

## THERMAL SPRAYING OF A MACHINE PART

### Field of the Invention

The present invention relates to a machine part, preferably an engine machine part, coated with a coating material by a thermal spray process and exposed to heat treatment of said coating material at an elevated temperature. The invention also discloses a method of applying a coating to machine parts.

### Technical Background

Specific demands have to be met by machine parts , particularly as concerns for example strength, anti-corrosive properties, wear resistance, ductility and material resilience.

Today, machine parts are generally manufactured from a cast-iron blank, which substantially meets the requirements imposed on the material as regards strength and resilience but when heated above certain limits a wear problem arise. There are a great number of machine parts subjected to wear caused by the internal friction between e.g. sliding surfaces in an engine system. Especially, in large marine diesel engines the friction forces can be of a large magnitude. In addition to the friction the hot environment can lower the strength of the material and rapidly result in great wear on a machine part made of cast iron, which does not possess the required scuffing resistance at high temperatures. A cast-iron engine part therefore often is provided with a wear-resistant layer or a running-in layer on the surfaces most exposed to wear.

However, difficulties do arise in achieving a sufficiently strong bond between the material of the blank and the material of the wear layer, which causes problems, because of the risk that the material of the wear layer will be torn away from the material of the blank. When this happens, the material of the blank-material surface

is exposed to wear in the area of contact with adjacent machine parts, which results in considerable shortening of the life of the machine part in question.

Another issue is that the coating gradually wears  
5 away, even if the bond between the surfaces is comparatively strong. The wear on the machine part progresses slowly as long as the wear layer is intact but very rapidly, once that layer has been worn away. As a result, it may be difficult to determine in time when, if possible,  
10 a machine part change should be made.

Thermal spraying is conveniently used to apply coatings on e.g. iron blanks. Generally, one issue with using thermal spraying for applying a coating is that the resulting coating comprises a fraction of loose particles.  
15 These loose particles increase the risk for "three-body-abrasion" between the sliding surfaces of two machine parts. Three-body-abrasion is often causing the process of gradual wearing indicated in the above.

In operation, some zones of a machine part, especially engine parts are exposed to high temperatures, to  
20 considerable temperature differences, and to the effects of a highly corrosive environment. In order to withstand the effects of these stress-inducing causes, the coatings of the machine parts therefore also must exhibit considerable ductility and thermal stability in addition to the  
25 before mentioned wear resistance. By ductility is to be understood herein the maximum possible deformation of the material before cracking begins. Not only in operation but also during manufacturing thermal shock and high temperature differences can cause similar effects on the machine parts subject to a heat treatment process, which  
30 will be further described in the following.

Various methods are known to post-heat or sinter a coating, which has been applied in order to provide a  
35 strong bond between coatings and a substrate. US 5,268,045 provides an example of such a prior art coating method, wherein the work piece to be coated is electro-

chemically cleaned, thermal spray coated with a metal or metals in order to provide an overlay coating and post heat treated at an elevated temperature, to diffuse said metal or metals into the surface of the work piece.

5           During such a process the coating will reach its melting temperature and there is a risk that also the underlying substrate is affected in such a way that stress is induced in the substrate. Furthermore, in such a process a hard coating with reduced ductility is obtained.

10           This is an issue for coatings on substrates and often for coatings on curve shaped blanks. When a coating applied to a blank is heated the blank will also be heated and it will consequently lead to an expansion of the machine part blank. After the heat treatment when the  
15 machine part is cooling off it will resume its original shape and consequently the newly bonded coating will be forced to follow the machine part blank. If the coating is applied on e.g. a curved shaped surface the coating will experience tensile stress during the cooling off re-  
20 sulting possibly in cracks or peel off. This might lead to shortage of the operable lifetime of the machine part.

Other issues related to prior art techniques will be described more in detail in the document. Hence it is desirable to find a method for providing a ductile wear re-  
25 sistant coating on a machine part with a strong bond. It is also an object to find a method for applying a coating on a machine part with minimized induced stress and also reducing the risk of loose particles and actual cracks within the coating. At present no method is known of ap-  
30 plying a coating of machine parts which overcomes the above issues.

#### Summary of the Invention

35           The object of the present invention is to provide a method of applying a coating, particularly intended for machine parts, that meets the requirements necessary re-

garding wear resistance, resilience, anti-corrosiveness, hardness, thermal stability and ductility.

Another object is to provide a coated machine part, which does not suffer from the above drawbacks found in the prior art. Other features and advantages of the present invention will become apparent from the following description of the invention.

