

Description

The present invention concerns a method of providing an abrasive material comprised of particulates and matrix on the surface of an article, comprising adhering a single layer of spaced apart ceramic particulates to the article surface so that the particulates adhere to the article and project from the surface in spaced apart fashion, depositing on the surface a layer of metal to fill the spaces between the particulates with matrix material which inherently has voids.

Gas turbine engines and other axial flow turbomachines have rows of rotating blades contained within a generally cylindrical case. It is very desirable to minimize the leakage of the gas or other working fluid around the tips of the blades where they come close to the case. As has been known for some time, this leakage is minimized by blade and sealing systems in which the blade tips rub against a seal attached to the interior of the engine case. Generally, the blade tip is made to be harder and more abrasive than the seal; thus, the blade tips will cut into the seal during those parts of engine operation when they come into contact with each other.

In the earlier systems of the type just described the blade tip was a superalloy material, possibly even having a hard face, and the seal was a metal which had a suitable propensity for wear. For instance, porous powder metals were used. Now however, ceramic containing seals are finding favor, such as those shown in US-A-3 975 165 to Elbert et al, US-A-4,269,903 to Klingman et al and US-A-4 273 824 to McCormas et al. The ceramic faced seals are considerably harder than the prior art metal seals and as a result, the prior art blade tips were deficient in being able to wear away the seal with little wear to themselves.

Consequently, there have been developed improved blade tips, most particularly of the type described in US-A-4 249 913 to Johnson et al "Alumina Coated Silicon Carbide Abrasive" of common ownership herewith. In the Johnson et al invention silicon carbide particulate of 0.20-0.76 mm average nominal diameter is coated with a metal oxide such as alumina and incorporated by powder metal or casting techniques in nickel or cobalt base alloys. A powder metal compact containing 30-45 volume percent particulate may be made and this part is then bonded, such as by diffusion bonding, liquid phase bonding or brazing to the tip of a blade.

GB-A-2 010 982 describes a turbomachinery blade showing abrasive particulates protruding from a matrix material at the tip of the blade.

US-A-2 820 746 describes a method of making a metal-bonded abrasive tool comprising abrasive particles and matrix on its surface wherein a single layer of spaced apart particles are adhered to the surface such that the particles project from the surface and a layer of matrix metal fills the spaces between the particles.

However, there are certain inherent characteristics of an abrasive tip made by the foregoing

technique. Specifically, the metal part can only be made in a practical minimum thickness, typically of the order of 1-2 mm thick. Usually, the abrasive tip part is made in the cross sectional shape of the tip of the turbine blade substrate. After being compacted or cast it is machined to a flat surface. Likewise, the blade tip is machined to a planar surface to receive the abrasive. Such planar machining is a practical limitation necessary to get good faying fit and minimum weld joint thickness, of the order of 0.05 mm. Unless this is done adequate bond strength in the 1100°C operating temperature range will not be attained. After bonding of the abrasive on a blade tip, a multiplicity of blades are assembled in a fixture which is adapted to rotate much like the disc of the engine in which they are used. They are then ground to a cylindrical or conical surface which corresponds with the interior surface of the engine case seals. As a result of this procedure, the abrasive will initially have a substantial thickness which will have to be ground to a substantial degree. The particulates are often costly and thus the approach is costly. Second, because practicality dictates a planar joint surface and because the final finished surface of the abrasive tipped blade will be cylindrical or conical, there will be a varying thickness of abrasive across the blade tip, as shown in Figure 9 herein. While the prior art blade tips are useful, it is more desirable that the abrasive portion of the tip be uniform in thickness across the curved surface. It is also very desirable to minimize the quantity of grits which must be used in the manufacturing process since they must be of the highest quality and their manufacture, including the oxide coating process, is expensive.

An object of the present invention is to provide on the tip of the blade a thin and uniform layer of abrasive coating adapted for use in the vicinity of 1100°C and higher. Thin layers of particulate bearing abrasive, although not adapted to operate at such high temperatures, have been known. For example, coated abrasives made from alumina, silica and silicon carbide are common products, as are metal bonded diamond and cubic boron nitride grinding wheels. Fused and unfused layers of sprayed metal are well known in the metallizing field. See for example US-A-3,248,189 to Harris, Jr. and US-A-4,386,112 of Eaton and Novak, the present applicants. However, any process of metal spraying grits and matrix metal is inherently inefficient in that only a fraction of the sprayed material actually hits and adheres to the surface. These difficulties are especially significant in light of the relatively small size, e.g., about 6 by 50 mm, of a typical turbine blade tip.

Of particular interest in the context of the present invention is the following art. Silicon carbide particles are bonded to a fabric using an organic binder and then overcoated with aluminum, and other metals, according to Fontanella US-A-3,508,890 and Duke et al US-A-3,377,264. Fisk et al in US-A-3,779,726

describe a method of making metal-abrasive tools containing silicon carbide and other grits which comprises encapsulating grit in a porous metal coating and then impregnating the encapsulating layer with other metal to unite the particles. Palena in US—A—4,029,852 describes how a non-skid surface is made by laying grits on a surface and spraying molten metal droplets over them. The Palena invention involves a relatively crude product, such as a stairway tread, in contrast to the finer product which characterizes metal bonded abrasives and the invention herein. Wilderin US—A—3,871,840 describes how encapsulating grits in a pure metal envelope improves the properties of a metal bonded abrasive made in various ways.

