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Thermal spraying — Recommendations for thermal spraying

Projection thermique — Recommandations pour la projection thermique

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12679 was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*.

Introduction

Thermal spraying encompasses processes used in the production of coatings and free-standing bodies for which spray materials are surface-melted, melted off or melted and then propelled onto suitably prepared workpiece surfaces. The workpiece surfaces are not surface-melted. In order to achieve specific coating properties, the spray coating can undergo additional post-treatment, either thermal or otherwise, for example, sealing.

Thermally sprayed coatings serve to improve the surface properties of a workpiece by manufacturing or repair operations. This can be done, for example, in relation to wear, corrosion, heat transfer or heat insulation, electrical conductivity or insulation, appearance and/or for restoring the part to working order. In certain cases, a spray coating can render a surface solderable.

Chiefly due to their bonding mechanism, thermally sprayed coatings without thermal post-treatment can be distinguished from coatings applied with other processes, such as deposition welding, brazing, physical vapour deposition (PVD) or chemical vapour deposition (CVD).

The advantages of thermal spraying are the following.

— The workpieces to be coated are only slightly heated so that distortion and any other undesired structural changes to the parent material are avoided. This does not apply if the coatings are thermally treated during or after the spraying process.

— The application is not dependent on the size of the workpiece or component. The operation can be stationary or mobile depending on the spraying process.

— Even geometrically complex components can be coated using the appropriate spray set-up.

— The untreated surface of spray coatings generally provides a good bond coat for painting.

— Depending on the spraying process and spray material, different coating thicknesses can be applied, although a coating thickness of approximately 10 µm is currently considered to be the lower limit.

Process-related disadvantages are as follows:

— the bond strength of thermally sprayed coatings without thermal post-treatment derives from adhesive forces only;

— the bond strength can be influenced due to an expansion mismatch between the coating and substrate material, especially in the case of a high operation temperature;

— spray coatings are micro-porous;

— the thicker the spray coating, the higher the residual stresses in the coating, and the degree of multi-axial stress thus increases;

— spray coatings without additional thermal post-treatment are sensitive to edge pressure, localized and linear loads and to impact stresses;

— there are restrictions in relation to the geometric dimensions, for example, for the inner coatings of workpieces whose inner diameter is too small.

Thermal spraying — Recommendations for thermal spraying

1 Scope

This International Standard includes general guidelines for the workmanlike production of metallic, metal-ceramic, oxide-ceramic and plastic coatings, by means of thermal spraying on metallic and non-metallic parent materials.

This International Standard provides recommendations for an appropriate and practical spray set-up, faultless manufacturing, monitoring, quality assurance and for non-destructive and destructive tests on the component and accompanying specimen. It describes details about negative effects which can occur. It also gives advice on how to prevent such effects.

Permissible coating loads and evaluation categories for quality are not the subject of this International Standard, as they are dependent on the operating conditions.

This International Standard can be used for contract purposes.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3452-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

ISO 14231, *Thermal spraying — Acceptance inspection of thermal spraying equipment*

ISO 14232, *Thermal spraying — Powders — Composition and technical supply conditions*

ISO 14918, *Thermal spraying — Approval testing of thermal sprayers*

ISO 14919, *Thermal spraying — Wires, rods and cords for flame and arc spraying — Classification — Technical supply conditions*

ISO 14920, *Thermal spraying — Spraying and fusing of self-fluxing alloys*

ISO 14921, *Thermal spraying — Procedures for the application of thermally sprayed coatings for engineering components*

ISO 14922-1, *Thermal spraying — Quality requirements of thermally sprayed structures — Part 1: Guidance for selection and use*

ISO 14922-2, *Thermal spraying — Quality requirements of thermally sprayed structures — Part 2: Comprehensive quality requirements*

ISO 14922-3, *Thermal spraying — Quality requirements of thermally sprayed structures — Part 3: Standard quality requirements*

ISO 14922-4, *Thermal spraying — Quality requirements of thermally sprayed structures — Part 4: Elementary quality requirements*

ISO 14923, *Thermal spraying — Characterization and testing of thermally sprayed coatings*

ISO 14924, *Thermal spraying — Post-treatment and finishing of thermally sprayed coatings*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
shot-peening effect
pressure strengthening by grit-blasting

3.2
sound pressure level
mean value of emitted sound

NOTE Sound pressure level is measured in decibels (dB).

