CONTENTS

	Preface
1	Introduction
2	Physical principles of plasma spraying process
2.1	Plasma beam
2.1.1	Characteristics of plasma beam
2.1.2	Temperature and output of plasma beam
2.1.3	Outlet velocity
2.2	Plasma gases
2.2.1	Dissociation, ionization and enthalpy of plasma-forming gases
2.2.1.1	Nitrogen
2.2.1.2	Hydrogen
2.2.1.3	Argon and helium
2.2.2	Thermal conductivity of plasma
2.2.3	Electric conductivity of plasma
2.3	Formation of plasma coatings
2.3.1	Powder transport, flight path and velocity of the sprayed particles
2.3.2	Interactions of molten material with the plasma beam and the surrounding atm
	sphere
2.3.3	Impingement of flying particles on the substrate
2.3.4	Thermal effects of the substrate and the sprayed layer
2.3.5	Physical and chemical transformation of material in spraying
2.4	Basic properties of plasma coatings
2.4.1	Structure
2.4.2	Density and porosity
2.4.3	Bonding, internal stresses, layer thickness
2.4.4	Strength, hardness, formability
2.4.5	Thermal and electrical conductivity
3	Equipment and accessories for plasma spraying technology
3.1	Principal scheme of plasma spraying equipment
3.2	Plasma torches
3.2.1	Plasma torches of foreign production
377	Plasma torches of domestic production — gas torch type 7-S and water-stabiliz