The aforementioned abrasive comprised of a previously fabricated particulate and metal structure, attached by a welding process to a turbine blade tip, has shown the characteristics of the abrasive which are useful. But while it is desirable that the thickness of the abrasive be reduced to the minimum necessary for a durable tip, such minimum cannot be attained with the bonded abrasive tip part because of practical manufacturing problems mentioned above. At the same time, it is known from past experience that the commonly available material systems associated with less exotic applications, some of which are described in the aforementioned patents, are not sufficiently durable even though they would appear capable of providing the desired minimum thickness. Therefore, it was necessary to conduct research and development to produce a superalloy turbine blade which had the desired abrasive tip.

The method according to the present invention is characterized by said ceramic particulates having a metal cladding, causing said metal cladding to adhere to the surface to obtain the adherence of the particulates to the article, and after having applied the matrix material heating the article to an elevated temperature to densify the matrix and to metallurgically bond the matrix to the metal clad particulates and the substrate; and machining the surface of the abrasive material to a finish surface so that the particulates are visible at the surface.

An object of the invention is to provide a thin layer abrasive on the surface of metal objects. In particular, an object of the invention is to provide on an airfoil for use in turbomachinery an abrasive material which is very light yet durable. This, it is desired to make the abrasive of ceramic particulates and metal, where as few particulates as possible are used. For high temperature use, the abrasive must be comprised of oxidation resistant materials, particularly a superalloy matrix metal, and the abrasive be well bonded to a superalloy substrate to resist thermal and mechanical stresses.

According to the invention, an article will have but a single layer of ceramic particulate on its surface. The particulates will be in contact with the surface of the substrate and will predomi-

nately extend through a surrounding matrix metal to a free machined surface. And when the machined surface is parallel to the surface on which the abrasive is laid, the particulates will thus have equal lengths and will be disposed at the surface in a most effective manner. To obtain the optimum performance from the abrasive the particulates are closely but evenly spaced. But they are carefully sized and placed so that at least 80 percent do not touch one another. Thus, the presence of surrounding matrix means that the particulates are well bonded into the abrasive and that the abrasive is well bonded to the substrate. The inventive abrasives are made from ceramics which have particulate aspect ratios less than 1.9 to 1, preferably in the vicinity of 1.5 to 1. This enables particulates to be present with generally uniform spacing at densities of 33—62 particulates per cm² of article surface, preferably 42—53, and with 10—20 volume percent ceramic.

In the preferred practice of the invention the abrasive material is applied to the tip of a superalloy turbine blade using sintering, plasma arc spraying and machining. The ceramic particulates are those which do not interact with the matrix material at elevated temperature. For example, alumina coated silicon carbide particulates are used. The particulates are further clad with a sinterable material, such as nickel. The particulates are laid on the surface and heated to a sintering temperature to thereby cause the nickel layer to metallurgically adhere to the substrate. Then, a superalloy matrix material is deposited over the particulates, usually by means of a "line of sight" process (the deposited metal travels in a straight line toward the surface). There are voids created in the vicinity of the irregular shaped particulates laying on the surface and subsequent processing, such as hot isostatic pressing, is used to densify the matrix around the particulates. This results in a metallurgical structure characterized by a dense superalloy matrix containing ceramic particulates having a region of interdiffused metal around them, which region is relatively depleted in the constituents of the matrix material and relatively rich in the constituent of the cladding material.

When the abrasive is on the tip of a blade which interacts with a ceramic seal, the matrix material is partially removed from the free machined surface of the abrasive, to expose 10—50 percent of the particulate length as measured from the substrate. This improves the ability of the abrasive to cut ceramic seals.

The invention is effective in providing on a relatively small cambered surface of an airfoil tip an abrasive material which is effective in protecting the blade tip from wear, cutting into ceramic abradable seals, resisting high temperatures and thermal stresses and otherwise achieving the objects of the invention.

The foregoing and other objects, features and advantages of the present invention will become more apparent from the following description of preferred embodiments and accompanying drawings.

In order that the invention may be fully understood reference is made on the accompanying drawings, wherein

Figures 1—4 show schematically the sequential steps by which particulates are placed on the surface of a substrate, enveloped in matrix, machined to a flat surface, and machined to a final configuration.

Figure 5 is a more detailed view of a portion of Figure 1 showing how particulates appear after they have been metallically adhered to the surface of the substrate.

Figure 6 is a more detailed view of a portion of Figure 2 showing how the matrix envelops particulates and includes porosity when a "line of sight" deposition procedure is used.

Figure 7 is a more detailed view of a portion of Figure 2 showing how the structure in Figure 6 is transformed after high temperature pressing to eliminate voids and cause interdiffusion.

Figure 8 shows generally a typical gas turbine blade having an abrasive layer on its tip.

Figure 9 shows in side view the appearance of a prior art abrasive blade tip, illustrating the varying thickness and bond joint.

Figure 10 is a side view of the blade in Figure 8, along line D, showing how particulates are present in a single layer and how they extend slightly above the matrix material of the abrasive.

The invention is described in terms of the bonding of a silicon carbide particulate and superalloy matrix abrasive material, called simply an "abrasive" herein, onto the tip of a typical advanced gas turbine engine turbine blade made of a single crystal nickel alloy, described in US-A-4,209,348. Alumina coated silicon carbide particulates of the type disclosed in US-A-4,249,913 to Johnson et al are preferably used in the invention. The disclosure of both the foregoing patents, commonly owned herewith, are hereby incorporated by reference. The invention will be applicable to other materials as well. As the Johnson et al patent indicates, an alumina coating on silicon carbide particulate is particularly useful because it prevents interaction between the silicon carbide and the surrounding matrix metal. Such interaction can occur during fabrication and during high temperature use, and can degrade the ability of the silicon carbide particulate to perform the abrasive function. Preferably, the alumina coating is 0.010—0.020 mm thick and is applied by a commercial chemical vapor deposition process.