3.3
etching
removing of surface material

NOTE Etching can be applied using liquid agents (wet chemical etching) or using gases in a recipient (dry etching, plasma etching). The etching agent reacts chemically with the substrate.

3.4
ion-etching
material removed by shooting the surface with high-energetic particles like ions

NOTE The ions cut off material at the impact point. The procedure is used in plasma technology application (vacuum coating technology).

3.5
corona discharge
dielectric discharge in air after exceeding the break-down field intensity; air molecules will be ionized by generating short-living ozone

4 Parent material

Virtually every kind of solid-state material can be coated by means of thermal spraying, provided its surface is suitably prepared. The achievable bond strength of the coating to the substrate is dependent on the spray material, spraying process and the physical and technological properties of the parent material used. The bond strength, amongst other things, is particularly influenced by the thermal conductivity of the parent material in comparison to the conductivity of the spray coating and the state of the parent material's surface. In general, hardened materials need a bond coat to give adequate bond strength. The possible coating thickness may be limited, depending on the bonding material being used. Certain surface-hardening processes, e.g. “nitriding”, may leave gaseous inclusions which would prevent proper bonding.

A variety of plastics, as well as glass and paper, can be thermally sprayed when using the appropriate spraying process and a surface treatment method adapted for the respective material.

As the workpieces to be coated by means of thermal spraying are generally only slightly heated, undesired structural changes to the parent material and changes to the component's geometry due to distortion are avoided to the greatest possible extent. However, distortions resulting from intensive grit-blasting during surface preparation, especially with thin-walled parts or as a result of residual compressive stresses on the surface of the substrate caused by process-related shot-peening effects, can occur. If coatings are thermally treated during spraying (processes with simultaneous fusing) or subsequently, undesired structural changes and significant geometric changes can occur.

For purposes of quality assurance during the manufacturing process, the parent materials and components to be coated should be stored in such a way that damage and/or undesired changes to the shape or surface are avoided.

5 Component geometry

The application of thermal spraying is independent, to the greatest possible extent, of the size of the workpiece or component to be coated. This is mainly true for flame and arc spraying. For plasma and HVOF (high-velocity oxygen fuel) spraying, closed-off spray booths are normally required due to the high noise and dust emissions. As a result, there may be restrictions to size of the component.

Certain prerequisites concerning the practical set-up shall be considered when using thermal spraying. If these rules are followed, even complex geometric parts can be coated with expertise. The most important rules can be summarized as follows:

— the area to be coated shall be accessible to the spray gun with all its electrical and/or gas connections, and the necessary spray distance and spray angle shall be maintained;

— sharp edges should be avoided; they cannot be covered with a spray coating;

— narrow radii should be avoided, otherwise turbulence in the spray jet can occur, which can lead to unsatisfactory coatings in terms of bond strength and density;

— problems with turbulence and undesired, loose particles sticking to the walls occur especially when spraying in narrow bores or blind holes;

— to prevent the coating from spalling, it has proved advantageous to pull the coating around rounded or chamfered edges;

— the arguments listed for thermal spraying, i.e. accessibility, sharp edges, narrow radii, bores and blind holes, also apply to grit-blasting when preparing the surface to be sprayed.

6 Spray materials

6.1 General

The spray materials used for thermal spraying cover a wide range of very different materials. It is virtually possible to spray any material which can be produced as a solid wire, cored wire, rod, cord or powder, and which does not sublimate in the arc or plasma or decompose when passing through the flame. In the special case of molten-bath spraying, the material is processed in its liquid state.

Generally, the following spray materials can be used for thermal spraying:

— metals and metal alloys;

— metal ceramics;

— hard phases embedded in a matrix material;

— oxide ceramics, plastics, as well as various hybrid materials.

6.2 Selection of spray materials

An important task for the designer and/or person responsible for the spray technology is the selection of the spray material which is most suited to the application. Fundamental to the selection are the demand's profile of the coating, the subsequent operating conditions and the most suitable spraying process. Corrosion and/or wear loads, for example, can determine the demand's profile. The operating conditions in a tribological system can be determined by an increased operating temperature or by operating temperatures which fluctuate in level and, in some cases, also in speed. The most suitable spraying process distinguishes itself in terms of its ability to fulfil coating requirements, such as density, bond strength, porosity, purity, etc. Here, the relevant process data, such as temperature level in the flame, in the arc or in the plasma, the dwell time of the spray particles in the hot zone and the particle velocity in flight and on impact on the substrate, play a decisive role.

