

Description

The invention refers to a process for preventing crack formation in nickel alloy substrates.

Jet engine parts are subject to extremely adverse conditions, such as dramatic temperature changes, constant and/or sudden vibration and the like. The jet engine parts, particularly the moving parts thereof, must be substantially defect free in order to satisfactorily withstand these conditions. Manufacture of the parts is therefore necessarily expensive, in view of the high degree of quality which must be maintained. Should a particular part not conform to the exacting standards specified and required, then it must be discarded or repaired, if possible.

EP-A-0 176 942 describes a process for repairing a portion of a substrate of a metallic material, comprising the step of concurrently applying to the portion a laser beam causing a molten pool and metal particles being of compositions substantially the same as the metallic material of the portion as to provide a repair layer on the portion consolidated from the particles and metallic material thereof. However, this process is disclosed only in connection with materials, such as Inconel 718, which are known as good weldable. Namely, Inconel 718 was developed to be weldable. That is the function of the gamma double prime phase, a hardening phase, which precipitates more sluggishly than does a material containing substantially a gamma-prime phase.

US-A-4 213 026 describes a process for reducing cracking in the gaseous tungsten arc welding of nickel base superalloy articles. For this welding process, filler wires are suggested hardened by precipitation of gamma-prime phase or gamma double prime phase, with or without gamma-prime phase, having an addition of a substantial amount of manganese of 0.5 through 3%. Though the addition of manganese is observed to reduce the incidence of heat-affected zone cracking, the results of using gamma-prime hardened filler wires is described as least satisfactory and as not significantly increasing resistance to post-weld heat treatment cracking.

FR-A-2 397 259 discloses a process for coating a surface to be protected of a substrate tending to crack formation by fusion. As an example for such substrates, nickel-based superalloys containing gamma-prime phase are mentioned. It is proposed to dispose an intermediate layer between the substrate and the surface layer deposited by fusion welding. This intermediate layer should contain besides aluminum and titanium an addition of a substantial amount of manganese. This manganese addition is thought to be due to the resistance against hot cracking. However, this process is very complicated due to the fact that it is necessary to deposit two different layers on the substrate.

Both, US-A-4 213 026 and FR-A-2 397 259, are in general teaching that nickel alloy substrates substantially strengthened by the presence of a gamma-prime phase, such as Inconel 713, are difficult to weld, particularly with a like material for the purposes of repair, and the like. Welding, because of the high temperatures involved, has a tendency to cause cracking at the area of the weld site, thereby resulting in destruction of the welded parts. The crack formation is believed to be due to the formation of gamma-prime, a phase of alloy resulting from the aluminum and titanium addition.

Therefore, the object of the disclosed invention is to provide a simple process permitting a nickel alloy substrate substantially strengthened by the presence of a gamma-prime phase to be welded without crack formations for instance but not only for purposes of repair and the like, particularly with a like material having a gamma-prime phase, or gamma-prime forming constituents.

This object is solved by a process according to claim 1 comprising the steps of:

- a) providing a substrate (10) to be treated, said substrate (10) comprising a nickel alloy substantially strengthened by the presence of a gamma-prime phase resulting from the presence of gamma-prime formers;
- b) irradiating a portion of said substrate (10) with a laser beam (24) and causing a molten pool of said alloy to be formed;
- c) dispersing a supply of coating particles (40) within said pool, said particles (40) comprising a nickel alloy; and
- d) effecting rapid relative motion between said laser beam (24) and said pool so that said pool rapidly solidifies and thereby minimizes formation of gamma-prime therein and adjacent thereto.

Surprisingly, this process is suitable to weld, for instance to repair nickel alloy substrates, which are known as difficult to weld, particularly with a like material having a gamma-prime phase, or gamma-prime forming constituents.

Preferred embodiments of the process according to claim 1 are given in the dependent claims.

The above and other objects and advantages and novel features of the present invention will become apparent from the following detailed description of the preferred embodiment of the invention illustrated in the accompanying drawings, wherein:

FIGURE 1 is a graph illustrating the time and temperature relationship for gamma-prime formation; and, FIGURE 2 is a fragmentary cross-sectional view illustrating an apparatus for performing the process of the invention.

