Thermal spray process with a keeping free of cooling air bores

The invention relates to a method of coating a surface of a body in accordance with the preamble of the independent method claim. The invention further relates to a turbine vane which is coated in accordance with such a method.

It is a usual measure today with turbine vanes, in particular with turbine vanes of gas turbines which are subject to very high thermal or corrosive stress such as are used as land-based industrial turbines or as aircraft engines, to provide the turbine vane with cooling air bores which extend through the vane and open into the outer surface of the turbine vane. During the operation of the turbine, a cooling medium, usually air, is then conducted through the cooling air bores and then exits at the surface of the turbine vane and provides a cooling. In this respect, a so-called film cooling is also frequently implemented, i.e. the fluid exiting from all the cooling air bores forms a protective gas film or vapor film on the surface of the turbine vane which considerably reduces the thermal strain on the vane.

Problems in particular occur when such components already provided with cooling air bores should be coated by means of a thermal spray process - either on repair or maintenance or on new manufacture. Such

coatings are frequently applied to the turbine vanes as thermal protective layers or as protection against (hot) corrosion.

In thermal spraying, coating material may now be deposited in the openings of the cooling air bores and considerably restrict their flow cross-section or the opening may completely clog. This naturally has a very disadvantageous effect on the cooling effect achieved in operation. The cooling air bores therefore have to be liberated from unwanted coating material in a further processing step.

This problem is particularly pronounced with bores having a very small diameter of, for example, less than one millimeter diameter. There is in particular the tendency with the already mentioned film cooling to provide more and smaller, i.e. narrower, cooling air bores, for example to realize a fluid film on the vane surface which is as homogeneous as possible. In this cooling principle, it is very important that all cooling air bores actually remain open.

It is also generally necessary on the thermal spraying of surfaces into which such cooling air bores open that the bores do not clog or that their flow cross-section is not reduced. A problem-free cooling performance can only be achieved in this way.

Different measures have already been proposed to solve this problem. It is, for example, proposed in WO-A-2010/078994 to introduce a masking material, preferably a polymer, into the cooling hole or into the outlet opening of the cooling air bore before the thermal coating. This masking material is hardened before the coating, for example by treating with UV radiation. After the coating procedure, the masking material then has to be removed again in a further processing step, wherein it has to be

ensured that the masking material really is completely removed. This is a complex and/or expensive procedure, in particular with very thin bores.

Starting from this prior art, it is therefore an object of the invention to propose a method with which a coating of a surface is made possible, wherein the flow cross-section of bores which open into the surface to be coated can be kept substantially constant. Furthermore, a turbine vane coated in this manner should be provided by the invention.

The subjects of the invention satisfying this object are characterized by the independent claims of the respective category.

In accordance with the invention, a method is therefore proposed of coating a surface of a body which has at least one throughgoing bore having an inlet and having an outlet, wherein the outlet is provided in the surface to be coated, in which method the coating takes place by means of thermal spraying, wherein, during the thermal spraying, the bore is flowed through by a fluid which flows out through the outlet of the bore and substantially prevents a constriction of the bore caused by the coating.

By the measure of allowing a fluid to flow through the bore during the thermal spraying, the coating material is prevented from penetrating into the bore or being deposited in the bore by the fluid exiting through the outlet. It is prevented in this manner that the flow cross-section of the bore is reduced during the thermal spraying or that the bore is even fully clogged. The particular advantage of this process lies in the fact that, after the thermal spraying, no additional processing step is required to open the bore or to widen it to the desired diameter again or to liberate it from hardened masking material.

The fluid is preferably a gas because the fluid flow can be controlled better by it; but generally a liquid can also be used as the fluid, for example also a liquid which then exits the outlet as a vapor. With respect to the avoidance of unwanted chemical reactions, the fluid is in particular preferably an inert gas, especially argon, because this is frequently used as a process gas in thermal spray processes.