The present invention provides a method of applying a coating material to at least part of a surface of a machine part, said method comprising the following steps, application of said coating material by a thermal spray process, heat treatment of said coating material at an elevated temperature and for a time effective to at least partially diffuse said coating material into the underlying surface, and to apply an additional coating material layer subject to successive heat treatments of each said coating material layer in order to lay down on said machine part surface a plurality of layers of same said coating material, wherein said heat treatment result in formation of necks in contact points between particles of at least said coating.

In accordance with the inventive method a strong bond between the coating material and the machine part surface as well as internally strong bonds within the coating is formed. By controlling the heating temperature, to which the coating material is exposed when applied on the machine part the coating material will develop necks in contact points (microwelds) between particles in said coating and machine part surface resulting in a strong bond between said particles. Depending on the material of the coating and machine part the contact point necks are developed by exposing said material to heating temperature below or close to the melting point of the coating material. A coating material intended for machine parts typically comprises a matrix material and a reinforcement material. Conveniently, but not exclusively, the coating material applied to the machine part

is in the range of 60 to 80% of the melting temperature of the reinforcement material of the coating. The matrix material will accordingly be exposed to heat near its melting temperature during short periods in time causing the formation of said necks in the material. By the inventive method there is provided a coating comprising open pores between the particles of the coating. Further, according to the inventive method the object of reducing loose particles in the coating of a machine part is met.

10        Preferably, the thermal spray device and a heat treatment device are connected and moved relatively to a machine part, while applying said coating material and heat treatment to said machine part.

By controlling the movement the time of exposure to heat can be controlled in a desired manner.

15        In order to provide the desired elevated heat treatment of said machine part induction heating is preferably used. Heat treatment by induction heating is considered effective and cost efficient but also other alternatives known by a person skilled in the art can be used. One such other alternative is laser.

Another benefit of the inventive method is that the resulting machine part coating has an evenly distributed porosity. Preferably, said resulting machine part coating has a porosity of between 1 to 15 vol%. The coating material comprising the yielded pores hence has the possibility to absorb deformations and imperfections caused by induced stress during use.

25        Open pores can also be used as a buffer for lubricating substances to provide a lubricant effect on the machine part during use and hence reduce friction and wear. Closed pores however can not easily receive externally fed lubricant and are hence of less use for machine parts if this is desired.

35        Further, each of said coating material layers typically have a thickness of between 0.005 to 0.40 mm. Preferably the thickness of one layer according to the inven-

tive method is around 0.01 mm. The thickness of one coating layer according to the inventive method is conveniently between 0.005 to 0.10 mm in order to develop the desired necks in the contact points between particles of the coating layer during heat exposure.

In a preferred method according to the invention, the coating material is of pulverulent type when fed to said thermal spray process. Alternatively said coating material has a wire like form when fed to said thermal spray process in order to achieve an efficient and controlled manufacturing process.

In a particularly preferred method of the invention the method is applied on a machine part comprising a curve shaped surface on which curve shaped surface said coating material is applied at least on some zones. For such machine parts the method is particularly well suited since problems with induced stress using conventional coating techniques on curve shaped machine parts are particularly difficult as mentioned in the background art. In order to further minimize the induced stress said machine part is preheated before the step of applying said coating material.

In accordance with the invention there is also provided a machine part, coated with a coating material by a thermal spray process, exposed to heat treatment of said coating material at an elevated temperature and for a time effective to at least partially diffuse said coating material into the underlying surface, and an additionally applied coating material layer subject to successive heat treatments of each said coating material layer in order to provide on said machine part surface a plurality of layers of same said coating material, said coating material comprising necks in contact points between particles in at least said coating.

In accordance with a preferred embodiment of the inventive machine part coating a strong bond between the coating material and the machine part surface as well as

internally strong bonds within the coating are achieved. By controlling the heat, to which the coating material is exposed when applied on the machine part the coating material will develop necks in contact points (microwelds) between particles in said coating and machine part surface resulting in a strong bond between said particles. Depending on the material chosen for the coating and for the machine part the contact point necks are developed by exposing said material to heat below the melting point of the material.

Conveniently, but not exclusively, the elevated heat treatment of the coating material on the machine part is applied within the range of 60 to 80% of the melting temperature of a reinforcement material used for the coating. By the inventive method there is provided a material creating open pores between the particles of the coating. Suitably the coating material is chosen from the group of at least one of the groups of the following materials: metals, metal alloys, carbides, silicates, ceramics, oxides, cermets and mixtures thereof.