A number of morphological forms of gamma-prime have been identified, these depending upon the stoichiometry and the thermal and mechanical history of the particular alloy. The heavily alloyed cast superalloys, such as Inconel 713, exhibit three different types of gamma-prime. One type has blossom-like eutectic formations comprising gamma and gamma-prime which are formed directly upon cooling of the melt. A second type is the coarse and somewhat blocky form which is formed directly upon solidification and cooling. The morphological appearance of this type in Inconel 713 is of angular shape, and in large amounts. The third type is the "second generation" gamma-prime. This type is interspersed between the larger blocky gamma-prime particles, and is believed to be primarily responsible for weld cracking. The second generation type is formed after the general precipitation of the previous two types during cooling to room temperature. The second generation probably forms at a temperature of about 815°C - 980°C, and can be found in small amounts in all such alloys.

The concentrations of aluminum and titanium effect the amount and the morphology of the gamma prime which is produced. Increasing the level of the aluminum and titanium concentration increases the instability of the alloy. Likewise, a chromium content of 10% shifts the gamma-prime eutectic toward higher aluminum and titanium concentration levels. Furthermore, the increased chrome content decreases the coarseness of the precipitate, increases the microstructural instability, lowers the gamma-prime solution temperature and improves the high temperature rupture properties.

Gamma-prime formation and its temperature of formation vary greatly from alloy to alloy. As a general rule, the higher the aluminum and titanium concentration, then the greater the amount of gamma-prime formed, as well as the higher the temperature required for gamma-prime stability.

The cast superalloys have massive primary gamma-prime structures, including the coarse somewhat blocky type of intragranular gamma-prime. The small, spherical second generation gamma-prime is generally found during cooling.

Inability to solution the gamma-prime before excessive grain growth or liquation occurs has heretofore severely limited subsequent heat treatment of the cast alloy. Aging treatments have relatively little effect on the various gamma-prime types at a temperature of less than 980°C. Above this temperature, however, the second generation gamma-prime resolutions and the blocky gamma-prime begins to agglomerate and to resolution.

Figure 1 discloses the relative concentration of gamma-prime with reference to temperature and time. It can be seen that gamma-prime forms relatively quickly once the temperature of formation has been achieved. The rapid precipitation of the gamma-prime from the initial nickel-aluminum-titanium molten matrix must be carefully controlled for the resulting cast alloy to have the desired properties.

Table I illustrates the nominal chemical compositions of Inconel 713 and Inconel 625. Those skilled in the art will understand that those alloys are manufactured by a particular source, and that corresponding alloys can be obtained from other manufacturers under the UNS Numbers NO7713 and NO6625, respectively.

TABLE I

5	Trade Name	Inconel 625	Inconel 713
	UNS Number	N06625	N07713
10	Al	0.40 max	Al 5.5 - 6.5
	C	0.10 max	B 0.005 - 0.015
	Cb	3.15 - 4.15	C 0.08 - 0.20
	Cr	20.0 - 23.0	Cb 1.8 - 2.8
	Fe	5.0 max	Cr 12.00 - 14.00
15	Mn	0.50 max	Fe 2.50 max
	Mo	8.0 - 10.0	Mn 0.25 max
	Ni	59.92 - 68.85	Mo 3.8 - 5.2
	P	0.015 max	Ni 66.885 - 76.265
	S	0.015 max	Si 0.50 max
	Si	0.05 max	Ti 0.5 - 1.0
20	Ti	0.40 max	Zr 0.05 - 0.15

It can be seen that Inconel 713 has a possible aluminum plus titanium concentration of from about 6% by weight to about 7.5%. Inconel 625, on the other hand, has gamma prime forming constituents, namely aluminum plus titanium, in a concentration of no more than .80% by weight.

As noted, the welding of a nickel alloy substrate having a gamma prime phase, or having gamma prime forming constituents, is frequently accompanied by weld cracking or subsequent post treatment cracking. The important phase, from a strengthening and welding standpoint, of Inconel 713 is the face centered cubic gamma prime phase that is based upon the composition $Ni_3(Al, Ti)$. Because of the presence of the gamma prime phase, the alloy tends to be susceptible to hot cracking (weld cracking) and postweld heat treatment cracking, PWHT (strain age or delay) cracking. The susceptibility to hot cracking is directly related to the aluminum and titanium contents (gamma-prime formers). Hot cracking occurs in the weld heat-affected zone; in other words, in that area which is subject to the high temperatures used in the weld process.