The matrix is a metal which is able to be bonded to the particulates and the substrate. The matrix in the best mode of the present invention is either a high temperature alloy, meaning an alloy adapted for use at a temperature of 600°C or higher such as the commercial alloys Inconel 600, Inconel 625, Hastelloy X, Haynes 188 and MCrAlY, or a superalloy, meaning an alloy based on Ni, Co or Fe such as commercial nickel base alloys Waspaloy, IN 100, U 700, MAR—M200, Inconel 718 which are strengthened by a gamma prime precipitate. Alloys of either type tend to have a

number of constituents of varying nature, e.g., Ni, Co, Fe, Cr and Al with either of the latter two elements particularly characterizing them, to provide oxidation resistance.

Preferably, the superalloy matrix has the nominal composition by weight percent of 21—25 Cr, 4.5—7 Al, 4—10 W, 2.5—7 Ta, 0.02—0.15 Y, 0.1—0.3 C, balance Ni. Another useful material is the cobalt base alloy having the nominal composition by weight percent of 18—30 Cr, 10—30 Ni+Fe, 5—15 W+Mo, 1—5 Ta+Cb, 0.05—0.6 C, 3.5—80 Al, 0.5—20 Hf and 0.02—0.1 Y, balance cobalt.

The configuration of the typical turbine blade is shown in Figure 8. The blade 20 is comprised of a root part 22 and an airfoil part 24. There is an abrasive layer 26 at the tip end 28 of the blade, the abrasive having been applied by the method of the present invention. The surface 30 of the abrasive tip has been finished to a cylindrical surface of revolution having a nominal radius R and circumference D. The radius R is the radius of the bladed turbine wheel in which the blades typically mount and is also nominally the radius of the inside diameter of the engine case in which the bladed turbine wheel is contained. As a matter of definition the z axis of the blade is that which corresponds with the radial direction. The tip of the blade has a mean camber line C which is the nominal center line of the airfoil tip cross section. The Figures 9 and 10 show a side view of the blade tip, as it appears looking along the line D toward the line C when the line C and the section have been unrolled into a z plane. Figure 10 shows the appearance of the constant thickness layer 26 of Figure 8. The uppermost surface 32 of the blade substrate 28 and the surface 30 of the abrasive both describe curvical surfaces. These curves are complex when rolled out, owing to the surface defined by the interaction of the camber shape and the cylindrical surface. The analogous view of a prior art blade tip, constructed in the manner described hereabove, is shown in Figure 9. While the outermost surface 30a of the abrasive is the same as the curvical surface 30 shown in Figure 10 the surface 32a of the blade substrate 28a is planar. Thus, the thickness of the abrasive in the radial or z axis direction varies across the camber length C of the airfoil. And there is a pronounced tendency for metal lacking grits to be present at the leading and trailing edges. It is also seen that in the invention of Figure 10 the abrasive is comprised of a single layer of particulate whereas in the prior art there are of necessity a multiplicity of grits near the center portion 35a of the camber line length. Also the prior art abrasive typically has a bond joint 31.

The process steps for making the thin abrasive tip are in part schematically illustrated by Figures 1—7 and are discussed further below. Figures 1—4 show in profile the tip of a gas turbine blade while Figures 5—7 show a portion of the tip in more detail, all viewed along the line D.

The abrasive tip of the present invention is intended to interact with a ceramic abradable

seal, as disclosed diversely in the U.S. patents mentioned hereabove. There are several unique aspects of the abrasive which have been discovered as necessary for good performance and which are different from the prior art tip abrasives. These include the composition of particulates and matrix; the sizing of the particulates, and density with which they are placed on the tip of the blade (both with respect to spacing and volume percent when included in a matrix material); the overall thickness of the abrasive layer; and, the degree to which the particulates are actually enveloped by and disposed in the matrix material. The parametric limitations recited herein are specifically the result of experience with an abrasive which includes a superalloy matrix and alumina coated silicon carbide particulates taught by the Johnson et al patent. However, it will be appreciated that many of the aspects will be pertinent to other particulates as well, particularly those which relate to the mechanical aspects.

The thickness of the abrasive must be limited and in accord with the sizing of the particulates. First, the abrasive contains a single layer of particulates as shown in Figure 10. A single layer of abrasive particulate is important in order to keep the mass of abrasive material at the tip at a minimum. Substantial centripetal force on the bond between the abrasive and the substrate of the tip results during operation. As the process details herein will make clear, the particulates will contact the substrate tip (or any incidental coating thereon). And, the overall thickness W of the metal matrix must be sufficiently small so that the ceramic particles in the finished abrasive project into space. For it has been found that when abrasives interact with ceramic seals there must be a portion of the particulate extending from the matrix metal, to interact with and cut into the ceramic. When this is not done, some of the matrix metal will be transferred to the ceramic abradable seal material and thus make it less abradable. When the ceramic is made less abradable the wear rate of the blade tip increases.

