Uniform	NiCrMoSiB	[141]
	Mechanical		Al2O3	[214]
			Al2O3, Cr2O3, Al2O3-Cr2O3	[206]
			NiCrMoSiB	[142]
		Galvanic	WC-CoCr, WC-NiCr, WC-CoCrMo, WC-CrMoNi	[218]
		High temperature	SUME SOL, Mo, WC-CoCr	[223]
		Uniform	Al2O3, CrNi-steel, CrMo-steel	[224]
	Environmental embrittlement		Stainless steel	[147]
			Zn, Al	[268]
Fresh water	Environmental embrittlement		Stainless steel wire	[147]
	Galvanic		Al, Zn, ZnAl	[253]
	Metallographic		Stainless steel	[250]
	Uniform		Stainless steel	[155]
		Mechanical	WC-Co, SFA, Cr2O3, Al2O3	[221]
		Environmental embrittlement	Zn	[252]
Molten metal	Galvanic		WC-Co, WC-CoCr, MoB-CoCr	[163]
	Metallographic		WC, Cr3C2-cermet	[258]
Molten salt	High temperature		Cr3C2-NiCr	[157]
			Cr-Ni-2,5Mo-1Si-0,5B (55 % and 58 % Cr)	[118]
			Ni-20Cr	[274]
			Ni-5Al, NiCrAl	[262]
			Nickel and cobalt-based self-fluxing alloys, iron-based amorphous alloy and chromium carbide cermet coatings	[176]

Table 2 *(continued)*

Type of corrosion	Environment and effects		Materials	Ref. no.
			NiCr	[159]
			WC-Co	[265]
			WC-NiCrFeSiB	[255]
			YSZ, CaO-SiO2-ZrO2	[122]
	Metallographic		Cr	[248]
	Uniform		Ni-20Cr	[290]
		Metallographic	Ni-20Cr	[298]
Non-aqueous solution	Galvanic		Al	[256]
	High temperature		CaZrO3	[172]
			CoNiCrAlY	[175]
			Ni-Cr, NiCrAlY	[277]
Soil corrosion	Mechanical		Ni-based	[259]
Steam	High temperature		Ni-50Cr	[151]
	Environmental embrittlement		Mullite/YSZ	[280]
Miscellaneous	High temperature		FeCrAl, NiAl	[296]
	Mechanical		Slurry erosion test	[185]
			WC-(Co/Cr/Mo/Ni) erosion-corrosion	[186]
	Metallographic		Titanium-manganese alloy	[117]
	Uniform	Metallographic	WC-CoCr	[251]

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