Inconel 713 is a precipitation hardenable nickel-based alloy. This alloy is strengthened by controlled precipitation of a second phase, known as the gamma-prime phase, from a supersaturated solid solution. For some precipitation hardenable alloys, precipitation occurs upon reheating of a solution-treated and quenched alloy to an appropriate temperature for a specific time. However, for Inconel 713 and some other like cast alloys, aging occurs directly as the solidified casting cools in the mold.

Microstructures of these alloys, having an aluminum plus titanium concentration of from about 5.5% to about 7.0%, disclose similar structures having scattered eutectic gamma-prime particles plus a fine precipitate. When the concentration increases to the order of 10.5%, then the microstructure contains a number of eutectic gamma-prime particles plus a coarse gamma-prime precipitate. The concentration of the gamma-prime formers plus the type of gamma-prime formed is therefore an important concentration when considering the weldment of these alloys.

The temperature range in which gamma-prime precipitation occurs also happens to be the temperature at which stress relief occurs. The welding caused precipitation of gamma-prime strengthens the alloy, while the alloy is simultaneously attempting to stress relief. Strengthening is accompanied by a reduction in ductility. The combination of the inability of the part to stress relief, coupled with the gain in strength and lost ductility are among the factors believed to be responsible for post weld heat treatment cracking. Cracking, as is known to those skilled in the art, is a strong function of the hardener content (aluminum plus titanium) of the alloy. During welding, some portion of the heat-affected zone (weld site and adjacent area) is heated into the aging temperature range. As the metal within the heat-affected zone solidifies, then the aging metal may form gamma-prime and become subjected to welding stresses. The combination of welding stresses and increased concentration of gamma-prime is thought to be a cause of hot cracking in the heat-affected zone of the alloy.

Figure 2 discloses an apparatus for practicing the laser cladding or welding of the invention. The substrate 10, as best shown in Figure 2, is comprised of a nickel-based alloy having a gamma-prime phase,

preferably including Inconel 713C. The substrate 10 has a surface defect 12 which must be repaired. As previously noted, Inconel 625 alloy may be used for repair, although this alloy may not have the appropriate properties. A better repair process involves laser cladding with Inconel 713, so that the properties are essentially unchanged.

Toward the above end, a laser nozzle 14 is positioned proximate the substrate 10 in the area of defect 12. The nozzle 14 is, preferably, of the type disclosed in US-A-4 724 299, in the name Albert W. Hammeke for LASER SPRAY NOZZLE AND METHOD, the assignee of which is also the assignee of the present application.

The nozzle 14 has a nozzle housing 16 which is attached to first telescope portion 18. The telescope portion 18 is slidably received within second telescope portion 20. Laser source 22, which preferably includes a continuous wave CO₂ laser with a power output of about 1.0 to about 5.0 kilowatts, radiates a beam 24. Naturally, the laser source 22 includes means for focusing the beam 24, and those skilled in the art will need no further explanation thereof.

Nozzle cone 26 is slidably received within aperture 28 of housing 16. The cone 26 has a central aperture 30 through which the beam 24 passes on its way to substrate 10. It can be noted that the housing 16 has an opening 32 to permit the beam 24 to pass therethrough.

Housing 16 includes an annular channel 34 disposed above perforated ring 36. The channel 34 communicates with powder supply duct 38 for conveying a quantity of cladding particles 40 to the nozzle 14. The particles 40 are transported through the duct 38 by a gas, preferably argon gas, so that the 713 alloy particles 40 are distributed about the channel 34 prior to flowing into chamber 42. Axial displacement of cone 26 regulates the gap between the cone 26 and the housing 16, and thereby regulates the flow of particles 40 from the nozzle 14.

A cooling ring 44 is mounted about the upper end of cone 26 and communicates with coolant supply duct 46 and with coolant exit duct 48 in order to remove generated heat from the cone 26.

The second telescope portion 20 includes an opening through which shrouding gas duct 50 communicates. The duct 50 serves as a source of supply for a shrouding gas, such as argon, which is used in the welding process. Although I have disclosed the use of argon for shrouding and for conveying the particles 40, those skilled in the art will understand that other gases are usable, depending upon the particular circumstance involved.