The most important spray materials have been standardized. The following are specified in standards: chemical composition of the material and its supply form as powder with its special features based on the manufacturing process, particle shape and particle size distribution, or as wire, rod or cord.

The following International Standards apply:

— for powder: ISO 14232;

— for wires, rods and cords: ISO 14919.

6.3 Supply, handling and storage

The supply form and its constancy from batch to batch, especially with spray powders, plays a fundamental role in ensuring a uniform quality for the finished coating. For this reason, it is recommended that manufacturing, supply and distribution be assessed and monitored by a suitable quality-management system. Details concerning such a procedure are described in EN 12074.

7 Gases for spraying

Industrial gases are used in all thermal spraying processes. Depending on the spraying process, these gases or their mixtures are employed as a fuel, combustion accelerator, plasma gas, shroud gas, propelling or atomizing gas, powder-feed gas, or for cooling the part to be coated or even the spray gun.

The physical and chemical characteristics of the industrial gases used for thermal spraying differ quite markedly from each other. Paying attention to these parameters, a gas or gas mixture, which fulfils the process and material requirements, can be selected for any thermal spray application.

The following gases are mainly used:

— as a fuel gas: acetylene (C_2H_2), propane (C_3H_8), propylene (C_3H_6), ethene (C_2H_4), hydrogen (H_2), natural gas;

— as a plasma gas: argon (Ar), helium (He), hydrogen (H_2), nitrogen (N_2) and their mixtures;

— as a combustion accelerator: oxygen (O_2);

— as a shroud gas: argon (Ar), nitrogen (N_2);

— as a propelling or atomizing gas: compressed air, nitrogen (N_2), argon (Ar);

— as a powder-feed gas: argon (Ar), nitrogen (N_2);

— for cooling: compressed air, carbon dioxide (CO_2).

Depending on the spraying process and the purpose of the application, varying high-purity levels are demanded of the gases. The gas producer is responsible for the gas purity whose level shall then be maintained at the user’s premises during the filling process, transport and withdrawal, and in the pipeline system.

In general, it is sufficient to indicate the purity of the gases used in thermal spraying with numerical values according to the number of “nines” before and after the point (4,6 = 99,996 %). Typical gas purities for thermal spraying are:

— Ethene 3,5

— Oxygen 3,5

— Hydrogen 3,0

— Nitrogen 4,6

— Argon 4,6

— Helium 4,6

For plasma spraying in particular, the purity of the gases has a big influence on the lifetime of the nozzle electrode system.

8 Liquid fuels for spraying

In several applications, the high-velocity flame spraying process is applied using liquid fuels, e.g. kerosene, *N*-paraffin, test benzene or petroleum. A low sulfur content has to be kept due to environmental reasons. Flash point, evaporation point and purity have to be considered, as well as additional instructions from the equipment supplier.

9 Spray equipment

9.1 General

The thermal spray equipment includes the spray device with all the electrical and gas supply and regulating equipment, possibly the handling system, plus the peripheral installations such as exhaust and filter systems, spray booth and soundproofing. Modern installations often include additional equipment for monitoring spray parameters and motion sequences by means of video cameras.

9.2 Spray device

The spray device is defined in ISO 14917 as the equipment required for thermal spraying.

Guidelines can be found in ISO 14231 for the qualification of the spraying installation including the transport system for the spray material. ISO 14231 can also be consulted when monitoring the state of the thermal spraying installation.

9.3 Mechanical equipment, rotating devices, handling systems, robots

In addition to the spray parameters for melting and melting off and for the transport of the spray material, the distance, setting angle and relative motion between the gun and workpiece have a decisive influence on the quality of the spray coating. In order to maintain these parameters as closely as possible, a mechanized spraying process should be used wherever possible rather than a manual one.

A handling system should fulfil the following requirements:

— capable of movements, speed and positioning with accuracy values appropriate to the application;

— sufficient static and dynamic loading capacity;

— stabilization of spray distance;

— non-susceptibility of control and regulation systems to influences from spray operation, for example, when igniting the plasma burner, and in relation to spray dust and heat from the flame, arc or plasma jet;

— simple and straightforward setting and programming of the handling system or rotating device.