For the 0.38 nominal thickness layer shown in Figure 3, about 0.15 mm of matrix material, or about 40%, is removed. Empirical tests and calculations show that about 10–50% of matrix must be removed to provide an effective abrasive tip when it interacts with a ceramic seal, in that the particulates will cut properly but at the same time will not be readily removed from the blade tip. A greater amount of removal will leave insufficient matrix to retain the particulates under the load they sustain during use.

The z axis thickness of our preferred tip abrasive is of about 0.38 ± 0.03 mm and for such a thickness the particulates' size will be that which corresponds with sieving between U.S. Sieve Series No. 35–40 (nominally 0.42–0.50 mm). Of course common sieving yields a distribution of particles sizes, especially since typical ceramic particulate is irregular. Some of the particulates will be smaller than No. 40 Sieve size. But, the

nominal minimum dimension of the particulates will be 0.42 mm, and such reflects the fact that the preponderance, e.g., 80 percent or more of the ceramics will necessarily extend through the matrix to the free surface 44, 30 of the abrasive as shown in Figures 3, 4 and 10. This is in contrast with the prior art shown in Figure 9 or in the patents previously referred to. When thicker abrasive layers are desired, it will be found useful to employ larger particulates, e.g., up to U.S. Sieve No. 20 (0.83 mm), to achieve the desired results.

Typically, the matrix is applied in sufficient thickness to envelop the particulates, and then the combination is machined to a finish dimension. Thus the preponderance of the particulates will have machined lengths, and when the free surface is parallel to the substrate surface as is usually desirable, the lengths will be equal.

In the best practice of the invention the particulate is evenly but relatively densely spaced. The density will be in the range 33–62 particulates per cm^2 . Yet, no more than 15–20% of the particulates by number must be agglomerated, i.e., in contact with one another. Spacing between the particulates is needed so they will be adequately enveloped by matrix and adequately adhered in the abrasive. In the invention the particulates are preponderantly surrounded entirely by matrix metal in the directions parallel to the surface (i.e., transverse to the z axis). By this is meant that at least 80 percent, typically 90 percent, of the particulates will be surrounded by matrix, excluding of course those exposed by finishing of the side edges of the tip.

To achieve the foregoing combination of higher densities and entirety of envelopment, we have discovered that the hot pressed silicon carbide particulate also must have an aspect ratio less than 1.9:1, preferably about 1.4–1.5 to 1. The aspect ratio is the nominal ratio of the longest axis of a particulate to its nominal cross section dimension. We measure aspect ratio by use of a Quantimet Surface Analyzer (Cambridge Instruments Ltd., Cambridge, England). This aspect ratio contrasts with ordinary particulate having an aspect ratio of 1.9–2.1 to 1, as was used in the prior art pressed powder metal abrasive tip. With such particulate, excess agglomeration occurred because when it is laid on the surface in the method of making the invention as shown in Figure 1 it will naturally lie with its longer length generally parallel with the surface. Such high aspect ratio particulates also tend to be less likely to project to the desired height, compared to more equiaxed particulates and inhibit the attainment of high density.

As mentioned, the particulates are enveloped in metal matrix. When the abrasive is machined to an even surface as shown in Figure 3, prior to removal of the part of the matrix, then the particulates will typically comprise about 10–20, preferably 15 volume percent of the total abrasive. This is less concentration than the taught in the Johnson et al patent. Concentrations above about 20 percent are now found to tend to cause

abrasive material failure due to cracking; concentrations less than 10 percent will tend to produce inadequate abrasive properties.

The aforementioned critical sizes, aspect ratios and densities must be attained in order to obtain the desired cutting action. Since a typical tip of a turbine blade is narrow, there will be very few particulates in this region. An object of the invention is to have a full line of particulates across the width of the blade as it is viewed approaching along the line D in Figure 8. With the abrasive features mentioned this will be obtained in about 90 percent of the blades. The remainder may have a few open spaces due to loss of particulates from the time of first placement on the part up to the time part is made ready for use.

Figure 1 shows in side view how the particulates 33 are first laid on the surface 32 of the substrate 28 where they will be subsequently permanently adhered. Prior to placing the silicon carbide particulates on the surface, they have had applied to their exteriors a coating of 0.010 mm vapor deposited alumina according to the Johnson et al patent, and a cladding of metal, such as chemically deposited nickel to a thickness of 0.005—0.050 mm. Procedures for applying nickel coatings to ceramic particulates are commercially available and also are revealed in US—A—3,920,410, 4,291,089 and 4,374,173. If the ceramic particulate material is inherently resistant to reaction with the matrix then the alumina coating would not be necessary.

Just before the particulates are laid on the surface of the blade tip, a coating of polymer adhesive which can be later vaporized at less than 540°C is applied to the surface, to hold the particulates in place after they are deposited. We prefer 1—20 volume percent polystyrene in toluene. The particulates are laid on the surface by first attracting them to a perforated plate to which a vacuum is applied, and then positioning the plate over the surface and releasing the vacuum momentarily. It will be evident that other techniques and adhesives may be used to place the particulate.