3.5	Powder feeder	63
3.3.1	Simple powder feeder type P 30	63
3.3.2	Double feeder, type TWIN 10	65
3.4	Direct current sources	67
3.5	Control box	70
3.6	Cooling system	74
3.7	Equipment for air exhaust and intake	76
3.8	Gas system	78
3.8.1	Pressure vessels with compressed gases	78
3.8.2	Evaporation station of liquified gases	80
3.9	Automatic plasma spraying equipment	82
3.9.1	FRB-8-300 automatic machine	82
3.9.2	WSP 500/1500 automatic equipment	84
3.9.3	Automatic equipment for spraying gas turbine runner discs	85
3.9.4	Industrial spraying robots	86
3.9.5	ROB-LH-1 robotized spraying system	89
4	Bonding and adherence of plasma coatings to the substrate	91
4.1	Kinds of bonding forces	91
4.2	Theoretical aspects of optimum adherence	93
4.3	Main factors affecting the adherence of coating to substrate	96
4.3.1	Coating thickness	96
4.3.2	Preliminary preparation of substrate surface	97
4.3.3	Spraying process parameters	99
4.4	Experimental evaluation of adherence of plasma-sprayed coatings to substrate .	100
		100
4.4.1	Test methods to determine adherence	100
4.4.1 4.4.2	Test methods to determine adherence	100 100 101
4.4.1 4.4.2 4.4.3	Test methods to determine adherence	100 100 101 103
4.4.1 4.4.2 4.4.3 4.4.4	Test methods to determine adherence	100 101 103 104
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Evaluation and comparison of the test methods	100 101 103 104 107
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Evaluation and comparison of the test methods Metallographic analysis of the bond	100 101 103 104 107 110
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate	100 101 103 104 107 110 110
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5.1 4.5.2	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiAl interlayer on the substrate	100 101 103 104 107 110 110 112
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiAl interlayer on the substrate Adherence of metallic and ceramic plasma-sprayed coatings	100 101 103 104 107 110 110 112 116
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiAl interlayer on the substrate Adherence of metallic and ceramic plasma-sprayed coatings Test of main parameters of plasma spraying on adherence of K 40, K 50 and	100 101 103 104 107 110 110 112 116
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiA1 interlayer on the substrate Adherence of metallic and ceramic plasma-sprayed coatings The effect of main parameters of plasma spraying on adherence of K 40, K 50 and K 55 powders to steel	100 101 103 104 107 110 110 112 116
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiA1 interlayer on the substrate Adherence of metallic and ceramic plasma-sprayed coatings The effect of main parameters of plasma spraying on adherence of K 40, K 50 and K 55 powders to steel Method, materials and equipment used	100 101 103 104 107 110 110 112 116 119 121
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2	Test methods to determine adherenceAdherence test according to DIN 50 160 StandardAdherence test according to DIN 50 161Adherence test according to DIN 50 161Adherence test by the stud methodEvaluation and comparison of the test methodsMetallographic analysis of the bondBond of metallic coating with substrateBond of ceramic coating with NiAl interlayer on the substrateAdherence of metallic and ceramic plasma-sprayed coatingsThe effect of main parameters of plasma spraying on adherence of K 40, K 50 andK 55 powders to steelMethod, materials and equipment usedThe effects of spraying distance and electric output on the adherence	100 101 103 104 107 110 110 112 116 119 121 121
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.1 4.7.2 4.7.3	Test methods to determine adherenceAdherence test according to DIN 50 160 StandardAdherence test according to DIN 50 161Adherence test according to DIN 50 161Adherence test by the stud methodEvaluation and comparison of the test methodsMetallographic analysis of the bondBond of metallic coating with substrateBond of ceramic coating with NiAl interlayer on the substrateAdherence of metallic and ceramic plasma-sprayed coatingsThe effect of main parameters of plasma spraying on adherence of K 40, K 50 andK 55 powders to steelMethod, materials and equipment usedThe effect of carrying gas flow rate on adherence	100 101 103 104 107 110 110 112 116 119 121 121 121 122
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.1 4.7.2 4.7.3 4.7.4	Test methods to determine adherence Adherence test according to DIN 50 160 Standard Adherence test according to DIN 50 161 Adherence test according to DIN 50 161 Adherence test by the stud method Evaluation and comparison of the test methods Metallographic analysis of the bond Bond of metallic coating with substrate Bond of ceramic coating with NiAl interlayer on the substrate Adherence of metallic and ceramic plasma-sprayed coatings The effect of main parameters of plasma spraying on adherence of K 40, K 50 and K 55 powders to steel The effects of spraying distance and electric output on the adherence The effect of carrying gas flow rate on adherence The effect of fed powder volume on adherence	100 101 103 104 107 110 110 110 112 116 119 121 121 121 122 123
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5	Test methods to determine adherenceAdherence test according to DIN 50 160 StandardAdherence test according to DIN 50 161Adherence test by the stud methodEvaluation and comparison of the test methodsBond of metallic coating with substrateBond of ceramic coating with NiAl interlayer on the substrateAdherence of metallic and ceramic plasma-sprayed coatingsThe effect of main parameters of plasma spraying on adherence of K 40, K 50 andK 55 powders to steelThe effect of spraying distance and electric output on the adherenceThe effect of fed powder volume on adherenceThe effect of powder granularity on adherence	100 100 101 103 104 107 110 110 112 116 119 121 121 122 123 124
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5 5	Test methods to determine adherence Image: Constraint of the state of the st	100 100 101 103 104 107 110 110 110 112 116 119 121 121 122 123 124 126
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5 5	Test methods to determine adherence	100 101 103 104 107 110 110 110 112 116 119 121 121 122 123 124 126
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5 5 5.1	Test methods to determine adherence Image: Section of powders for plasma spraying in industrial applications Adherence to table for selection of suitable powders Image: Section of suitable powders	100 101 103 104 107 110 110 110 112 116 119 121 122 123 124 126 126 126
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5 5 5.1 5.2 5.2	Test methods to determine adherence Image: Construct of the student of the stude	100 101 103 104 107 110 110 110 112 116 119 121 121 122 123 124 126 126 140
4.4.1 4.4.2 4.4.3 4.4.4 4.4.5 4.5 4.5.1 4.5.2 4.6 4.7 4.7.1 4.7.2 4.7.3 4.7.4 4.7.5 5 5.1 5.2 5.2.1 5.2	Test methods to determine adherence Image: Constraint of the student of the stud	100 101 103 104 107 110 110 110 112 116 119 121 122 123 124 126 126 140 140