TABLE II

Base Material Thickness	= 1,59 - 12,7 mm
Clad Deposit Thickness	= 0,13 - 1,27 mm
Clad Deposit Track Width	= 1,27 - 6,35 mm
Shroud Gas Flow Rate (Argon)	= 0,17 - 0,453 m ³ /h
Feed Gas Flow Rate (Argon)	= 0,0566 - 0,113 m ³ /h
Powder Feed Rate	= 0.10 - 0.40 grams/second
Laser Power	= 1.0 - 5.0 Kilowatts
Travel Speed	= 25,4 - 254 cm
Powder Particle Size	= - 80/ + 325 mesh

Table 2 discloses certain operating parameter ranges which I have found advantageous in welding Inconel 713C substrate with Inconel 713 particles. Naturally, there is no optimum set of parameters because the optimum processing parameters will depend, among other things, on the size of the clad deposit required. For example, the parameters for cladding a deposit 0,762 mm by 4,76 mm would be different than for a clad deposit of 1,27 mm by 6,35 mm. Furthermore, the shroud and feed gas flow rate, the powder feed rate, and the powder particle size are somewhat variable, depending upon the powder feed mechanism chosen.

I believe that laser cladding of these precipitation hardenable alloys, with particles of like nominal composition, can be done without the previously noted cracking because of the lower and localized heat input which occurs through laser processing. The laser produces a very narrow heat affected zone. Furthermore, the molten pool, produced by the irradiation of the substrate and into which the particles 40 are dispersed, rapidly solidifies upon the beam being withdrawn. The result is, therefore, a smaller volume of material having passed more rapidly through the gamma-prime forming temperature region than was heretofore possible via conventional fusion welding techniques. In other words, a smaller fraction of gamma-prime is formed because the alloy in the molten pool is not maintained at the gamma-prime forming

temperature for very long, the temperature change being quite dramatic and in the order of several thousand degrees or more per second.

It can be noted from Table 2 that the base material thickness (substrate thickness), is on the order of 10-12 times the thickness of the clad deposit. The result is that the mass of the substrate substantially exceeds the mass of the molten pool plus particles. The resulting mass differences cause the substrate to act as a heat sink which rapidly cools the pool, essentially as it is formed because of the rapid relative motion between the beam and the pool.

Preferably, the substrate 10 moves relative to the nozzle 14 in order to effect the relative motion between the substrate 10 and the beam 24 which is required for the rapid solidification to occur. The beam 24 irradiates a portion of the defect 12 and forms a molten pool comprised of the alloy of substrate 10. The particles 40 are then blown into the molten pool into which they become dispersed. The beam 24 is moved relative to the substrate 10 at a rapid speed in order to prevent excessive melting of the substrate 10, while assuring that a sufficient quantity of the alloy substrate is melted. Rapid motion, on the order of 25,4 - 254 cm per second, is generally sufficient to assure compliance with these two competing parameters.

Claims

1. A process for preventing crack formation in nickel alloy substrates having a gamma prime phase, comprising the steps of:
 - a) providing a substrate (10) to be treated, said substrate (10) comprising a nickel alloy substantially strengthened by the presence of a gamma-prime phase resulting from the presence of gamma-prime formers;
 - b) irradiating a portion of said substrate (10) with a laser beam (24) and causing a molten pool of said alloy to be formed;
 - c) dispersing a supply of coating particles (40) within said pool, said particles (40) comprising a nickel alloy; and
 - d) effecting rapid relative motion between said laser beam (24) and said pool so that said pool rapidly solidifies and thereby minimizes formation of gamma-prime therein and adjacent thereto.
2. A process according to claim 1, including the step of providing a substrate (10) having gamma-prime forming constituents of a concentration less than 10,5% by weight.
3. A process according to claim 1 or 2, including the step of providing a substrate (10) having gamma-prime forming constituents of a concentration of at least about 5,5% by weight.
4. A process according to claim 2 or 3, including the step of providing a substrate (10) having gamma-prime forming constituents of no more than about 7,5% by weight.
5. A process according to any one of claims 1 through 4, including the step of providing a substrate (10) having at least 60% by weight nickel.
6. A process according to any one of claims 1 through 5, including the step of providing particles (40) having gamma-prime forming constituents.
7. A process according to claim 6, including the step of providing particles (40) having a nominal chemical composition corresponding substantially to the nominal chemical composition of the substrate (10).
8. A process according to any one of claims 6 and 7, including the step of providing particles (40) having gamma-prime forming constituents not exceeding 7,5% by weight.
9. A process according to any one of claims 1 through 8, including the step of moving the laser beam (24) relative to said pool at a speed of from about 25,4 to about 254 cm per minute.
10. A process according to any one of claims 1 through 9, including the step of forming said pool to have a mass substantially less than the mass of said substrate (10).
11. A process according to any one of claims 1 through 10, including the steps of:
 - a) providing a substrate (10) having a surface defect (12); and



temperature for very long, the temperature change being quite dramatic and in the order of several thousand degrees or more per second.