The flow rate at which the fluid flows through the bore or through the totality of all bores naturally depends on the respective process parameters and can be optimized to the application. It has in particular proved itself in practice with processes in the underpressure area if the flow rate of the fluid is at most 5 SLPM (standard liters per minute) and preferably amounts to at most 1 SLPM.

In a preferred application, the thermal spraying is a plasma spraying process.

The method in accordance with the invention is particularly well suited when the thermal spraying is a plasma spraying process which is carried out at a process pressure which is less than 10,000 Pa. LPPS processes (LPPS = low pressure plasma spraying) are especially suitable, in particular those in which a value is selected for the process pressure between 50 and 2000 Pa, preferably between 100 and 800 Pa.

In a special embodiment of the LPPS process relevant to practice, a starting material for the coating is sprayed onto the body in the form of a process jet, wherein the starting material is injected into a plasma defocusing the process jet and there partly or completely changes into a liquid phase, and wherein the coating takes place by deposition from the

liquid phase. This process is also called a LPPS-TF process, where TF stands for thin film.

A further embodiment very relevant to practice is an LPPS process with deposition from the gas phase. In this respect, a starting material for the coating is sprayed onto the body in the form of a process jet, wherein the starting material is injected into a plasma defocusing the process jet and there at least partly changes into a gaseous state, and wherein the coating takes place by deposition from the gaseous phase. The designation LPPS-TF is sometimes also used for this process; however, since it is an - at least partial - deposition from the gaseous phase or vapor phase, the designation PS PVD (plasma spray physical vapor deposition) is also used for this process.

The method in accordance with the invention is in particular suitable for the coating of turbine vanes which have one or more cooling air bores. The body is then a turbine vane and the at least one bore is a cooling air bore.

The turbine vane preferably has a foot which is connected to a source for the fluid during the coating so that the fluid can flow from the foot of the turbine vane through the at least one cooling air bore to the outlet of the cooling air bore.

The method is particularly suitable when the turbine vane has a plurality of cooling air bores which are flowed through by the fluid.

A turbine vane is further proposed by the invention which is coated in accordance with the method in accordance with the invention.

In an embodiment variant, the cooling air bore opens obliquely into the surface to be coated. It is naturally also possible that the cooling air bore opens substantially perpendicular into the surface to be coated. Combinations of these two variants are also possible.

In a preferred embodiment of the turbine vane, the thickness of the coating increases as the distance from the outlet of the bore increases until said thickness has reached its maximum value. Due to the fluid flow exiting during the coating, it is more difficult for the coating material to be deposited in the direct vicinity of the respect outlet than somewhat further away where the flow is already weaker. The transition from the outlet of the bore to the surface of the body is no longer so abrupt or sharply edged due to this increase in the layer thickness, but is rather somewhat sloped or rounded. This is advantageous for the operation of the turbine vane viewed from the aspect of the flow behavior of the cooling air. In particular with film cooling processes, an even more homogeneous cooling film can hereby be realized at the surface of the turbine vane.

Further advantageous measures and preferred embodiments of the invention result from the dependent claims.

The invention will be explained in more detail in the following with reference to embodiments and to the drawing. There are shown in the schematic drawing, partly in section:

Fig. 1 a sectional representation of a fluid-cooled turbine vane;

Fig. 2 a cross-sectional representation of a section of the wall of a gas-cooled turbine vane, which is coated in accordance with

an embodiment of the method in accordance with the invention, with a bore serving as a cooling air bore; and

Fig. 3 as Fig. 2, but for a different bore.

The method in accordance with the invention serves for the coating of a surface of a body which has at least one throughgoing bore which opens into the surface to be coated. In the following, reference is made with exemplary character to the application particularly important for practice that the body is a turbine vane 1 (see Fig. 1) which is gas cooled in operation.