9.4 Essential auxiliary equipment

Auxiliary equipment essential for thermal spraying includes equipment for cooling the burner system and possibly the energy supply, too, for cooling the workpiece and/or the coating, for detecting, removing by suction and transporting the spray dust, collecting the spray dust in a suitable filter system which, at the same time, releases the exhaust air mixed with the combustion or plasma gas residue into the atmosphere, safely and in compliance with environmental regulations. The spray booth and sound-proof chamber are also essential components of the auxiliary equipment.

The peripheral equipment, especially for detecting and removing the spray dust, can also influence the quality of the spray coating by acting upon the spray jet and the safe discharge of rebounded spray particles. For this reason, this equipment should always be kept in good working order.

Every spraying process produces a typical sound pressure level. During plasma processes and the various HVOF processes, the A-weighted sound pressure level can reach values of more than 125 dB(A), making sound-proofing measures with a considerable sound pressure level reduction potential necessary. As a rule, dust build-up generally occurs in addition to the sound pressure levels; spray booths should offer good sound absorption/insulation and also be able to prevent dust deposits as far as possible. As these conditions contradict each other to a certain extent, priorities shall be set concerning the design. For mechanized spraying, non-absorbing, smooth walls can be used. For manual spraying, sound-absorbing, open-pored inner walls and ceilings are to be preferred.

During the spraying process, particle-loaded smoke and gas currents result from the spray materials, gases and ambient air. The dust in this smoke and gas are generally classified as hazardous and should therefore be detected at their source and safely eliminated. To this end, a system of detection, conduction and filtering is required.

Catching normally takes place directly at the source using exhaust hoods; these should be adapted to the geometric properties of the workpiece. The catching speed at the source should be measured in such a way that deposits and the risk of a dust explosion are avoided.

Wet and dry filters have been proven to be very effective filter systems. Monitoring functions, for example, by measuring the pressure difference, is absolutely essential. When spraying plastics or when toxic gases occur during the spraying process, wet filters are to be preferred.

Particularly, in the case of potentially carcinogenic dust, attention shall be paid to special national regulations when removing any residue from the floor and when disposing of the spray dust from the filter system.

10 Surface preparation prior to spraying

10.1 General

In order to achieve adequate bond strength of the spray coating, the substrate surface should be carefully prepared and coated immediately. The permissible intermission time depends on the spray material, the sensitivity of the parent material and possible influences of dust, vapour and moisture on the prepared surface due to temperature drops below the dew-point or rain while spraying outside.

10.2 General pretreatments, degreasing, cleaning

Before preparing the surface for spraying, rust, scale, dust and similar impurities should be removed mechanically. Oily and greasy impurities should be removed by degreasing. The latter can be carried out either by heating (cracking the oil or grease residue), immersion or atomizing methods, with or without additional mechanized support, for example, with ultrasound, brushes or steam-jet cleaning. Aqueous detergents or organic solvents are suitable. However, when using solvents, attention shall be paid to environmental regulations. After degreasing, the prepared surface should be rinsed and dried.

10.3 Grit-blasting and other preparation methods

The metallic surface should be prepared in such a way that a technically clean bonding area results. Usually, the surface to be coated should be roughened. The necessary roughness of the surface to be coated depends on the particular application. Grit-blasting is a suitable method to achieve an efficient, roughened metallic surface. In this way, the surface area is also increased.

Preparation by means of grit-blasting depends on the type and the particle size of the abrasive, and also on the blasting parameters, for example, blasting time per unit area, distance, blasting angle, impact speed of the abrasive, overlapping of blasting runs, and type of grit-blasting device or grit-blasting method (pressure or syphon blasting). The wear state of the abrasive influences the quality of the grit-blasted surface significantly and should therefore be monitored.

Normally, grit-blasted surfaces are assessed according to their appearance. Prior to thermal spraying, these surfaces should display a spotless and uniform appearance. Even humidity, especially in industrial atmospheres, can impair the spray result. The "standard of cleanliness Sa 3" according to ISO 8501-1 represents a necessary but, in many cases, inadequate requirement.

Differences between the desired and actual roughness of the grit-blasted surface can be assessed using reference samples. Such reference samples are described in ISO 8503-1. When testing the roughness, the prepared surface shall not be contaminated.

The compressed air used for grit-blasting should be free of oil and moisture. Abrasives can be selected in accordance with ISO 11126-7 and ISO 11124-2.

