

Description

Method for generating a component by a powder-bed-based additive manufacturing method and powder for use in such a method

The invention relates to a method for generating a component, more particularly composed of a superalloy, by a powder-bed-based additive production method. With this method the component is built up layer by layer in a powder bed by the melting of particles forming the powder bed by an energy beam such as, for example, an electron beam or a laser beam. In this case the powder bed is preheated to a temperature below the melting temperature of the particles, before and while the particles are melted. The invention further relates to a powder suitable for use in a powder-bed-based additive production method, consisting of a metal alloy.

A method of the type specified at the outset is known from EP 1 355 760 B1, for example. The method for selective laser melting (SLM) that is discussed in said document is said to be suitable for processing of materials with high melting points. Given the interest that exists in producing components having a low degree of inherent stresses from materials with high melting points as well, said document proposes that before the powder is melted, the powdered material is preheated to a temperature of at least 500°C. This temperature, however, must still be clearly below the melting point of the material of the powder. Alternative methods are selective laser sintering (SLS) and electron beam melting (EBM).

With SLM, SLS, and EBM, the components are produced layer by layer in a powder bed. These methods are therefore also referred to as powder-bed-based additive manufacturing methods. One layer at a time of the powder is generated in the powder bed, and is subsequently subjected to melting or sintering by the energy source (laser or electron beam) locally in those regions in

which the component is to form. In this way the component is generated successively, layer by layer, and on completion can be removed from the powder bed.

Furthermore, according to Y.-C. Hagedorn et al., "Processing of Nickel based superalloy MAR M-247 by means of High Temperature Selective Laser Melting (HT-SLM)", High Value Manufacturing, pages 291 to 295, London 2014, there is a desire for superalloy materials as well, in powder form, to be processed by means of selective laser melting. In this case, however, the problem occurs that the products produced are subject to high inherent stresses, and that cracks may occur because of this fact. The authors therefore propose relatively intensive preheating of the powder.

It is known, furthermore, that powders which are highly preheated undergo caking to one another in accordance with the mechanism of sintering. This gives rise to the problem, in the case of selective laser melting, that the powder bed solidifies and may also stick to the surface of the component produced. Cleanly removing the component produced from the powder bed is then no longer possible. Moreover, the powder cannot be reused if the particles undergo caking to one another. This makes the method more expensive, since raw material regularly has to be discarded. The caking/sticking of the powder bed may additionally lead to an uneven surface of the powder bed. This complicates the application of further powder layers, and may give rise to geometric defects in the surface of the powder bed. As a result, the quality of the components under production is impaired.

DE 198 23 341 A1 discloses powders which consist of a metal alloy. The particles of this powder have a core and a shell, with the melting point of the alloy fraction in the core being higher than that of the shell. According to the document indicated above, these particles are said to be especially

suitable for producing components by sintering. The reason given for this is that the particles melt more quickly than if they were fabricated homogeneously from the desired alloy composition. Accordingly, lower sintering temperatures are possible on sintering treatment. During the sintering treatment, the desired alloy composition comes about at the end in the sintered component.

It is therefore an object of the invention to specify a method for generating a component, more particularly composed of a superalloy, by a powder-bed-based additive production method, that allows the production of components which satisfy the requirements imposed on the components. It is an object of the invention, moreover, to specify a powder which finds use in such a method.

The object is achieved in accordance with the invention by the method specified at the outset, by virtue of the fact that a powder composed of a metal alloy is used, with particles of powder consisting of core and a shell. In the core there is a first metallic alloy fraction and in the shell there is a second metallic alloy fraction. The first and second metallic alloy fractions may therefore themselves consist of a metal or a metal alloy. In accordance with the invention, the first alloy fraction has a lower melting temperature than the second alloy fraction.

The inevitable effect of the difference in alloy composition between core and shell, with even a core or a shell composed only of a metal being understood as constituting a differing alloy composition, is that both the alloy composition of the core and the alloy composition of the shell are different from the alloy composition of the metal alloy of the particle. The alloy composition of a particle in question therefore consists of the totality of all the alloying elements forming the particle. The alloy compositions in each case of the core and

of the shell must therefore be selected such that in totality, taking account of the respective mass fraction of core and of shell in the particle, the desired metal alloy of the powder is formed. For the ultimate formation of alloy, a melting or sintering operation of the powder is then used, leading to diffusion of the alloy fractions and to the formation of the desired metal alloy composition (more on this hereinafter). Another factor to be taken into account is that alloying elements possibly evaporate during the production operation and must therefore be present in the particles (i.e., in the core and/or in the shell) at a concentration which compensates the evaporation loss.