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Preferably, the substrate 10 moves relative to the nozzle 14 in order to effect the relative motion between the substrate 10 and the beam 24 which is required for the rapid solidification to occur. The beam 24 irradiates a portion of the defect 12 and forms a molten pool comprised of the alloy of substrate 10. The particles 40 are then blown into the molten pool into which they become dispersed. The beam 24 is moved relative to the substrate 10 at a rapid speed in order to prevent excessive melting of the substrate 10, while assuring that a sufficient quantity of the alloy substrate is melted. Rapid motion, on the order of 25,4 - 254 cm per second, is generally sufficient to assure compliance with these two competing parameters.

Claims

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 - a) providing a substrate (10) to be treated, said substrate (10) comprising a nickel alloy substantially strengthened by the presence of a gamma-prime phase resulting from the presence of gamma-prime formers;
 - b) irradiating a portion of said substrate (10) with a laser beam (24) and causing a molten pool of said alloy to be formed;
 - c) dispersing a supply of coating particles (40) within said pool, said particles (40) comprising a nickel alloy; and
 - d) effecting rapid relative motion between said laser beam (24) and said pool so that said pool rapidly solidifies and thereby minimizes formation of gamma-prime therein and adjacent thereto.
2. A process according to claim 1, including the step of providing a substrate (10) having gamma-prime forming constituents of a concentration less than 10,5% by weight.
3. A process according to claim 1 or 2, including the step of providing a substrate (10) having gamma-prime forming constituents of a concentration of at least about 5,5% by weight.
4. A process according to claim 2 or 3, including the step of providing a substrate (10) having gamma-prime forming constituents of no more than about 7,5% by weight.
5. A process according to any one of claims 1 through 4, including the step of providing a substrate (10) having at least 60% by weight nickel.
6. A process according to any one of claims 1 through 5, including the step of providing particles (40) having gamma-prime forming constituents.
7. A process according to claim 6, including the step of providing particles (40) having a nominal chemical composition corresponding substantially to the nominal chemical composition of the substrate (10).
8. A process according to any one of claims 6 and 7, including the step of providing particles (40) having gamma-prime forming constituents not exceeding 7,5% by weight.
9. A process according to any one of claims 1 through 8, including the step of moving the laser beam (24) relative to said pool at a speed of from about 25,4 to about 254 cm per minute.
10. A process according to any one of claims 1 through 9, including the step of forming said pool to have a mass substantially less than the mass of said substrate (10).
11. A process according to any one of claims 1 through 10, including the steps of:
 - a) providing a substrate (10) having a surface defect (12); and



b) irradiating at least a portion of said defect (12) with the laser beam (24) for causing said pool to be formed.

12. A process according to claim 11, including the step of irradiating said defect (12) with the laser beam (12) having a power of from about 1,0 to about 5,0 kilowatts.

13. A process according to any one of claims 1 through 12, including the step of pneumatically conveying said coating particles (40) to said pool so that said particles (40) thereby enter said pool and become dispersed therein.

14. A process according to any one of claims 1 through 9, including the step of shrouding said pool with an inert gas.

15. A process according to claims 13 and 14, including the step of conveying said particles (40) with an inert gas corresponding to said shrouding gas.

16. A process according to claim 15, including the step of providing a shrouding gas corresponding chemically to the conveying gas.

17. A process according to any one of claims 1 and 15, including the step of focusing the laser beam (24) on the substrate (10).

18. A process according to claim 16, including the step of focusing said laser beam (24) so that said laser beam (24) has a diameter at said substrate of from about 1,27 to about 6,35 mm.

19. A process according to any one of claims 1 through 18, including the step of providing particles (40) having a mesh size of from about -80 to about +325.