Thorough cleaning of the surface after grit-blasting is essential to remove any abrasive residue; this can be done best by suction or blowing-off using oil-free, dry compressed air. With plastic substrates, dust resulting from static charging is very difficult to remove from the surface. In this case, special measures, such as blowing-off with ionized air or antistatic baths, may be necessary. In particular applications, high-pressure water blasting can be applied successfully in the case of surface preparation of aluminium and mild steel materials.

Further details on the surface preparation of metallic materials are described in EN 13507. ISO 14921 provides more detailed instructions on the application of thermally sprayed coatings for engineering components.

For secondary applications, coarse turning, milling, grinding or brushing are sufficient for the preparatory work. However, the properties of the parent material should not be impaired in any way. Damage can occur if stresses are introduced or if the surface is compressed. With plastics, pores may be exposed or fibre inserts damaged.

When preparing the surface of non-metallic materials prior to thermal spraying, a more extensive chemical-physical, thermal or mechanical surface treatment may be necessary after cleaning and degreasing. Physiochemical activation methods include etching or ion-etching. Thermal preparation should dry, clean and physical-chemically activate the surface. For this purpose, open flames, radiation heat, low temperatures or corona discharges can be used.

10.4 Covering, masking of areas not to be coated

Areas of a workpiece which shall not be coated, for example, guide grooves and keyways, or bores, need to be covered before grit-blasting and spraying. Self-adhesive tapes, hardwood, rubber, silicone or metallic devices are suitable here. The masking material should not contaminate the surface to be coated.

Further instructions concerning masking, especially when spraying self-fluxing alloys, are given in ISO 14920.

11 Thermal spraying procedure

11.1 Spraying procedure specification

A spraying procedure specification containing the data for the entire spraying process should be compiled for every spray application. The spraying procedure specification should be compiled by the spraying specialist (see 14.2.2) responsible for the spray technology. The thermal spraying specialist is responsible for compliance with this specification.

Before making any changes to the parent material, spray material, auxiliary materials, design, coating thickness or spraying process, the spraying specialist should be consulted; if necessary, the specification shall be changed or recompiled.

The basis of the spraying procedure specification are the results from spray specimens and/or empirical values.

If a thermal post-treatment is intended for the parts to be coated, the specimens used to compile the specification should also undergo the post-treatment.

The spraying procedure specification should include the following details:

— manufacturer;

— workpiece with a reference number and, if necessary, a sketch of the component showing the part to be coated;

— substrate material;

— functional task of the coating;

— preparation methods;

— coating thickness, if necessary, before and after the finishing process, or each coating thickness if a coating consists of bond and top coat;

— spraying process;

— spray material, including lot number for spray powders if necessary;

— thickness of spray layers;

— instructions on preheating, temperature range and, if necessary, preheating range;

— instructions on cooling when spraying and, if necessary, temperature limits for the workpiece;

— spray parameters (amperage, voltage, fuel, plasma gases, powder-feeder gas, atomizing compressed air, etc.);

— type of surface post-treatment, if necessary, with reference to sealing or thermal post-treatment.

A sample-spraying-procedure specification form is given in ISO 14921.

11.2 Applying the spraying process

11.2.1 Preheating

In order to keep the heat-related stresses between the substrate and the spray coating to a minimum, preheating is often recommended. The preheating temperature depends on the type of parent material and spray material, amongst other things. The heat input from spraying should be taken into account, if necessary. Preheating temperatures are often between 80 °C and 150 °C. Preheating can also help to remove residual moisture from the substrate's surface before spraying. In many applications, the bond strength can be increased by preheating.

When spraying plastics, preheating the substrate is of particular significance. Due to the fact that the plastic particles are only surface-melted when passing through the flame, this being only sufficient for the minimal bond strength of the particles to the substrate's surface, the energy stored in the workpiece should effect a fusing of the sprayed plastic particles. The preheating temperatures depend on the plastic spray materials used and their melting point. If the preheating temperature is too low, the coating will be too porous and the bond strength to the substrate significantly reduced. If the temperature is too high, a slight oxidation or depolymerization can occur, which is made visible by discoloration.

11.2.2 Cooling

The thermal spray's heat input into the component or the coating shall be taken into account in many applications. For thin-walled components, the heat input can lead to undesirable deformation, which may cause the coating to spall. For parent materials with bad heat conduction, a localization of heat can occur in the spray zone, possibly leading to high residual stresses in the coating which can cause cracks in the coating, or even spalling.