In contradistinction to the proposal in the above-recited DE 198 23 341 A1, therefore, the invention uses the more highly melting alloy fraction as the shell of the particles, even though this brings about the very opposite of the purpose intended in said document, namely that incipient melting of the particle surfaces is achieved only at higher temperatures. It has emerged, however, that the particles according to the invention, on processing in powder-bed-based additive manufacturing methods, have far less of a tendency to cake to one another in the powder bed (that is, outside the volume of the component under production). In the case of methods such as laser melting and laser sintering, therefore, caking can be prevented by sintering or at least incipient sintering of the powder particles, so making these particles available advantageously for subsequent manufacturing operations. A further advantage is that because of the lower propensity for incipient sintering of the coated particles, the removal of powder from internal cavities is facilitated, so enabling the production of complex, delicate structures, of the kind occurring, for example, in the case of the leading and trailing edges of gas turbine blades.

In accordance with the invention, in the case of electron beam melting, it is easier to carry out only incipient sintering of

the particles in the powder bed, in order to prevent the effect known as the smoke effect. This refers to a swirling of the metallic particles owing to the electrical fields which act during electron beam melting; in this context it is sufficient for even a certain adhesion of the particles in the powder bed to one another to be generated, this adhesion being ideally reversible, i.e., redissoluble. Incipient sintering therefore means an incomplete sintering, the effect instead being that of the generation of a certain dissoluble adhesion between the particles with one another.

The layer on the particles may advantageously have a thickness of 0.1 μm to 3 μm . This thickness on the part of the shell is sufficient to provide the core of the particles with adequate shielding, ruling out the effect of any caking. Here it is advantageous for the particles to have a size of at least 10 μm and at most 50 μm , preferably an average particle size of 25 μm to 30 μm . This ensures that the core has sufficient volume to allow the establishment of a desired alloy composition between core and shell. The dimensioning of the particle diameter and hence also of the core diameter, and also of the thickness of the shell, hence permits the establishment of the alloy composition of the overall particles.

A superalloy used is advantageously a nickel-based superalloy. These superalloys can be used, for example, to produce the blades of gas turbines. In the case of this material, the powder is advantageously preheated to a temperature of at least 800°C and at most 1000°C, or even to at most 1200°C. Moreover, by means of the apparatus which introduces the heat into the powder bed for the purpose of preheating, it is ensured that the cooling after the production of the component occurs at a rate of at most 1°C per second. This can be used advantageously to allow the formation, within the component made from the nickel-based superalloy, of γ' precipitates of intermetallic phases, which characterize the typical microstructure of the nickel-based

superalloy. For the formation of these precipitates, it is general knowledge that the growth of the cuboid γ' precipitates is suppressed if cooling is too rapid. If the component is cooled down more slowly than at 1°C per second, however, the stated precipitates do come about if the temperature is below the γ' solidus temperature. The solidus temperature is at 1150°C. To ensure slow cooling from this temperature level, the temperature of the powder bed must be slightly lower. A temperature level of between 900°C and at most 1000°C has proven advantageous in this respect.

Furthermore, the object is achieved by the powder specified at the outset, with particles of this powder consisting of a core and a shell. In the core there is a first metallic alloy fraction and in the shell there is a second metallic alloy fraction, having an alloy composition which differs from the first alloy fraction. The first alloy fraction has a lower melting temperature than the second alloy fraction. When a powder of the invention of this kind is used in a powder-bed-based additive manufacturing method, the advantages stated above are achieved, these advantages being valid for the powder likewise.