Fig. 1 shows, in a longitudinal sectional representation, an embodiment of a gas-cooled turbine vane 1 such as is known from the prior art. The turbine vane 1 includes a turbine blade 2 and a foot 3 with which the turbine vane 1 is installed on the rotor or on the hub. A plurality of cooling air passages 4 are typically provided in the interior of the turbine vane 1 and are flowed through by a gas - usually air - in the operation of the turbine to cool the turbine vane 1. The flow development of the cooling air is illustrated in Fig. 1 by the arrows without reference symbols. A plurality of cooling air bores 5 extend from the cooling air passages 4 through the wall of the turbine vane 1 so that the cooling air can exit at the surface 10 of the turbine vane 1. Each cooling air bore 5 has an inlet 51 (see Fig. 2) through which the cooling air enters into the bore 5 and an outlet 52 which is disposed in the outer surface 10 of the turbine vane 1 and through which the cooling air flows out of the bore 5.

As already mentioned, the method in accordance with the invention is not restricted to the coating of turbine vanes, but is rather very generally suitable for the coating of a surface 10 of a body 1 which has at least one

throughgoing bore 5, i.e. which can be flowed through by a fluid, having an inlet 51 and an outlet 52, wherein the outlet 52 is provided in the surface 10 to be coated. Such a body can, for example, also be a tubular body whose outer surface is to be coated and whose wall is provided with a plurality of bores 5.

In the method in accordance with the invention, the surface 10 of the body 1, here the surface 10 of the turbine vane 1, is coated by means of thermal spraying. In accordance with the invention, the bore 5 is flowed through by a fluid during the thermal spraying, said fluid flowing out through the outlet 52 of the bore 5 and thus substantially preventing a narrowing of the outlet 52 or of the bore 5 caused by the coating. It is at least largely prevented by the fluid exiting during the thermal spray process that coating material is deposited in the outlet 52 or in the bore 5. The flow cross-section of the bore 5 is thus maintained; even after the coating, the bore 5 still has the same flow cross-section as before the coating.

The same cooling air passage 4 or cooling air bores 5 are therefore used for the throughflowing fluid during the thermal spraying as are used in the normal operation of the turbine for the cooling medium.

The method in accordance with the invention is suitable for all thermal spray processes such as flame spraying, high-velocity flame spraying (HVOF), arc spraying, e.g. wire arc spraying, laser spraying, cold gas spraying and all plasma spraying processes, e.g. plasma spraying at normal pressure (APS), plasma spraying at underpressure (VPS or under a protective gas atmosphere.

A gas, and specifically an inert gas, is preferably used as the fluid for the throughflow of the bore 5 during the coating process. It can be avoided by

the use of an inert gas that unwanted chemical reactions which can be caused by the fluid flowing out of the bores 5 occur during the thermal spraying. A particularly preferred gas is argon because this inert gas is used as a process gas in a number of spray processes.

The flow rate at which the fluid flows out of the bore 5 or out of the bores 5 during the thermal coating can be adapted in dependence on the application and on the thermal spraying process. The flow rate should, on the one hand, be selected so high that a deposition of the coating material in the bore is prevented. On the other hand, the flow rate should be selected so high that it does not result in a considerable degrading of the coating process.

In practice, flow rates of at most 5 SLMP (standard liters per minute) and especially of at most 1 SPLM have specifically proved themselves for plasma spray processes in the underpressure range on the use of argon.

A special embodiment of the method in accordance with the invention will now be explained with reference to Figs. 2 and 3 in which an LPPS process (LPPS: low pressure plasma spraying) is used for the thermal spraying. This process is described generically in WO-A-03/087422. The process described there is one which is there also described as an LPPS thin-film process (LPPS-TF = LPPS thin film). A conventional LPPS plasma spray method is modified in a technical process manner by the LPPS thin film process, with a space through which a plasma flows ("plasma flame" or "plasma jet") being widened due to the changes and being expanded to a length of up to 2.5 m. The geometrical extent of the plasma results in a uniform expansion - a "defocusing" - of a powder jet which is injected into the plasma using a propellant gas. The material of the powder jet which is dispersed to form a cloud in the plasma and is melted partly or completely

there moves in a uniform distribution over a widely expanded surface of the body to be coated.