20. A process according to any one of claims 1 through 19, including the steps of:

a) providing a substrate (10) having a thickness of from about 1,59 to about 12,7 mm.;

b) forming a molten pool having a depth of from about 0,127 to about 1,27 mm; and

c) providing coating particles (40) substantially corresponding to the nominal chemical composition of said substrate (10).

21. A process according to claim 20, including the step of supplying particles (40) at a rate of from about 0,10 to about 0,40 grams per second.

Patentansprüche

1. Ein Verfahren zum Verhindern von Rißbildung in nickellegierten Substraten, die eine Gamma-Primärphase haben, das die folgenden Schritte aufweist:

a) das Vorsehen eines zu behandelnden Substrats (10), wobei besagtes Substrat (10) eine Nickellegierung aufweist, die im wesentlichen durch die Anwesenheit einer Gamma-Primärphase verfestigt ist, die von der Anwesenheit eines Gamma-Primärphasen-Bildners herrührt;

b) das Bestrahlen eines Teilstücks des besagten Substrats (10) mit einem Laserstrahl (24) und das Erzeugen eines Schmelzbades der besagten zu bildenden Legierung;

c) das Verteilen eines Vorrats von Beschichtungspartikeln (40) innerhalb des besagten Bades, wobei besagte Partikel (40) eine Nickellegierung aufweisen;

und

d) das Ausführen schneller Relativbewegung zwischen besagtem Laserstrahl (24) und besagtem Bad, so daß besagtes Bad schnell erstarrt und dadurch darin und daran angrenzend die Bildung von Gamma-Primärphase minimiert.

2. Ein Verfahren gemäß Anspruch 1,

das den Schritt des Vorsehens eines Substrats (10) beinhaltet, das Gamma-Primärphasen bildende Bestandteile mit einer Konzentration von weniger als 10,5 Gew.% hat.



3. Ein Verfahren gemäß Anspruch 1 oder 2,
das den Schritt des Vorsehens eines Substrats (10) beinhaltet, das Gamma-Primärphasen bildende
Bestandteile mit einer Konzentration von mindestens ungefähr 5,5 Gew.% hat.
- 5 4. Ein Verfahren gemäß Anspruch 2 oder 3,
das den Schritt des Vorsehens eines Substrats (10) beinhaltet, das Gamma-Primärphasen bildende
Bestandteile mit nicht mehr als ungefähr 7,5 Gew.% hat.
- 10 5. Ein Verfahren gemäß einem der Ansprüche 1 bis 4,
das den Schritt des Vorsehens eines Substrats (10) beinhaltet, das mindestens 60 Gew.% Nickel hat.
6. Ein Verfahren gemäß einem der Ansprüche 1 bis 5,
das den Schritt des Vorsehens von Partikeln (40) beinhaltet, die Gamma-Primärphasen bildende
Bestandteile haben.
- 15 7. Ein Verfahren gemäß Anspruch 6,
das den Schritt des Vorsehens von Partikeln (40) beinhaltet, die eine chemische Nennzusammenset-
zung haben, die im wesentlichen der chemischen Nennzusammensetzung des Substrates (10) ent-
spricht.
- 20 8. Ein Verfahren gemäß der Ansprüche 6 und 7,
das den Schritt des Vorsehens von Partikeln (40) beinhaltet, die Gamma-Primärphasen bildende
Bestandteile haben, die 7,5 Gew.% nicht überschreiten.
- 25 9. Ein Verfahren gemäß einem der Ansprüche 1 bis 8,
das den Schritt des Bewegens des Laserstrahls (24) relativ zu besagtem Bad mit einer Geschwindigkeit
von ungefähr 25,4 bis ungefähr 254 cm pro Minute beinhaltet.
- 30 10. Ein Verfahren gemäß einem der Ansprüche 1 bis 9,
das den Schritt des Bildens des besagten Bades beinhaltet, das eine Masse hat, die wesentlich
geringer als die Masse des besagten Substrates (10) ist.
- 35 11. Ein Verfahren gemäß einem der Ansprüche 1 bis 10,
das die folgenden Schritte beinhaltet:
 - a) das Vorsehen eines Substrates (10), das einen Oberflächendefekt (12) hat; und
 - b) das Bestrahlen wenigstens eines Teilstücks des besagten Defekts (12) mit dem Laserstrahl (24),
um das zu bildende Bad zu erzeugen.
- 40 12. Ein Verfahren gemäß Anspruch 11,
das den Schritt des Bestrahleins des besagten Defekts (12) mit dem Laserstrahl (12) beinhaltet, der
eine Leistung von ungefähr 1,0 bis ungefähr 5,0 Kilowatt hat.
- 45 13. Ein Verfahren gemäß einem der Ansprüche 1 bis 12,
das den Schritt des pneumatischen Förderns der besagten Beschichtungspartikel (40) zu besagtem
Bad beinhaltet, so daß besagte Partikel (40) dadurch in besagtes Bad eintreten und darin verteilt
werden.
- 50 14. Ein Verfahren gemäß einem der Ansprüche 1 bis 9,
das den Schritt des Einhüllens des besagten Bades mit einem inerten Gas beinhaltet.
- 55 15. Ein Verfahren gemäß anspruch 13 und 14,
das den Schritt des Förderns der besagten Partikel (40) mit einem inerten Gas beinhaltet, das
besagtem Einhüllungsgas entspricht.
16. Ein Verfahren gemäß Anspruch 15,
das den Schritt des Vorsehens eines Einhüllungsgases aufweist, das dem Fördergas chemisch
entspricht.