Next the blade with the organically bonded particulates is heated while in a vertical position to a temperature of at least 1000°C, typically about 1080°C for 2 hours, in a vacuum of about 0.06 Pa using a heat-up rate of about 500°C per hour. Other inert atmospheres may be used. This step first volatilizes the polystyrene adhesive and then causes solid state bonding or sintering of the nickel cladding to the surface of the blade. The nature and location of the bond joint 34 as it is metallographically observable upon removal from the furnace is shown in Figure 5. Owing to the irregular shape of the particulates and the thinness of the metallic cladding on the particulates, the bond 34 is relatively delicate and located only at the points where particles 33 are very close to the surface 32. As will be appreciated, when the matrix is a superalloy it is not desirable to have a great deal of bond metal either around the particulate or bonding it to the sub-

strate of the blade. It is also undesirable to expose the substrate to a temperature higher than about 1080°C and therefore, the choice of cladding on the particulates is limited to materials which will produce a bond at such conditions. Furthermore, the cladding material must be one which is compatible with and which tends to interact with both the substrate and the subsequently applied matrix material. These limitations nonetheless allow for a variety of materials to be used. Preferably, nickel, cobalt or mixtures thereof are used. Alloying additions which are known to promote bonding may be also included. Generally, the basis metals of the cladding will tend to be those from the transition series of the periodic table when nickel, cobalt or iron base matrix and substrate alloys are involved. Under certain circumstances a coating may be applied to the surface 32 to enhance the desired adhesion.

Next, the particulates are oversprayed with a layer of matrix material deposited by plasma arc spraying to a thickness T of about 1.1—1.3 mm as shown in Figures 2 and 6. A nickel base superalloy as described generally above is used, such as that having the composition by weight percent 25 Cr, 8 W, 4 Ta, 6 Al, 1.0 Hf, 0.1 Y, 0.23 C, balance Ni.

The -0.037 mm (-400 U.S. Sieve Series Mesh) powder is applied by argon-helium plasma arc spraying in a low pressure chamber. For example, commercially available equipment such as a 120 kw low pressure plasma arc spray system of Electro-Plasma Inc. (Irving, California, USA) may be used. See also US—A—4,236,059. A blade is placed in the spray chamber which is evacuated to a pressure of 26 kPa or less. The oxygen level in the atmosphere is reduced to a level of 5 ppm by volume or less, such as by contacting the atmosphere in the chamber with a reactive metal. The workpiece blade is positioned with respect to the plasma arc device so that the tip cross section to be sprayed is normal to the axis along which the molten particulates travel. The blade is suitably masked around its periphery so that errant spray does not deposit on the sides of the blade.

Prior to initiating the actual deposition, the workpiece is simultaneously heated by the hot plasma arc gas to an elevated temperature of at least 700°C, typically 850°C, while being made cathodic with respect to a ground electrode located near to or as an integral part of the plasma arc device. A current of about 70 amperes is applied to a typical turbine blade tip for a period of about 2—10 minutes to aid in removing any oxide layers which may have accumulated on the part. The purpose of the heating process is to increase the receptivity of the part to the plasma arc spray and improve the bonding, as well as to decrease the residual stresses which are present after the workpiece, including the matrix metal and substrate, has cooled to room temperature. The abrasive will thus be made more resistive to cracking or spalling failure.

The metal matrix is applied to a thickness of 0.6—1.3 mm, preferably 1.1—1.3 mm as indicated. Preferably, the matrix material is deposited

by a physical process in a thickness and quality such that the layer of metal is impenetrable to argon gas at elevated pressure, e.g., at least 130 MPa. This impermeability is attainable with the above described plasma spray process, provided sufficient thickness is applied. Although the layer will be impermeable it will nonetheless be characterized by some porosity as shown in Figure 6. In particular, porosity 38 is present in the material above the surface of the particulates and there are voids 40 adjacent may be of the particulates. The voids 40 are characteristic of the metal spraying process and would be produced by any "line of sight" deposition process, or one in which the deposited material physically travels in a straight line. Another process that may be used is a physical vapor deposition process. See US-A-4,153,005 to Norton et al.

Next, the part is subjected to a densification, preferably by using hot isostatic pressing. Generally, this comprises deforming the abrasive material beyond its yield or creep-limit point at elevated temperature. Preferably, the part is subjected to 1065°C and 138 MPa argon pressure while at elevated temperature, to close the aforementioned pores and voids. Other hot pressing procedures may be used to consolidate the matrix and achieve the object of densification and bonding. After the matrix is consolidated, the part is cooled in the furnace and removed.

But Figure 7 shows in more detail how the abrasive appears in a metallographically prepared specimen. The superalloy matrix 36 is dense and fully envelops the particulates. And there is a region 42 surrounding each particulate 33, which region is deficient in chromium and aluminum and heavier elements, and rich in nickel, compared to the composition of the matrix material. This is of course a result of the nickel cladding layer which was applied to the particulate and as such it is a characteristic of the invention.

Next, the rough surface of the abrasive shown in Figure 2 is machined using a conventional procedure such as grinding to produce the shape shown schematically in Figure 3. The free surface 44 provides the desired z length dimension T' which will characterize the finished blade. Next, the surface 44 of the blade is contacted with an etchant or other substance which will attack the matrix material, to thereby remove a portion of it. For example, electrochemical machining can be used.

As will be appreciated, the invention is comprised of particulates which are aligned along the article surface. Such a two-dimensional approach to fabrication produces an abrasive which is quite uniform and effective, compared to that resulting from the prior art three-dimensional approach which is embodied by mixing and consolidating particulate with metal powders. In the invention, the free machined abrasive surface is characterized by relatively uniform cross sectional areas of ceramics (reflecting the maximum to minimum particle sizes). This is contrasted with the widely

varying areas reflecting the maximum to zero particle size which characterize the prior art powder metal abrasive. And when a portion of the matrix is partially removed, the presence of particulate material at the original free surface of the invention is unchanged. But in the prior art some of the particulates will be lost and the amount of free surface ceramic diminished, since portions of the particulates will have only been held in the abrasive by the matrix which is removed. In this respect a further advantage flows from the invention.