Preferable, according to the invention the coating material comprises a metallic compound chosen from a group consisting of  $\text{Cr}_3\text{C}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{CuAl}$  and  $\text{Al}_2\text{O}_3$ . These compounds and metal alloys have proven well adapted for the making of machine part coatings of high quality with excellent wear and sliding performances. The coating according to a preferred embodiment comprises a mixture partly in the form of metal, partly in the form of reinforcement. In accordance with a preferred embodiment of the invention the coating material is a cermet. Cermet is a group of coatings that combine a ceramic and a metal or alloy. A frequently used example is Chrome Carbide (the ceramic constituent) in a Nickel/Chrome matrix. It is anticipated that a person skilled in the art may use other ceramic compounds, alloys and cermets (not mentioned here) in order to provide a coating on a machine part according to the invention.

Further it is provided according to the invention a machine part, wherein each of one said coating material layers typically have a thickness of between 0.005 to 0.10 mm. Preferably the thickness of one layer according to the inventive machine part is around 0.01 mm. The thickness of a coating layer according to the inventive machine part is conveniently between 0.005 to 0.10 mm in order to develop the desired necks in the contact points between particles of the coating layer during manufacturing. The total thickness of the coating depends on the size and type of machine part. For machine parts used in marine diesel engines a total thickness of the coating can be up to around 5 mm.

#### 15 Brief Description of the Drawing

Currently preferred embodiments of the present invention will now be described in more detail, with reference to the accompanying drawing.

Fig. 1 is a schematic representation of an arrangement for using the method of applying a coating material to a machine part according to the present invention.

Fig. 2 is a schematic representation of a part of a machine part comprising a coating in accordance with the invention.

Fig. 3 is a schematic representation of an enlarged partial view of fig. 2 in accordance with the present invention.

Fig. 4 is a schematic representation of an example of a resulting coating using another prior art method.

#### 30 Detailed Description of Preferred Embodiments

A currently preferred method according to the invention will be described together with a preferred embodiment of a machine part according to the present invention with reference to the accompanying drawings.

Referring now to Fig. 1, a machine part 1 is arranged for being provided with a coating. The coating

manufacturing arrangement further comprises a thermal spraying device 3 and a heat treatment device 5. Preferably, but not necessarily, a protective cover (not shown) is provided for covering surrounding elements from e.g. spraying. Further, an inductor constitutes the heat treatment device 5. The inductor 5 can be applied in a number of ways depending on the size of the machine part 1. In the present embodiment more than one inductor 5 is shown. A cleaned machine part 1 is arranged to be treated by the coating arrangement. The machine part is preferably a cast-iron blank. In accordance with a preferred embodiment of the invention a coating material 4 is applied to the desired parts of the machine part 1 by means of thermal spraying. The thermal spraying device 3 conveniently uses e.g. plasma, arc, HVOF, or flame spraying technology, which is considered well known for a person skilled in the art.

The machine part 1 is continuously moved in relation to the thermal spraying device 3 and heat treatment device 5 or vice versa during the spraying and instantly the coating material can be subject to heat treatment at elevated temperature. According to a preferred method the periphery speed of the machine part surface to be coated is around 20 m/min in relation to the thermal spraying device when applying the coating material and heat treatment.

The coating according to a preferred embodiment comprises a mixture partly in the form of metal, partly in the form of a reinforcement material. The coating material is preferably heated to between 60 to 80 % of the melting temperature of the reinforcement material in said coating during a short period of time.

Each cycle of applying the coating material 4 and heating the coating material 4 will result in a new coating layer 24 on the machine part surface, which is illustrated in Fig. 2. In Fig. 2 only three layers 24 are shown to illustrate the principle, but normally more than

10 layers will be applied and preferably more than 50. The number of layers 24 of course depends on e.g. the thickness of the layers 24 etc. According to a preferred embodiment of the invention each coating layer 24 has a thickness of typically 0.01 mm. The total thickness of the applied coating 24a of a machine part 1 is preferably around 0.8 mm, but possibly up to around 5 mm. These figures are however only given by way of example to give an idea of the properties to be used and it is understood by a person skilled in the art that it is possible to adjust the properties such as the thickness of the layers 24, the periphery speed during manufacturing of the coating as well as the number of layers 24 etc. in accordance with specific demands of the present machine part 1 to be coated.