In order to avoid such problems during the spraying process, a more or less intensive cooling of the component and/or the coating may be necessary. A number of gases can be used for cooling, depending on the magnitude of the heat input, the geometry of the component, the heat dissipation and distribution possibilities in the coating and substrate, and the sensitivity of the coating to residual stresses; a number of gases can be used for cooling.

In the simplest case, air blasting with dry, oil-free compressed air is sufficient. Carbon dioxide achieves the most intensive cooling.

Whereas cooling with compressed air merely achieves a cooling effect by convection, with carbon dioxide cooling, after the formation of snow and the sublimation of the snow in the gas phase, the sublimation energy is withdrawn from the substrate or the coating. This means that the cooling effect is increased considerably. Moreover, the cold gas flow cools by convection. Due to the intensive cooling effect of carbon dioxide cooling, special attention should be paid to the type, localization and motion control of the cooling nozzle.

Appropriate configuration of the cooling nozzle, when air-blasting with compressed air or carbon dioxide, can facilitate a cleaning effect on the spray zone in addition to cooling.

11.2.3 Spraying of bond coats

In certain applications, depending on the spray material, parent material and spraying process, the bond strength of the desired coating may be inadequate. In order to improve this a special bond-coat material should be sprayed onto the prepared surface and the desired top coat should be sprayed after that. Using this method, the bond strength of the coating system may be markedly increased.

Depending on the application, the following spray materials have proven to be suitable as bond coats:

— alloys of nickel, copper or iron combined with aluminium;

— certain nickel-based materials;

— molybdenum.

Even when spraying with plastics, the bond strength can be improved by applying a bonding agent. Such bonding agents can be applied by immersion or spraying. The thickness of the dry layer should be between 8 µm and 15 µm. Processing specifications from the manufacturer should be complied with.

11.2.4 Thermal-spray operating methods

To guarantee a good coating quality, the spraying devices and installations shall be kept in perfect working order. Acceptance criteria for spraying devices are given in ISO 14231.

The optimum spray distance varies according to the process, spray material and desired coating property. The impingement angle of the spray jet to the surface of the workpiece should be around 90° and be not less than 45°. Attention shall be paid to keep the spray parameters constant. Modern computer-controlled spraying installations can correct gas volumes and output losses from wear-related changes in the nozzle in closed loops.

When coating flat surfaces, intersecting spray passes are very effective. When coating rotationally symmetric parts, attention should be paid to adequate overlapping of the spray passes.

The achievable thickness of a thermal spray coating is limited due to the effect of shrinking forces within the coating, parallel to the surface of the workpiece. This reduces the bond strength. The thickness is limited by the type of spray material, the density of the coating, the energy supply of the respective spraying process and the physical and technological differences between the parent and spray materials. Suitable preheating or cooling measures can decrease the effect of these differences.

In order to prevent the coating from spalling at the ends and edges, it has proven to be advantageous to pull the coating around rounded or chamfered edges.

For inner coatings, particularly blind holes, special blast and spraying methods shall be used to prevent unwanted deposits of spray particles having insufficient bond strength.

Various methods are recommended for determining optimal spray parameters. They include spray specimens to assess the spray spot and the degree of surface melting of the particles on the substrate, a bending specimen to assess the adhesion of the coating to the substrate, or determining the optimal deposition rate according to ISO 17836.

12 Post-treatment of the coating

The subsequent machining or treatment of a thermally sprayed component is, in many cases, decisive for the success of its later application. In relation to solid materials, the properties of thermally sprayed coatings differ considerably, a fact which shall be taken into account, especially when machining such parts. The loads resulting from machining processes are often the highest which the coating is subjected to.

Details on how to machine or treat sprayed coatings by turning, milling, grinding, shot peening, brushing, polishing and super-finishing are given in ISO 14924.

Sealing and organic coating (painting) of thermally sprayed coatings against corrosive attacks, to improve sliding properties, or to achieve special surface characteristics, are the most important methods to post-treat spray coatings. For further details see ISO 14920 and ISO 14924.

Post-heat-treatment of spray coatings is always particularly beneficial if a high coating density is required and if higher demands are placed on the bond strength between the coating and substrate. Consideration should be given to a possible impairment of the parent material. Bonding can be achieved by fusing self-fluxing alloys. For further details see ISO 14920.

In special cases, thermally sprayed coatings can be post-treated using diffusion annealing in a vacuum or in an inert shroud-gas atmosphere. The diffusion processes in the interface yield a marked increase in the bond strength between the coating and the substrate. It is important to bear in mind that, due to structural changes, the parent material may be severely impaired.