17. Ein Verfahren gemäß einem der Ansprüche 1 und 15,
das den Schritt des Fokussierens des Laserstrahls (24) auf dem Substrat (10) beinhaltet.
18. Ein Verfahren gemäß Anspruch 16,
das den Schritt des Fokussierens des besagten Laserstrahls (24) beinhaltet, so daß besagter Laserstrahl (24) an besagtem Substrat einen Durchmesser von ungefähr 1,27 bis ungefähr 6,35 mm hat.
19. Ein Verfahren gemäß einem der Ansprüche 1 bis 18,
das den Schritt des Vorsehens von Partikeln (40) beinhaltet, die eine Maschengröße von ungefähr -80 bis ungefähr +325 haben.
20. Ein Verfahren gemäß einem der Ansprüche 1 bis 19,
das die folgenden Schritte beinhaltet:
 - a) das Vorsehen eines Substrates (10), das eine Stärke von ungefähr 1,59 bis ungefähr 12,7 mm hat;
 - b) das Bilden eines Schmelzbades, das eine Tiefe von ungefähr 0,127 bis ungefähr 1,27 mm hat; und
 - c) das Vorsehen von Beschichtungspartikeln (40), die im wesentlichen der chemischen Nennzusammensetzung des besagten Substrats (10) entsprechen.
21. Ein Verfahren gemäß Anspruch 20,
das den Schritt des Zuführens von Partikeln (40) mit einer Rate von ungefähr 0,10 bis ungefähr 0,40 g pro Sekunde beinhaltet.

Revendications

1. Un procédé permettant de prévenir la formation de fissures dans les substrats en alliages de nickel qui possèdent une phase gamma-prime, comprenant les étapes suivantes :
 - a) la fourniture d'un substrat (10) à traiter, ledit substrat (10) comprenant un alliage de nickel fortement renforcé par la présence d'une phase gamma-prime résultant de la présence de constituants initiateurs de phase gamma-prime;
 - b) l'exposition d'une partie dudit substrat (10) à l'action d'un faisceau laser (24) et la constitution d'une zone où ledit alliage que l'on cherche à former se trouve à l'état fondu;
 - c) la dispersion d'un essaim de particules de restauration (40) à l'intérieur de ladite zone, lesdites particules (40) étant constituées d'un alliage de nickel; et
 - d) la génération de mouvements relatifs rapides entre ledit faisceau laser (24) et ladite zone de telle sorte que ladite zone se solidifie rapidement et que la formation de phase gamma-prime à l'intérieur et au voisinage de ladite zone soit minimisée par ce moyen.
2. Un procédé selon la revendication 1, comprenant l'étape qui consiste en la fourniture d'un substrat (10) dont la teneur en constituants initiateurs de phase gamma-prime est inférieure à 10,5% en poids.
3. Un procédé selon la revendication 1 ou 2, comprenant l'étape qui consiste en la fourniture d'un substrat (10) dont la teneur en constituants initiateurs de phase gamma-prime est environ au moins de 5,5% en poids.
4. Un procédé selon la revendication 2 ou 3, comprenant l'étape qui consiste en la fourniture d'un substrat (10) dont la teneur en constituants initiateurs de phase gamma-prime ne dépasse pas 7,5% en poids environ.
5. Un procédé selon l'une quelconque des revendications 1 à 4, comprenant l'étape qui consiste en la fourniture d'un substrat (10) dont la teneur en nickel est d'au moins 60% en poids.
6. Un procédé selon l'une quelconque des revendications 1 à 5, comprenant l'étape qui consiste en la fourniture de particules (40) contenant des constituants initiateurs de phase gamma-prime.
7. Un procédé selon la revendication 6, comprenant l'étape qui consiste en la fourniture de particules (40) dont la composition chimique nominale correspond essentiellement à la composition chimique nomina-



le du substrat (10).