According to one advantageous embodiment of the powder, the core of the particles comprises primarily nickel (1455°C) and the shell of the particles comprises one or more of the following metals: cobalt (1495°C), iron (1538°C), chromium (1907°C), molybdenum (2623°C), tantalum (3020°C) or tungsten (3422°C). The temperature figures in parentheses indicate the melting temperature of the respective metals. This allows the core (measured on the target alloy dictated by the particles) to contain a superproportionally large quantity of nickel and for the shell to include a superproportionally large quantity of an element having a melting point higher than that of nickel, as for example Co, Cr, Mo, W, Ta. The alloys which can be generated with these metals are nickel-based alloys, which are suitable preferably for high-temperature applications, such as, for

example, turbine components, especially turbine blades. These materials, processed to form powders, can be employed advantageously in an additive production method, where heating of the powder bed is possible, since the construction of the powder particles with core and shell advantageously prevents the powder bed sintering together or renders such sintering amenable to targeted influencing (incipient sintering).

The particles, advantageously, may have the alloy composition, for example, of Mar M 247, CM 247 LC or Rene 80, with the shell comprising preferably tungsten or else, in the case of Rene 80, chromium. The composition of these alloys is apparent from Table 1.

Table 1

All oy	C	Cr	Co	W	Mo	Ta	Al	Ti	Hf	B	Zr	Nb	Ni
Mar M 247	0.1 5	8.4	10. 0	10. 0	0. 7	3. 0	5. 5	1. 0	1. 5	0.0 15	0.0 5	-	BA L
CM 247 LC	0.0 7	8.1	9.2	9.5	0. 5	3. 2	5. 6	0. 7	1. 4	0.0 15	0.0 15	-	BA L
Ren e 80	-	10. 0	9.5	6.0	4. 0	5. 0	4. 2	3. 5	0. 2	-	-	0. 5	BA L

Furthermore, the alloy compositions may also consist of a nickel-based single-crystal alloy, such as CMSX-4, for example. Appropriate cooling of the powder bed allows components produced additively with such alloy to be produced with a monocrystalline structure and/or a structure having very large grains. Examples of single-crystal alloys based on nickel are apparent from Table 2.

Table 2

Alloy	Cr	Al	Ti	Ta	W	Mo	Co	Re	Hf	others
CMSX-4	6.4	5.5	0.9	6.3	6.2	0.5	9.3	2.8	0.7	-
RR 2000	10	5.5	4	-	-	3	15			V1.0
PWA 1484	5.0	5.7	-	8.7	5.9	1.9	10.0	3.0	0.1	-
CMSX-10	2	5.7	0.2	8	5	0.4	3	6	0.03	NB 0.1
CMSX-10M	2	5.78	0.24	8.2	5.4	0.4	1.7	6.5	0.03	NB 0.08
Rene N6	4.2	5.75	-	7.2	6	1.4	12.5	6	0.15	C 0.05, B 0.004
TMS-80	2.9	5.8	-	5.8	5.8	1.9	11	4.9	0.1	Ir 3

The shell of the particles of the single-crystal alloys preferably comprises tungsten and/or tantalum. To achieve an extremely high melting point in the shell, it is possible according to one advantageous embodiment of the invention for the shell to consist to an extent of more than 99 mass%, preferably completely, of a single metallic alloy element. Consisting completely of one alloy element, however, strains the bounds of what is technically possible, and so up to one mass% of other alloy constituents can be allowed. The advantage of generating the shell only from a single metallic alloy element is that the shell contains substantially no alloy compositions which, owing to formation of eutectic mixtures, normally have a lower melting point than their elemental alloy constituents. As a result it is possible advantageously to raise the melting temperature optimally through choice of the corresponding metal, specifically up to the melting temperatures (indicated) respectively above. The greatest increase in the melting temperature of the shell can be achieved, advantageously, with the alloy element of the relevant alloy composition of the particle that has the highest melting temperature.

A prerequisite for the selection of the alloy element of the shell is that this element is present to a sufficient extent in the alloy composition of the particle. In order to be able to form a shell of sufficient thickness, an alloy fraction of 5 mass% is considered to be sufficient. Alloy fractions of up to 10% lead to thicker shells, which have the advantageous effect of protecting the core more effectively. Larger alloy fractions would result in even thicker shells; however, with regard to the formation of alloy during the melting of the particles, this is regarded as a disadvantage, since it would result in excessive separation of the alloy owing to division of the alloy elements between the core and the shell, respectively, of the particle. In this case, therefore, according to one advantageous embodiment of the invention, there is at least one alloy element of the shell that is also present in the core, the concentration of this alloy element in the core being lower than in the shell. In other words, the shell is produced in a required thickness, and, so to speak, excess material of the alloy element forming the shell is not employed to increase the thickness of the shell further, but is instead present as an alloy element in the core. This shortens the necessary process of diffusion of the alloy element of the shell into the core, with the advantageous effect of supporting the formation of alloy during the melting of the powder and/or reducing the required diffusion processes in the component as it forms.