Further according to the invention the coating material 4 comprises a metallic compound chosen from a group consisting of e.g.  $\text{Cr}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$ . These compounds and metal alloys have proven to result in machine part coatings of high quality. In accordance with a preferred embodiment of the invention the coating material is a cermet. Cermet is a group of coatings that combine at least a ceramic and at least a metal or an alloy. A frequently used example is Chrome Carbide (the ceramic constituent) in a Nickel/Chrome matrix. It is anticipated that a person skilled in the art may use other ceramic compounds, alloys and cermets (not mentioned here in detail) in order to provide a coating on a machine part according to the invention.

In accordance with a preferred embodiment of the inventive machine part 1 a strong bond between the coating material 4 and the machine part surface 22 as well as internally strong bonds within the coating is achieved. By controlling the heat, to which the coating material is exposed when applied on the machine part 1 the coating material 4 will be forced to develop necks (microwelds) in contact points between particles in said coating and

machine part surface resulting in a strong bond between said particles. Conveniently, but not exclusively, the elevated heat treatment of the coating material on the machine part is in the range of 60 to 80% of the melting  
5 temperature of at least the reinforcement material of said coating material.

This is further illustrated in Fig. 3, where a schematic enlargement of the bonding between particles 21 in one layer 24 is shown. By the inventive method there is  
10 provided a coating of a machine part, which coating comprises open pores between the particles 21 of the coating. Depending on the material of the coating and machine part 1 the contact point necks 23 are developed by exposing said material to heat below the melting point of the  
15 material. The contact point necks 23 provides additional strength to the coating. The step of exposing the coating to an elevated temperature will hence cause a significantly stronger bond compared to the mechanical bonding normally achieved by just thermal spraying.

20 In Fig. 4 the effect of applying excessive heat, which for other applications might be beneficial but not for these types of machine part coatings, to a coating layer or an entire coating of a substrate is shown. When applying excessive heat during coating of a substrate the  
25 coating material will melt. In order to be able to compare the size of the illustrated coated part in Fig. 3 it has a size that is about equal to that of Fig. 4. It can be seen that the coating in Fig. 4 show a significant decrease in porosity, the porosity is not evenly distributed,  
30 and that the pores are closed.

Closed pores are not generally able to provide any lubricant effect. Furthermore, the ductility provided by such a coating with few and unevenly distributed pores is generally not sufficient for use in a machine part coating.  
35 ing. Though the bond will be strong in such a coating other characteristics, as mentioned, are not adapted to meet the conditions that will be applied on a machine

part. It has been found that, due to the formation of necks within and between the multilayers of the coating during heat treatment according to the invention, a strong bonded coating with excellent ductility and wear resistance can be achieved.

Further, there is a risk for other properties of the machine part to be negatively effected when excessive heat is used applying a coating. According to the invention there is thus provided a method that provides a coating to a machine part with limited damage to the machine part blank, good adherence thereto, open pores and a sufficient porosity.

The inventive coating is suitably applied on sliding surfaces of machine parts, which are exposed to wear. Preferably the coating can be used on sliding surfaces in pumps, hydraulic pumps, and fire extinguishing pumps. The inventive coating is particularly suitable for coating machine parts used in internal combustion engines, and most preferably in marine diesel engines.

According to a preferred embodiment of the invention the coating is applied to at least parts of the sliding surface of a cylinder liner. The cylinder liner could either be fully coated or coated in a predetermined pattern on desired parts. One example of such a coating pattern is a helical geometry on the inside surface of the cylinder liner.

According to alternative preferred embodiments of the invention the machine part is a piston, a piston rod or a piston skirt. It is considered particularly suitable to provide a coating of the annular grooves of a piston with the inventive coating. According to yet another alternative embodiment of the invention the coating is applied partly or fully on certain parts of the inner sliding surface of stuffing box rings.

Other alternative embodiments, on which the coating according to the invention may be applied are on at least

suitable parts of a cam shaft and/or a crank shaft and sliding surfaces of camshaft cams.

Furthermore, it is considered beneficial to provide sliding surfaces of a shaft packing with the inventive  
5 coating. According to an embodiment of the present invention a sliding surface of a fuel pump is provided with the inventive coating material. In accordance with a further embodiment of the invention a coating may be provided on heat and wear loaded parts of inlet valves  
10 and/or outlet valves, which valves are preferably used in large two-stroke diesel engines.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent for one skilled in the art that various  
15 changes and modifications can be made therein without departing from the spirit and scope thereof. Thus it is understood that various methods such as plasma, HVOF, and arc spraying or other related methods can be used to apply the inventive composition to a machine part. The arrangement and method for applying the coating and heat to  
20 the coating on the machine part may of course be adjusted to present needs and is not limited by the above-described method, which is only given by way of example. Thus, another possible option for applying a coating may  
25 be by means of a laser arrangement.