Claims

1. The method of providing an abrasive material (26) comprised of particulates (30) and matrix (36) on the surface (32) of an article, comprising adhering a single layer of spaced ceramic particulates (30) to the article surface (32) so that the particulates (30) adhere to the article and project from the surface (32) in spaced apart fashion, depositing on the surface a layer of metal to fill the spaces between the particulates with matrix material which inherently has voids characterized by said ceramic particulates (30) having a metal cladding, causing said metal cladding to adhere to the surface (32) to obtain the adherence of the particulates to the article and after having applied the matrix material (36) heating the article to an elevated temperature to densify the matrix and to metallurgically bond the matrix to the metal clad particulates and the substrate; and machining the surface of the abrasive material to a finish surface so that the particulates are visible at the surface.

2. The method of claim 1, characterized by depositing the layer of metal using a line-of-sight deposition process.

3. The method of claim 2, characterized by using plasma arc spraying for depositing.

4. The method of claim 1, characterized by sizing the ceramic particulate to predominately have a nominal dimension greater than the thickness to which the abrasive material is machined.

5. The method of claim 4, characterized by using argon gas hot isostatic pressing to generate a temperature of at least 1065°C and a pressure of at least 130 MPa, to which pressure said matrix is essentially impenetrable when deposited.

6. The method of claim 1, characterized by adhering particulates which are sized between 0.42 and 0.841 mm (No. 20 and 40 U.S. Sieve Series) to the surface with a density of 33-62 particulates per cm² of substrate surface.

7. The method of claim 1, characterized by sizing and spacing the particulates so that less than 15 percent are contacting one another when they are metallurgically adhered on the surface.

8. The method of claim 1, characterized by removing a portion of the matrix layer after machining of the abrasive to decrease its thickness and to thereby free the portions of the particulates which extend to the machined abrasive material surface of surrounding matrix.

by a physical process in a thickness and quality such that the layer of metal is impenetrable to argon gas at elevated pressure, e.g., at least 130 MPa. This impermeability is attainable with the above described plasma spray process, provided sufficient thickness is applied. Although the layer will be impermeable it will nonetheless be characterized by some porosity as shown in Figure 6. In particular, porosity 38 is present in the material above the surface of the particulates and there are voids 40 adjacent may be of the particulates. The voids 40 are characteristic of the metal spraying process and would be produced by any "line of sight" deposition process, or one in which the deposited material physically travels in a straight line. Another process that may be used is a physical vapor deposition process. See US—A—4,153,005 to Norton et al.

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But Figure 7 shows in more detail how the abrasive appears in a metallographically prepared specimen. The superalloy matrix 36 is dense and fully envelops the particulates. And there is a region 42 surrounding each particulate 33, which region is deficient in chromium and aluminum and heavier elements, and rich in nickel, compared to the composition of the matrix material. This is of course a result of the nickel cladding layer which was applied to the particulate and as such it is a characteristic of the invention.

Next, the rough surface of the abrasive shown in Figure 2 is machined using a conventional procedure such as grinding to produce the shape shown schematically in Figure 3. The free surface 44 provides the desired z length dimension T' which will characterize the finished blade. Next, the surface 44 of the blade is contacted with an etchant or other substance which will attack the matrix material, to thereby remove a portion of it. For example, electrochemical machining can be used.

As will be appreciated, the invention is comprised of particulates which are aligned along the article surface. Such a two-dimensional approach to fabrication produces an abrasive which is quite uniform and effective, compared to that resulting from the prior art three-dimensional approach which is embodied by mixing and consolidating particulate with metal powders. In the invention, the free machined abrasive surface is characterized by relatively uniform cross sectional areas of ceramics (reflecting the maximum to minimum particle sizes). This is contrasted with the widely

varying areas reflecting the maximum to zero particle size which characterize the prior art powder metal abrasive. And when a portion of the matrix is partially removed, the presence of particulate material at the original free surface of the invention is unchanged. But in the prior art some of the particulates will be lost and the amount of free surface ceramic diminished, since portions of the particulates will have only been held in the abrasive by the matrix which is removed. In this respect a further advantage flows from the invention.

Claims

1. The method of providing an abrasive material (26) comprised of particulates (30) and matrix (36) on the surface (32) of an article, comprising adhering a single layer of spaced ceramic particulates (30) to the article surface (32) so that the particulates (30) adhere to the article and project from the surface (32) in spaced apart fashion, depositing on the surface a layer of metal to fill the spaces between the particulates with matrix material which inherently has voids characterized by said ceramic particulates (30) having a metal cladding, causing said metal cladding to adhere to the surface (32) to obtain the adherence of the particulates to the article and after having applied the matrix material (36) heating the article to an elevated temperature to densify the matrix and to metallurgically bond the matrix to the metal clad particulates and the substrate; and machining the surface of the abrasive material to a finish surface so that the particulates are visible at the surface.

2. The method of claim 1, characterized by depositing the layer of metal using a line-of-sight deposition process.

3. The method of claim 2, characterized by using plasma arc spraying for depositing.

4. The method of claim 1, characterized by sizing the ceramic particulate to predominately have a nominal dimension greater than the thickness to which the abrasive material is machined.

5. The method of claim 4, characterized by using argon gas hot isostatic pressing to generate a temperature of at least 1065°C and a pressure of at least 130 MPa, to which pressure said matrix is essentially impenetrable when deposited.