Further details of the invention are described below with reference to the drawing. Identical or corresponding elements in the drawing are each provided with the same reference symbols and are explained more than once only insofar as there are differences between the individual figures.

Figure 1 shows, in section, a laser melting unit in which an exemplary embodiment of the method of the invention is carried out;

Figs. 2 to 4 show selected steps in the implementation of the method according to Figure 1, with a small detail of the component under production being shown in section; and

Figure 5 shows a detail of an exemplary embodiment of the component of the invention which has been produced in accordance with Figures 2 to 4.

Represented schematically in Figure 1 is a unit 11 for laser melting. This unit has a process chamber 12 in which a powder bed 13 can be produced. To produce, respectively, one layer of a powder bed 13, a spreading means in the form of a doctor blade 14 moves over a powder store 15 and subsequently over the powder bed 13, so forming a thin layer of powder in the powder bed 13. A laser 16 then generates a laser beam 17, which is moved by an optical deflection apparatus with mirror 18 over the surface of the powder bed 13. At the point of impingement of the laser beam 17, the powder is melted, to form a component 19.

The powder bed 13 comes about on a building platform 20, which can be lowered step by step, by the thickness of one powder layer in each case, in a pot-shaped housing 22 by means of an actuator 21. In the housing 22 and also in the building platform 20 there are heating devices 23 provided, in the form of electrical resistance heaters (induction coils are an alternative option), which are able to preheat the component 19 being formed and also the particles of the powder bed 13. To permit the energy required for preheating, on the outside of the housing 22 there is insulation 24 of low thermal conductivity.

Represented in Figure 2 is an edge of the component 19 to be produced, as could be produced, for example, in a unit according to Figure 1. This component is located in the powder bed 13, the borders of which are indicated by a dash-dotted line. Selected particles 25 from the powder bed 13 are also shown, consisting

of the material of a nickel-based alloy. The component to be produced may be, for example, a turbine blade.

The particles 25 consist in each case of a core 26 and a shell 27. The core 26 comprises primarily nickel and further constituents of the nickel-based alloy. The shell 27 consists, for example, of tungsten and otherwise of elemental alloy impurities to a technically irrelevant extent. Accordingly, the surface of the particles 25 has a melting temperature of above 3400°C. This allows the powder bed to be preheated at up to 1000°C without adjacent particles 25 becoming caked together.

Represented schematically in Figure 2 (as also in Figures 3 and 4) are the particles 25; the size proportions between the core 26 and the shell 27 are not true to scale. Additionally, a discrete transition between core 26 and shell 27, as shown in Figure 2, is not absolutely necessary. Gradient layers are also conceivable, in which a transition between core 26 and shell 27 is not abrupt but instead occurs with a concentration gradient (not shown). This advantageously supports the diffusion processes which lead, by melting of the particles, to the formation of alloy in the composition intended for the component. For the melting temperature at the surface of the particles 25, all that is necessary is that the shell 27 there has the composition required to achieve the melting temperature present there.

Gradient layers may also be formed during the production of the particles themselves, if that process is accompanied by certain diffusion events of alloy elements in the core 26 and/or in the shell 27. Possible production methods for the particles include, for example, galvanic or electroless electrochemical coating processes, of the kind already described in DE 198 23 341 A1. Another possibility is that of production by ALD processes as known in the art (ALD stands for Atomic Layer Deposition). In this case layers of atoms are applied to the particles, so as

to form, preferably, very thin layers. To generate the required layer thickness, a number of coating steps may be necessary in the ALD process.

Figure 3 shows how one part of the powder bed 13 is melted by means of the laser beam 17, specifically the part which lies at the edge of the component 19. In this case, the cores 26 of the particles 25 are melted. The shells 27 around the cores 26 have a higher melting point and initially still remain in the melt bath, and form shell fragments 28 which remain in the molten material, where they dissolve (alloy formation with the desired alloy composition of the particles). This process may proceed very quickly and is represented here only in model form.