It is disclosed in WO-A-03/087422 that a plasma is generated with sufficiently high specific enthalpy so that a substantial portion of the coating material changes into the vapor phase and is deposited from the vapor phase on the surface to be coated. Reference is made here to WO-A-03/087422 with respect to the plasma parameters and the details of the process.

A major aspect of the process disclosed in WO.-A-03/087422 is that a substantial portion of the coating material is deposited from the vapor phase on the body to be coated. Since this process is not necessarily directed to the generation of thin films it is today frequently also called a PS PVD process (PS PVD: plasma spray physical vapor deposition) instead of an LPPS-TF process, whereas the term LPPS-TF process is used for such processes in which thin films of less than 50 micrometers, for example, are generated, wherein the deposition usually takes place from the liquid phase, i.e. the coating material moves onto the surface to be coated in the form of small droplets.

In the embodiment of the process in accordance with the invention explained with reference to Figs. 2 and 3, a PS PVD process is used as thermal spraying such as is disclosed, for example, in the already cited WO-A-.03/087422 (but called LPPS-TF there), i.e. the deposition of the coating material on the surface 10 to be coated takes place at least to a substantial amount of at least 50% of the coating deposited on the surface 10 from the gas phase.

Fig. 2 shows a cross-sectional representation of a section of the wall of a gas-cooled turbine vane 1 which is coated in accordance with such an embodiment of the method in accordance with the invention having the bore 5 serving as a cooling air bore. The outlet 52 of the bore 5 opens substantially perpendicular into the surface 10 to be coated of the turbine vane 1. Fig. 3 shows, in a representation analog to Fig. 2, a bore 5 which opens obliquely - that is not at a right angle - into the surface 10 to be coated. Both Fig. 2 and Fig. 3 show the turbine vane 1 with a coating 11 already deposited on the surface 10. Since it is sufficient for understanding, only one bore 5 is shown in each case in Figs. 2 and 3.

To prepare for the coating, the turbine vane 1 is first fastened to a holder, not shown, with which it can be introduced into the coating chamber. It is in this respect in particular preferred with plasma processes in the underpressure range if the coating chamber is situated before an antechamber from where the turbine vane 1 to be coated can be introduced by means of the holder through a sluice wall into the coating chamber. Such a plant having an antechamber is disclosed, for example, in EP-A-1 006 211.

The holder or the foot 3 of the turbine vane 1 is now connected to a source in which an inert gas, preferably, argon, is stored. In this respect, the connection takes place such that the argon can flow from the source through the foot 3 of the turbine vane 1 through the at least one cooling air bore 5 in a correspondingly same manner as the cooling medium flows through the turbine vane 1 during the operation of the turbine. A plurality of cooling air bores 5 are naturally preferably provided which are then all flowed through by the argon during the coating, as the arrows without reference symbols in Figs. 2 and 3 indicate.

The pressure in the coating chamber is brought to the desired process pressure of less than 10,000 Pa, preferably to a value between 50 Pa and 2000 Pa, and especially to a value between 100 and 800 Pa.

After the turbine vane 1 has been brought into the coating chamber at the desired process pressure, the argon flow through the cooling air bore 5 is started as the arrows without reference symbols in Figs. 2 and 3 indicate. A starting material for the coating in the form of a process jet is now sprayed onto the turbine vane 1 by means of a plasma spray apparatus, wherein the starting material is injected into a plasma defocusing the process jet and changes there at least partly into the gaseous phase. The coating of the turbine vane 1 now takes place by deposition from the gaseous phase while the argon gas flows through the bore 5.

The exiting argon can in this respect additionally effect a positive cooling effect on the surface 11. The argon is pumped out of the coating chamber together with the process gas.

In an alternative process management, the LPPS-TF process is carried out so that the starting material is partly or completely plasticized in the plasma or changes into the liquid phase and the coating then takes place by deposition from the liquid phase.

During the coating process, the argon gas flowing through the bore 5 prevents the coating material from being deposited in the bore 5 or in the outlet 52. It is thus ensured that each bore 5 still has the same flow cross-section as before the thermal spraying after the end of the thermal spraying.