6. The method of claim 1, characterized by adhering particulates which are sized between 0.42 and 0.841 mm (No. 20 and 40 U.S. Sieve Series) to the surface with a density of 33—62 particulates per cm² of substrate surface.

7. The method of claim 1, characterized by sizing and spacing the particulates so that less than 15 percent are contacting one another when they are metallurgically adhered on the surface.

8. The method of claim 1, characterized by removing a portion of the matrix layer after machining of the abrasive to decrease its thickness and to thereby free the portions of the particulates which extend to the machined abrasive material surface of surrounding matrix.



9. The method of claim 1, characterized in that 10—50 percent of the matrix thickness is removed.

10. The method of claim 1, characterized by bonding the metal clad organic adhesive to the substrate surface with an organic adhesive to position it prior to metallicity adhering it to the surface, and then removing the adhesive during the adhering step.

11. The method of claim 1, characterized in that the article is a gas turbine superalloy blade and the abrasive material is formed on a curved tip surface, characterized by machining the abrasive material surface so the abrasive material has a uniform thickness.

12. The method of claim 1, characterized in that the metallic adhering is achieved by sintering at an elevated temperature in an inert atmosphere which avoids oxidation of the metal which clads the particulate.

13. The method of claim 1, characterized by depositing particulates having an aspect ratio of less than 1.9 to 1.

14. The method of claim 11, characterized by particulates having an aspect ratio of about 1.5 to 1 or less.

15. The method of claim 3, characterized by heating the article surface to at least 700°C before and during plasma arc spraying at a subatmospheric pressure, to form an impermeable matrix layer; and then, hot isostatic pressing the matrix layer to densify and bond the layer to the particulate and substrate.

Patentansprüche

1. Verfahren zum Beschichten der Oberfläche (32) eines Gegenstands mit einem Schleifmaterial (26), das aus Partikeln (30) und einer Matrix (36) besteht, durch Befestigen einer einzelnen Schicht von gegenseitigen Abstand aufweisenden keramischen Partikeln (30) an der Gegenstandsfläche (32), so daß die Partikel (30) an den Gegenstand haften und von der Oberfläche (32) aus in gegenseitigem Abstand vorstehen, Auftragen einer Metallschicht auf die Oberfläche, um die Zwischenräume zwischen den Partikeln mit Matrixmaterial zu füllen, das inherent Hohlräume hat, dadurch gekennzeichnet, daß die keramischen Partikel (30) eine Metallhülle haben und daß veranlaßt wird, daß die Metallhülle an der Oberfläche (32) haftet, um das Anhaften der Partikel an dem Gegenstand zu erzielen, und daß, nachdem das Matrixmaterial (36) aufgetragen worden ist, der Gegenstand auf eine erhöhte Temperatur erhitzt wird, um die Matrix zu verdichten und die Matrix mit den metallumhüllten Partikeln und dem Substrat metallurgisch zu verbinden, und daß die Oberfläche des Schleifmaterials zu einer fertigen Oberfläche bearbeitet wird, so daß die Partikel an der Oberfläche sichtbar sind.

2. Verfahren nach Anspruch 1, gekennzeichnet durch Auftragen der Metallschicht unter Verwendung eines Sichtlinienauftragsverfahrens.

3. Verfahren nach Anspruch 2, gekennzeichnet durch Anwenden des Plasmaspritzens zum Auftragen.

4. Verfahren nach Anspruch 1, gekennzeichnet durch Sichten der keramischen Partikel, damit diese überwiegend eine nominelle Abmessung haben, die größer als die Dicke ist, auf die das Schleifmaterial bearbeitet wird.

5. Verfahren nach Anspruch 4, gekennzeichnet durch die Verwendung von isostatischem Heißen in Argongas, um eine Temperatur von wenigstens 1065°C und einen Druck von wenigstens 130 Mpa zu erzielen, wobei die Matrix, wenn sie aufgetragen ist, bei diesem Druck im wesentlichen undurchdringlich ist.

6. Verfahren nach Anspruch 1, gekennzeichnet durch Befestigen von Partikeln, die eine Größe zwischen 0,42 und 0,841 mm (Nr. 20 und 40 der US-Siebreihe) haben, an der Oberfläche mit einer Dichte von 33-62 Partikeln pro cm² der Substratoberfläche.

7. Verfahren nach Anspruch 1, gekennzeichnet durch Wahl der Größe und des Abstands der Partikel derart, daß weniger als 15 Prozent einander berühren, wenn sie an der Oberfläche metallisch befestigt sind.

8. Verfahren nach Anspruch 1, gekennzeichnet durch Abtragen eines Teils der Matrixschicht nach dem Bearbeiten des Schleifmaterials, um deren Dicke zu verringern und dadurch die Teile der Partikel, die sich zu der bearbeiteten Schleifmaterialoberfläche erstrecken, von umgebender Matrix zu befreien.

9. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß 10—50 Prozent der Matrixdicke entfernt werden.

10. Verfahren nach Anspruch 1, gekennzeichnet durch Verbinden der metallumhüllten keramischen Partikel mit der Substratoberfläche durch einen organischen Klebstoff, um sie zu positionieren, bevor sie an der Oberfläche metallisch befestigt werden, und anschließendes Entfernen des Klebstoffes während des Befestigungsschrittes.

11. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Gegenstand eine Gasturbinensuperlegierungsschaufel ist und daß das Schleifmaterial auf einer gekrümmten Spitzenoberfläche gebildet wird, gekennzeichnet durch Bearbeiten der Schleifmaterialoberfläche, so daß das Schleifmaterial eine gleichmäßige Dicke hat.

12. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das metallische Befestigen erreicht wird durch Sintern bei einer erhöhten Temperatur in einer inerten Atmosphäre, die Oxidation des Metalls, welches die Partikel umhüllt, verhindert.

13. Verfahren nach Anspruch 1, gekennzeichnet durch Auftragen von Partikeln, die ein Schlankheitsverhältnis von weniger als 1,9 zu 1 haben.

14. Verfahren nach Anspruch 11, gekennzeichnet durch Partikel, die ein Schlankheitsverhältnis von etwa 1,5 zu 1 oder weniger haben.

15. Verfahren nach Anspruch 3, gekennzeichnet durch Erhitzen der Gegenstandsfläche auf wenigstens 700°C vor und während des Plasma-



spritzens bei einem unteratmosphärischen Druck, um eine dichte Matrixschicht zu bilden, und anschließendes isostatisches Heißpressen der Matrixschicht, um die Schicht zu verdichten und mit den Partikeln und dem Substrat zu verbinden.

Revendications

1. Procédé destiné à fournir une matière abrasive (26) constituée de particules (30) et d'une matrice (36), sur la surface (32) d'un article, ce procédé consistant à faire adhérer une seule couche de particules en céramique espacées (30) à la surface de l'article (32), de telle sorte que les particules (30) adhèrent à l'article et fassent saillie à la surface (32) de manière espacée; déposer sur la surface une couche de métal destinée à remplir les espaces ménagés entre les particules, la matière de matrice étant munie de lacunes inhérentes, caractérisé en ce que les particules de céramique (30) sont munies d'une cuirasse métallique; en ce qu'on fait adhérer cette cuirasse métallique à la surface (32) pour obtenir l'adhérence des particules à l'article et en ce que, après avoir appliqué la matière de matrice (36); en ce qu'on chauffe l'article à une température élevée en vue de densifier la matrice et de lier par métallisation la matrice aux particules à cuirasse métallique et au substrat; et en ce qu'on usine la surface de la matière abrasive pour obtenir une surface finie, de telle sorte que les particules soient visibles à la surface.

2. Procédé selon la revendication 1, caractérisé en ce qu'on dépose la couche de métal en faisant appel à un procédé de dépôt de "champ visuel".

3. Procédé selon la revendication 2, caractérisé en ce qu'on utilise la pulvérisation à l'arc de plasma pour le dépôt.

4. Procédé selon la revendication 1, caractérisé en ce qu'on dimensionne les particules de céramique pour obtenir une dimension nominale prédominante, supérieure à l'épaisseur à laquelle on usine la matière abrasive.

5. Procédé selon la revendication 4, caractérisé en ce qu'on utilise la compression isostatique à chaud au gaz d'argon pour obtenir une température d'au moins 1065°C et une pression d'au moins 130 MPa, pression à laquelle la matrice est essentiellement imperméable lors du dépôt.

6. Procédé selon la revendication 1, caractérisé en ce qu'on fait adhérer des particules ayant une dimension comprise entre 0,42 et 0,841 mm (séries de tamis américains n° 20 et n° 40) à la

surface, avec une densité de 33—62 particules par cm² de surface de substrat.

7. Procédé selon la revendication 1, caractérisé en ce qu'on dimensionne et on espace les particules, de telle sorte que moins de 15% se touchent l'une ou l'autre, lorsqu'elles adhèrent par métallisation à la surface.

8. Procédé selon la revendication 1, caractérisé en ce qu'on élimine une portion de la couche de matrice après usinage de l'abrasif, afin de diminuer son épaisseur et libérer ainsi les portions des particules qui font saillie en direction de la surface de matière abrasive usinée de la matrice environnante.

9. Procédé selon la revendication 1, caractérisé en ce qu'on élimine 10—50% de l'épaisseur de la matrice.

10. Procédé selon la revendication 1, caractérisé en ce qu'on lie les particules de céramique à une cuirasse métallique à la surface du substrat, avec un adhésif organique, afin de les disposer avant de les faire adhérer par métallisation à la surface et en ce qu'on élimine ensuite, l'adhésif au cours de l'étape d'adhésion.

11. Procédé selon la revendication 1, caractérisé en ce que l'article est une aube en superalliage de turbine à gaz et en ce que la matière abrasive est formée, sur une surface courbe, de pointes, caractérisé en ce que l'on usine la surface de matière abrasive de telle sorte que l'épaisseur de la matière abrasive soit uniforme.

12. Procédé selon la revendication 1, caractérisé en ce qu'on obtient l'adhésion métallique par frittage, à une température élevée, dans une atmosphère inerte qui évite l'oxydation du métal enrobant les particules.

13. Procédé selon la revendication 1, caractérisé en ce qu'on dépose des particules ayant un rapport longueur/largeur inférieur à une valeur allant de 1,9 à 1.

14. Procédé selon la revendication 11, caractérisé en ce que les particules sont munies d'un rapport longueur/largeur d'environ 1,5 à 1 ou moins.

15. Procédé selon la revendication 3, caractérisé en ce qu'on chauffe la surface de l'article à une température d'au moins 700°C, avant et durant la pulvérisation à l'arc de plasma, sous une pression subatmosphérique, pour obtenir une couche de matrice imperméable; et en ce qu'ensuite, on soumet la couche de matrice à une compression isostatique à chaud pour densifier et lier la couche aux particules et au substrat.