It can be seen in Figure 4 how the laser 17 is moved over the powder bed 13, with the melt bath, as shown in Figure 4, traveling from left to right. As it does so, a layer of the component 19 to be produced corresponding to the layer thickness d of the powder bed is formed. If the laser beam 17 travels further, the material solidifies, with formation of the volume of the component at the same time. The effect of the heating indicated in Figure 1 is that the cooling rate of the material of the component 19 under production is less than 1°C per second and the formation of alloy is not disrupted by an excessive cooling rate.

In Figure 5, the completed component can be seen. It is represented schematically as a ground section. The material of which the component 19 is made is a nickel-based superalloy. The controlled cooling rate has successfully had the effect of achieving a high proportion of so-called γ' precipitates 30 composed of intermetallic phases. They are embedded in a matrix 31 of the component. Consequently, by means of the selective laser melting according to the invention, it is possible to achieve a component microstructure of a kind hitherto generatable, according to the prior art, only by casting, of

turbine blades, for example. The microstructure therefore differs from the microstructure of the particles processed.

Claims

1. A method for generating a component (19) by a powder-bed-based additive production method, wherein the component (19) is built up layer by layer in a powder bed (13) by use of an energy beam (17) to melt particles (25) which form the powder bed (13) and which are composed of a metal alloy, the powder bed (13) being heated to a temperature below the melting temperature of the particles (25), wherein a powder composed of a metal alloy is used, with particles (25) of the powder consisting of a core (26) and a shell (27), where

- in the core (26) there is a first metallic alloy fraction and in the shell (27) there is a second metallic alloy fraction, having an alloy composition differing from the first alloy fraction, and
- the first alloy fraction has a lower melting temperature than the second alloy fraction, and

wherein a superalloy, more particularly nickel-based superalloy, is used as metal alloy.

2. The method as claimed in claim 1, wherein the shell (27) on the particles (25) has a thickness of at least 0.1 μm and at most 3 μm .

3. The method as claimed in either of the preceding claims, wherein particles (25) used have a particle size of at least 10 μm and at most 100 μm , preferably an average particle size of 25 μm to 30 μm .

4. The method as claimed in any of the preceding claims, wherein electron beam melting (EBM) is carried out as additive manufacturing method, the particles (25) being incipiently sintered in the powder bed.

5. The method as claimed in claim 1,

wherein the powder bed (13) is heated to a temperature of at least 800°C and at most 1200°C.

6. The method as claimed in either of claims 1 and 5, wherein the component (19) after completion thereof is cooled down at a rate of at most 1°C/s.

7. A powder suitable for use in a powder-bed-based additive manufacturing method, consisting of a metal alloy, wherein particles (25) of the powder consist of a core (26) and a shell (27), where

- in the core (26) there is a first metallic alloy fraction and in the shell (27) there is a second metallic alloy fraction, having an alloy composition differing from the first alloy fraction, and
- the first alloy fraction has a lower melting temperature than the second alloy fraction, and

wherein a superalloy, more particularly nickel-based superalloy, is used as metal alloy.

8. The powder as claimed in claim 7, wherein

- the core (26) of the particles (25) comprises primarily nickel and
- the shell (27) of the particles comprises cobalt and/or iron and/or chromium and/or molybdenum and/or tantalum and/or tungsten.

9. The powder as claimed in claim 8, wherein the particles have the alloy composition of Mar M 247, CM 247 LC or Rene 80.

10. The powder as claimed in claim 9, wherein the shell (27) comprises tungsten or, in the case of the alloy composition Rene 80, chromium.

11. The powder as claimed in claim 8,
wherein the particles have the alloy composition of a nickel-
based single-crystal alloy.

12. The powder as claimed in claim 11,
wherein the shell (27) comprises tungsten and/or tantalum.

13. The powder as claimed in any of claims 7 to 12,
wherein the shell (27) consists to an extent of more than
99 mass% of a single metallic alloy element.

14. The powder as claimed in claim 7, 8, 9 or 12,
wherein the shell (27) consists to an extent of more than
99 mass% of that metallic alloy element having the highest
melting temperature in the alloy composition of the particle
(25).

15. The powder as claimed in any of claims 7 to 14,
wherein at least one alloy element of the shell (27) is also
included in the core (26), the concentration of this alloy
element being lower in the core (26) than in the shell (27).