13 Health, safety and environmental aspects

In order to prevent possible hazards to people and the environment as a result of thermal spraying, specific protective measures for the different energy sources should be taken. This applies especially to the gas supply and the generation and conduction of the electric current. Protective measures should be taken against the formation and distribution of process-related noise, radiation such as dazzle, thermal and UV radiation, and of air-contaminants.

The following items need to be identified and considered with regard to existing requirements. This applies particularly to the last paragraph.

Possible health hazards from air-contaminants to thermal sprayers, operating staff and persons working in the area of influence depend on their type and their magnitude. Special attention should be paid to hazardous substances for which “reference concentration values” (chromate, cobalt, nickel and their compounds) or low “maximum working-place concentration” values (lead, copper, vanadium and their compounds) have been defined.

Suitable ventilation measures shall ensure the hazard-free removal of air-contaminants (dust, smoke, gases) in compliance with the national environmental regulations for residual dust and/or hazardous substances in the exhaust air.

An efficient exhaust system should be installed directly at the source. If the installation of an effective exhaust system is not practicable, all persons in the hazard zone shall be equipped with a suitable respiratory-protection apparatus.

Particularly high requirements shall be met by the separation equipment when recycling the ventilated air. The smoke and dust detected by means of ventilation measures shall not be released into the air but shall be precipitated in a suitable separator.

Personnel involved in thermal spraying processes shall undergo medical examinations in compliance with the national regulations, in order to recognize any health impairments in time and take the necessary preventative measures.

NOTE Health, safety and environmental aspects are regulated by national laws resulting from the EU Directive 95/63/EC.

14 Recommendations for quality assurance

14.1 Quality-assurance measures

14.1.1 General

To ensure a maintainable quality of the spray coatings or coated components according to requirements, it is essential that all the factors involved in the process be monitored and any changes arising be kept to a minimum.

This is especially important for spray coatings, because the use of non-destructive tests is drastically limited in contrast to welds. This is due to their completely different structure.

To ensure quality, the following factors should be monitored:

— thermal spraying installations;

— spray materials and auxiliary materials;

— the implementation of the entire process from the preparatory work through to post-treatment;

— qualifications of personnel;

— tests on the component and the accompanying specimen.

A quality-management system shall ensure compliance with the conditions specified.

14.1.2 Quality management

The availability of a functional quality-management system (e.g. ISO 9001), which fulfils the respective quality requirements of the components or coatings, is an important prerequisite for the sustainable quality of coatings produced by thermal spraying or components having thermal-spray coatings.

ISO 14922-1, ISO 14922-2, ISO 14922-3 and ISO 14922-4 include guidelines for the quality requirements to be met by the manufacturer of thermally sprayed coatings. The guidelines apply to new components, as well as to the repair or maintenance of heavily stressed components, irrespective of whether the parts were previously coated or should be coated for the first time to improve their function. The guidelines apply to spraying operations carried out in workshops and on sites.

ISO 14922-2, ISO 14922-3 and ISO 14922-4 have been structured in such a way that they can be used for any type of component.

The standard can also be used to assess the suitability of the manufacturer, as to whether spray coatings or even components with thermally sprayed coatings can be produced in the prescribed quality according to the requirements.

The standard can also serve as a basis for determining the requirements between the parties to the contract.

14.1.3 Quality assurance measures for thermal spraying installations

With respect to plasma, arc and flame spraying installations, ISO 14231 provides details on quality checking procedures for the acceptance of new equipment as well as on monitoring the operational stability of spraying installations during and/or after a spraying operation.

14.1.4 Quality assurance measures for spray materials used in thermal spraying

Wires, rods, and cords for thermal spraying are described in ISO 14919.

ISO 14232 deals with powders for thermal spraying. In addition to the chemical analysis, particle shape and particle size distribution of spray powders, the manufacturing method of the powders also plays a significant role. The consistency of the powder within a lot and from consignment to consignment is therefore very important for a uniform coating quality. For more demanding spraying jobs, the powder should first be inspected to ensure a consistent coating quality. Besides checking the Inspection Certificate, for example, according to or corresponding to ISO 10474 the inspection can confine itself to flow behaviour and particle fraction analysis. In some cases, a materialographic investigation of the powder is advisable. In borderline cases, a spray test and, if necessary, a fusing test should determine the powder's usability.