A particular advantage of the method explained with reference to Fig. 2 and Fig. 3 is that a more homogeneous, that is slower, transition takes place from the edge of the bore 5 to the coating 11 due to the fluid flowing out of the bore 5 during the thermal spraying. As Fig. 2 and Fig. 3 show, the thickness of the coating 11 increases continuously in the region marked by B as the distance from the outlet 52 of the bore 5 increases until said thickness has reached its maximum value d. This slow increase of the coating is due to the fact that the outflowing fluid makes the deposition of the coating material more difficult in the direct proximity of the outlet 52 during the coating, with this difficulty decreasing as the distance from the outlet 52 increases.

It can be seen in Fig,. 2 that with a perpendicular opening of the bore 5 this continuous increase of the thickness of the coating takes place symmetrically, that is, in accordance with the illustration, on both sides of the outlet 52 of the bore 5.

On an oblique opening of the bore 5, as is shown in Fig. 3, the inclined increase of the coating 11 occurs essentially only on one side, namely on the left side of the outlet 52 in accordance with the illustration.

This slow increase in the thickness of the coating 11 seen in the direction of flow also has advantages for the operation of the turbine because the cooling air exiting from the cooling air bore 5 is hereby better conducted over the surface of the turbine vane 1 in the operating sate and turbulence at the outlet 52 of the bore 5 can be at least reduced.

Claims

1. A method of coating a surface (10) of a body (1) which has at least one throughgoing bore (5) having an inlet (51) and having an outlet (52), wherein the outlet (52) is provided in the surface (10) to be coated, in which method the coating takes place by means of thermal spraying, characterized in that, during the thermal spraying, the bore (5) is flowed through by a fluid which flows out through the outlet (52) of the bore (5) and substantially prevents a constriction of the bore (5) caused by the coating.

2. A method in accordance with claim 1, wherein the fluid is a gas, in particular an inert gas, and specifically argon.

3. A method in accordance with one of the preceding claims, wherein the flow rate of the fluid amounts at most to 5 SLPM and preferably at most to 1 SLPM.

4. A method in accordance with any one of the preceding claims, wherein the thermal spraying is a plasma spray process.

5. A method in accordance with any one of the preceding claims, wherein the thermal spraying is a plasma spray process which is carried out at a process pressure which amounts to less than 10,000 Pa.

6. A method in accordance with claim 5, wherein a value between 50 and 2000 Pa, preferably between 100 and 800 Pa is selected for the process pressure.

7. A method in accordance with claim 5 or claim 6, wherein a starting material for the coating is sprayed onto the body (1) in the form of a process jet, wherein the starting material is injected into a plasma defocusing the process jet and there partly or completely changes into a liquid phase, and wherein the coating takes place by deposition from the liquid phase.

8. A method in accordance with claim 4 or claim 5, wherein a starting material for the coating is sprayed onto the body (1) in the form of a process jet, wherein the starting material is injected into a plasma defocusing the process jet and there at least partly changes into a gaseous phase, and wherein the coating takes place by deposition from the gaseous phase.

9. A method in accordance with any one of the preceding claims, wherein the body is a turbine vane (1) and the at least one bore is a cooling air bore (5).

10. A method in accordance with claim 9, wherein the turbine vane (1) has a foot (3) which is connected to a source for the fluid during the coating so that the fluid can flow from the foot (3) of the turbine vane (1) through the at least one cooling air bore (5) to the outlet (52) of the cooling air bore (5).

11. A method in accordance with claim 10, wherein the turbine vane (1) has a plurality of cooling air bores (5) which are flowed through by the fluid.

12. A turbine vane coated in accordance with a method in accordance with any one of the claims 1 to 11.

13. A turbine vane in accordance with claim 12, wherein the cooling air bore (5) opens obliquely into the surface (10) to be coated.

14. A turbine vane in accordance with claim 12, wherein the thickness of the coating (11) increases as the distance from the outlet (52) of the bore (5) increases until said thickness has reached its maximum value (d).