CLAIMS

1. A method of applying a coating material to at least part of a surface (22) of a machine part (1), preferably an engine working part, said method comprising the following steps, application of said coating material by a thermal spray process, heat treatment of said coating material at an elevated temperature and for a time effective to at least partially diffuse said coating material into the underlying surface, and to apply an additional coating material layer (24) subject to successive heat treatments of each said coating material layer (24) in order to lay down on said machine part surface (22) a plurality of layers (24) of same said coating material, wherein said heat treatment result in formation of necks (23) in contact points between particles (21) of at least said coating.
2. A method according to claim 1, wherein the elevated heat treatment temperature of the coating material of the machine part is in the range of 60 to 80% of the melting temperature of the coating material.
3. A method according to any one of claims 1-2, wherein said thermal spray device (3) and a heat treatment device (5) are connected and moved relatively to a machine part (1), while applying said coating material (4) and a heat treatment to said machine part (1).
4. A method according to any one of claims 1-3, wherein said heat treatment of said machine part (1) is provided by induction heating.
5. A method according to any one of claims 1-4, wherein said resulting machine part coating is provided with an evenly distributed porosity.

6. A method according to any one of claims 1-5, wherein said resulting machine part coating has a porosity of between 1 to 15 vol%.

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7. A method according to any one of claims 1-6, wherein at least 10% of the pores of said resulting machine part coating are open pores (23).

10 8. A method according to any one of claims 1-7, wherein each of said coating material layer (24) typically has a thickness of between 0.005 to 0.4 mm.

15 9. A method according to any one of claims 1-8, wherein said coating material is of pulverulent type when fed to said thermal spray process.

20 10. A method according to any one of claims 1-8, wherein said coating material has a wire-like form when fed to said thermal spray process.

25 11. A method according to any one of claims 1-10, wherein said coating material comprises at least one of the following materials: metals, metal alloys, carbides, silicates, ceramics, cermets and mixtures thereof.

30 12. A method according to any one of claims 1-11, wherein said coating material comprises a metallic compound chosen from a group consisting of  $\text{Cr}_3\text{C}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{CuAl}$  and  $\text{Al}_2\text{O}_3$ .

13. A method according to any one of claims 1-12, wherein said machine part (1) is preheated before the step of applying said coating material.

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14. A method according to any one of claims 1-13, wherein said machine part (1) comprises a curve shaped surface on which curve shaped surface said coating material is applied at least on some zones.

5 15. A machine part (1), coated with a coating material by a thermal spray process, exposed to heat treatment of said coating material at an elevated temperature and for a time effective to at least  
10 partially diffuse said coating material into underlying surface, and additionally applied coating material layers (24) subject to successive heat treatments of each said coating material layer in order to provide on said machine part surface (22) a plurality of layers (24) of  
15 the same said coating material, said coating material forming necks (23) in contact points between particles (21) in at least said coating.

16. A machine part (1) according to claim 15, wherein the  
20 elevated heat treatment temperature of the coating material of the machine part is in the range of 60 to 80% of the melting temperature of the coating material.

17. A machine part (1) according to claim 15-16, wherein  
25 said heat treatment of said machine part is provided by induction heating.

18. A machine part (1) according to any one of claims 15-17, wherein said machine part coating has an evenly distributed porosity.  
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19. A machine part (1) according to any one of claims 15-18, wherein said machine part coating has a porosity of between 1 to 15 vol%.

20. A machine part (1) according to any one of claims 15-19, wherein at least 10% of the pores of said resulting machine part coating are open pores (23).
- 5 21. A machine part (1) according to any one of claims 15-20, wherein each of said coating material layers (24) typically have a thickness of between 0.005 to 0.4 mm.
- 10 22. A machine part (1) according to any one of claims 15-21, wherein said coating material comprises at least one of metals, metal alloys, carbides, silicates, ceramics, cermets, oxides and mixtures thereof.
- 15 23. A machine part (1) according to any one of claims 15-22, wherein said coating material comprises a metallic compound chosen from a group consisting of  $\text{Cr}_3\text{C}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{CuAl}$ ,  $\text{Al}_2\text{O}_3$  and mixtures thereof.
- 20 24. A machine part (1) according to any one of claims 15-23, wherein said coating material is a cermet.
- 25 25. A machine part (1) according to any one of claims 15-24, wherein said coating is applied on at least part of a curve shaped surface of said machine part (1).