5.2.3	Corrosion resistance (C)	•	•	•		•		,	145
5.2.4	Electrical conductivity and electrical resistance (D)	·	·	·		•	•		146
5.2.5	Renovation of worn parts (E)	·	·	·		·			147
6	Technological procedure of plasma spraying	•	•						149
6.1	Preliminary preparation of surfaces prior to spraying								149
5.1.1	Mechanical machining			•					149
5.1.2	Chemical degreasing					•			151
5.1.3	Abrasive cleaning								151
6.2	Application of interlayers improving adherence								156
5.2.1	General properties of interlayers					· •		•	156
5.2.2	Molybdenum							•	157
5.2.3	Nickel-aluminium				• •				158
5.2.4	Niobium, tantalum, nickel, nickel-chromium								159
5.2.5	Cermet interlayers								159
63	Spraving procedure								160
631	Plasma gas selection								160
637	Working parameters of the spraying process	•	•	•					162
6321	The effect of working parameters on the coating density	•	•	•	•				163
5.3.2.1	The effect of electric input and gas flow rate	·	·	•	• •	•		•	163
5.2.2	The effect of distance	·	·	•	•	•		•	164
6271	The effect of volume of powder fed	·	·	•	• •	•		•	165
3.3.2.4	The effect of volume of powder real	·	·	•	•	•		•	165
5.5.2.5 6 7 7	Masking	•	•	•	•	•		•	166
).).) () /	Masking	·	·	•	•	• •		•	167
).).4 () 5	French and cooling	·	•	•	•	•		•	160
	Spraying of culture rotary and planar surfaces	•	·	•	•	• •		•	176
5.5.0	Spraying of cylindrical surfaces and cavines from inside	•	·	•	•	•••	, .	•	176
0.3.0.1	Plasma forches for internal spraying of cylindrical surfaces	·	·	·	•	•••	,	•	170
).3.6.2		•	·	·	•	•••	•	·	1/0
5.3.7	Spraying in snielding atmospheres	·	•	·	•	•••	•	•	100
5.3.7.1	Plasma spraying in local inert atmosphere	·	·	•	•	• •	•	•	102
6.3.7.2		·	•	•	•	• •	•	·	185
6.3.7.3		·	•	·	•	• •	•	·	180
6.4	Final treatment of the sprayed surface	·	·	·	•	• •	•	• •	189
6.4.1	Sealing and remelting of coatings	·	·	·	·	• •	•	•	189
6.4.2	Chip machining	·	·	·	·	• •	•	·	190
6.4.3	Grinding	·	•	•	•	• •	•	•	191
7	Application of plasma-sprayed coatings in industry and research .		•	•	•	•	•	•	194
7.1	A survey of industrial applications of plasma-sprayed coatings.					•			194
7.1.1	Textile industry			•		•	•	•	194
7.1.2	Paper and printing industries								195
7.1.3	Automotive industry and the production of combustion engines								197
7.1.4	Glass industry								201
7.1.5	Electrotechnical industry		•						204
7.1.6	Hydraulic machines and mechanisms								206
7.1.7	Chemical industry								209
7.1.3 7.1.4 7.1.5 7.1.6 7.1.7	Automotive industry and the production of combustion engines Glass industry Glass industry	• • • •			• • •	• • •	• • •		1 2 2 2 2 2

7.1.8	Rolling mills, founding, metallurgy	212	
7.1.9	Protection of stationary gas turbine blades against high-temperature corrosion	217	
7.1.10	Plasma sprayed coatings in production of aircraft jet engines	220	
7.1.11	Production of shaped parts of refractory materials	223	
7.1.12	Nuclear technology and survey of other applications	226	
7.2	Application of plasma spraving technology in research and development	228	
721	Development of wear-resistant materials with improved friction properties	228	
722	Protective coatings on mining equipment structures, to prevent igniting sparks	230	
723	Preparation of composite materials reinforced with fibres	233	
724	Application of plasma-sprayed coatings in medicine	236	
7.2.4			
8	Testing of physical and mechanical properties of plasma sprayed coatings	240	
8.1	Measurement of basic mechanical properties	241	
8.2	Metallographical studies	242	
8.3	Adherence tests	242	
84	Hardness measurement	243	
85	Measurement of coating porosity	244	
8.6	Measurement of erosion resistance of coatings	246	
0.0 9 7	Cavitation and abrasion tests	240 247	
0./	Thermal resistance of continge	247	
0.0		251	
8.9		251	
8.10		255	
8.11	Tests of wear resistance and friction properties	254	
8.12	Tests of thermal conductivity	255	
8.13	Other tests	256	
9	Problems of work safety in the operation of plasma spraying equipment	259	
9.1	Safety problems in surface preparation prior to plasma spraying	259	
9.2	Dangers in plasma spraying	260	
9.2.1	Electric installation	260	
9.2.2	Radiation and heat	261	
9.2.3	Noise	262	
9.2.4	Working gases and pressure vessels	263	
9.2.5	Effect of ozone and nitrous gases	264	
9.3	Danger from metal dust and the vapours of spraying materials	264	
9.3.1	Beryllium	267	
9.3.2	Lead	268	
9.3.3	Cadmium	269	
9.3.4	Copper, zinc and tin	269	
9.3.5	Aluminium and steel	270	
	Conclusions	272	
	Deferences	274	
		417	

8