- 5 8. Un procédé selon l'une des revendications 6 ou 7, comprenant l'étape qui consiste en la fourniture de particules (40) dont la teneur en constituants initiateurs de phase gamma-prime n'excède pas 7,5% en poids.
- 10 9. Un procédé selon l'une quelconque des revendications 1 à 8, comprenant l'étape qui consiste à déplacer le faisceau laser (24) par rapport à ladite zone fondue à une vitesse comprise dans l'intervalle allant d'environ 25,4 cm à environ 254 cm par minute.
- 10 10. Un procédé selon l'une quelconque des revendications 1 à 9, comprenant l'étape qui consiste en la formation de ladite zone fondue en vue d'obtenir une masse nettement inférieure à la masse dudit substrat (10).
- 15 11. Un procédé selon l'une quelconque des revendications 1 à 10, comprenant les étapes suivantes :
 - a) la fourniture d'un substrat (10) présentant un défaut de surface (12); et
 - b) l'exposition d'une partie au moins dudit défaut de surface (12) à l'action du faisceau laser (24) pour la constitution de ladite zone que l'on cherche à former.
- 20 12. Un procédé selon la revendication 11, comprenant l'étape consistant à exposer ledit défaut de surface (12) à l'action d'un faisceau laser (24) dont la puissance est comprise dans un intervalle allant d'environ 1,0 kilowatt à environ 5,0 kilowatts.
- 25 13. Un procédé selon l'une quelconque des revendications 1 à 12, comprenant l'étape qui consiste à transporter de façon pneumatique lesdites particules de restauration (40) en direction de ladite zone de telle sorte que lesdites particules (40) pénètrent par ce moyen à l'intérieur de ladite zone et se dispersent à l'intérieur de ladite zone.
- 30 14. Un procédé selon l'une quelconque des revendications 1 à 9, comprenant l'étape qui consiste à protéger ladite zone d'un gaz inerte.
- 15 15. Un procédé selon les revendications 13 et 14, comprenant l'étape qui consiste à transporter lesdites particules (40) au moyen d'un gaz inerte correspondant au gaz protecteur.
- 35 16. Un procédé selon la revendication 15, comprenant l'étape qui consiste à fournir un gaz protecteur qui corresponde chimiquement au gaz de transport.
- 40 17. Un procédé selon l'une quelconque des revendications 1 à 15, comprenant l'étape qui consiste à focaliser le faisceau laser (24) sur le substrat (10).
18. Un procédé selon la revendication 16, comprenant l'étape qui consiste à focaliser ledit faisceau laser (24) de telle sorte que le diamètre dudit faisceau laser (24) au niveau du substrat soit compris dans l'intervalle allant d'environ 1,27 mm à environ 6,35 mm.
- 45 19. Un procédé selon l'une quelconque des revendications 1 à 18, comprenant l'étape qui consiste à fournir des particules (40) dont la maille de tamis est comprise dans l'intervalle allant d'environ -80 à environ +325.
- 50 20. Un procédé selon l'une quelconque des revendications 1 à 19, comprenant les étapes suivantes :
 - a) la fourniture d'un substrat (10) dont l'épaisseur est comprise dans l'intervalle allant d'environ 1,59 mm à environ 12,7 mm;
 - b) la constitution d'une zone fondue dont la profondeur est comprise dans l'intervalle allant d'environ 0,127 mm à environ 1,27 mm; et
 - c) la fourniture de particules de restauration (40) dont la composition chimique nominale correspond
- 55 essentiellement à la composition chimique nominale dudit substrat (10).
21. Un procédé selon la revendication 20, comprenant l'étape qui consiste à fournir des particules de restauration (40) à une cadence comprise dans un intervalle allant d'environ 0,10 g/sec à environ 0,40

g/sec.

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