14.2 Personnel qualification

14.2.1 General

Thermal spraying is one of the special processes which requires qualified personnel for its supervision and for the execution of the spraying operation on assemblies or single workpieces in order to achieve confidence in the manufacture of the spray coatings and to guarantee the reliability of the operation.

14.2.2 Thermal spraying specialist (TSS)

The personnel supervising the production of spray coatings should be able to co-ordinate all activities connected with thermal spraying. The TSS is responsible for the proper planning, execution, monitoring and inspection of the operation. The TSS should be consulted on matters concerning suitable spray design and set-up.

Tasks and responsibilities of the European thermal spraying specialist are specified in ISO 12690.

14.2.3 Thermal sprayer

To guarantee the manufacturing quality of thermal spray coatings, the spraying personnel should be examined, provided, of course, the sprayer or operator has a direct influence on the manufacturing procedure and the coating quality.

The approval testing shall ensure that only those thermal sprayers that have displayed adequate practical experience and knowledge of the spraying process, spray materials and the industrial safety regulations relevant to the respective spraying process are involved in the operation.

The approval testing of thermal sprayers is defined in ISO 14918.

15 Testing of components and accompanying specimens

15.1 General

To assess the quality of a spray coating, destructive and non-destructive tests are normally carried out. Choosing the appropriate tests should depend on the respective application. Coating quality tests should be carried out on the component as far as possible. If this is not possible, accompanying specimens should be tested.

In line with state-of-the-art technology, not all factors important for the quality of a coating can be tested on the component using non-destructive methods. No practical non-destructive method for determining a qualitative adhesion or quantitative bond strength therefore exists to date.

15.2 Tests on the component itself

The following properties of a thermally sprayed coating can be tested on the component by means of non-destructive methods.

— Visual inspection enables the following surface phenomena to be detected: unevenness, nodules, loose particles, detachment of the coating at the edges, differences in roughness, discoloration due to overheating and open cracks on the surface.

— Dimensional checks can determine whether the dimensional stability of the workpiece is within the tolerance limits.

— Measuring the roughness can determine any deviations in roughness in relation to nominal values.

— A negative impression of the surface enables the detection of unevenness, roughness or cracks. This replica technique is useful to carry out in those areas inaccessible to direct visual inspection, or if the roughness cannot be measured directly on the component.

— The penetration test according to ISO 3452-1 enables fine cracks on the surface to be detected. Due to the typical porosity of spray coatings, this testing method is only suitable for coatings which have undergone thermal post-treatment, or for applications employing spraying processes which can produce an almost complete dense coating (detonation, HVOF or cold spraying).

— Macro-hardness tests according to ISO 6508-1 or ISO 6506-1 can determine differences in hardness or deviations from the desired value. If the geometry or insufficient stiffness of the component, or risk of damaging the spray coating prevent a hardness test carried out on the component, this test should then be performed on the accompanying specimen, e.g. according to ISO 6507-1.

— Mechanical, magnetic or electromagnetic measuring methods can determine the coating thickness, provided process-specific conditions are fulfilled.

Further details on non-destructive tests and the definition of irregularities are defined in ISO 14923.

Bibliography

[1] ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

[2] ISO 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method*

[3] ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

[4] ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

[5] ISO 8503-1, *Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates — Part 1: Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces*

[6] ISO 9001, *Quality management systems — Requirements*

[7] ISO 10474, *Steel and steel products — Inspection documents*

[8] ISO 11124-2, *Preparation of steel substrates before application of paints and related products — Specifications for metallic blast-cleaning abrasives — Part 2: Chilled-iron grit*

[9] ISO 11126-7, *Preparation of steel substrates before application of paints and related products — Specifications for non-metallic blast-cleaning abrasives — Part 7: Fused aluminium oxide*

[10] ISO 12690, *Metallic and other inorganic coatings — Thermal spray coordination — Tasks and responsibilities*

[11] ISO 14917, *Thermal spraying — Terminology, classification*

[12] ISO 14919, *Thermal spraying — Wires, rods and cords for flame and arc spraying — Classification — Technical supply conditions*

[13] ISO 17836, *Thermal spraying — Determination of the deposition efficiency for thermal spraying*

[14] EN 12074, *Welding consumables — Quality requirements for manufacture, supply and distribution of consumables for welding and allied processes*

[15] EN 13507, *Thermal spraying — Pre-treatment of surfaces of metallic parts and components for thermal spraying*

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