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REVIEW OF APPLICATION AND RESEARCH BASED ON COLD SPRAY COATING MATERIALS

Cold spray technology is an advanced spray technology, and its technical principle is the same as that of additive manufacturing technology. Cold spraying technology combines multiple advantages in the spraying field: not only can the deposition of thick coatings be achieved, but the coatings prepared by this technology have the characteristics of high density, low oxygen content, good mechanical properties of the coating surface, and high deposition efficiency. Cold spraying technology can prepare corrosion-resistant coatings, high-temperature resistant coatings, wear-resistant coatings, conductive coatings, anti-oxidation coatings, and other functional coatings. After decades of development and exploration, cold spraying technology is preparing metal coatings. The application is very wide and the process is mature; the same cold spray technology can also prepare non-metallic coatings. Mainly to immerse repair and protect the surface of metal alloy parts and a small part of non-metal parts, so that these parts have better mechanical properties and mechanical behavior. This article mainly reviews the application of cold spray technology in the field of spray materials and summarizes the existing conventional metal series, rare metal series and non-metal material, conventional non-ferrous metals: copper, titanium, aluminum and nickel. Metal materials are currently widely used in the field of cold spraying. Among them, titanium-based metals restrict their applications due to their own properties; rare metals: tungsten, tantalum, and niobium-based metal materials. The application of rare metals in cold spraying is still in its infancy stage; non-metallic materials: polymer materials and ceramic powder materials, non-metallic materials have the characteristics of surface modification and strengthening technology, but also have low oxygen content, low thermal stress, high density, good bonding strength, in the deposition process and the substrate will not change the advantages of physical organization structure. Finally, the existing problems of rare metal materials and non-metal materials are raised.

Keywords: *cold spraying; aviation; metal materials; polymer materials; ceramic powder materials.*

1. The principle of cold spray technology

The cold spray technology was invented in the 1980s by researchers at the Institute of Theoretical and Applied Mechanics, Siberian Branch of Russia. This technology uses ultra-high-speed powder particles to hit the surface of the substrate, and finally the powder particles are deposited on the surface of the substrate. Coating method [1]. Through decades of research and academic exchanges, many countries around the world have also established cold spray technology research and development teams to conduct in-depth research and exploration on the spray deposition principle and application field expansion of cold spray systems.

Cold Gas Dynamic Spray (Cold Gas Dynamic Spray, referred to as CS), referred to as cold spray technology. This technology is a new type of spray deposition technology developed on the basis of aerodynamic science. Spray deposition is a process in which powder particles are accelerated in the Laval nozzle by the action of an acceleration medium (usually nitrogen, air or helium). The final ultra-high speed (300 m/s-1200 m/s) powder particles hit the substrate to achieve deposition, and eventually form a uniform and dense coating on the substrate [2-3]. Only when the powder particle material exceeds the critical speed specific to the sprayed material, the powder particles are adhered to the surface of the substrate through plastic deformation, and finally the deposition on the substrate can be achieved. The main reason is "adiabatic shear instability" [4].

There are many factors that affect the physical properties, mechanical properties and Microstructure of the coating, such as: the geometry of the Laval nozzle, the characteristics of the powder particle material, the temperature of the spray material and the substrate, the spray distance, the speed of the powder particles and the spray angle and other factors.

2. Applications of cold spray technology

Cold spray technology prepares other functional coatings such as corrosion-resistant coatings, high-temperature-resistant coatings, wear-resistant coatings, conductive coatings, and oxidation-resistant coatings by depositing coatings, which can repair parts that have the above problems in order to improve the physical and mechanical properties of parts and extend service life, it has very good economy, such as: turbine blades, pistons, bearings, cylinders, valves, seals and casings and other parts. Now cold spraying technology has broad application prospects in the fields of aviation, aerospace, ships, automobiles, chemicals, electronics, paper making and machinery.

The materials of the cold spraying technology are initially developed around conventional metal materials. Through continuous research and development, they have been extended to other materials. They have been successfully used in the cold spraying technology and have achieved good results. The materials currently available for cold spray technology can be classified into six categories: metals, metal matrix composites, ceramics, polymers, nanostructured materials and non-metallic base materials. For example: repairing space shuttle solid fuel rocket thrusters with Al coating, repairing components in aircraft structures, repairing gas turbine sealed enclosures [5, 6]; cold spray technology MCrAlY and TBCS materials have very good high temperature resistance, so they are often used as a material for preparing high temperature resistant coatings and thermal barrier coatings; cold spray technology Cu-Cr-Al material has very good oxidation resistance, so it is often used to prepare anti-oxidation layers; In cold spray technology, cermet, metal-based Composite materials and wear-resistant alloys have very good wear resistance, so they are often used to prepare wear-resistant coatings; Mg, Al, Cu, Ti, of which Mg and Al are light metals and are often used in aircraft, missiles, torpedoes, radar, satellites, with high specific strength characteristics alloys are mainly used in aircraft and engine structural parts [7]. Table 1 shows the spraying materials commonly used in current cold spraying technology.

3. Application of spray materials

3.1. Cu-based metal materials

In the field of non-ferrous metals, Cu is second only to Al. Cu is susceptible to oxidation at high temperatures, and pores are easily generated during the precipitation of supersaturated hydrogen [8]. Cold spray technology is a low-temperature spray technology, so Cu can effectively avoid the occurrence of oxidation problems of Cu powder particles during spraying.

Table 1

The materials that can be used for cold spraying

Materials	Specific materials
Metal	Al, Zn, Cu, Ni, Ca, Ti, Ag, Co, Fe, Nb, W
High melting point metal	Mo, Ta
Alloy	Ni-Al, Al-Fe, Al-Cu, Cu-W, Al 7075, Al A357, Ti-6Al-4V
Ceramic	Al2O3, Cr2O3, SiC, WC, TiO2, Cr3C2-NiCr, WC-Co, TiN,
Polymer	UHMWPE, HDPE, PA-12, PFA

Zhang [9] and other scholars prepared a Cu-Ti-B4C composite coating (powder composition Cu = 81.99 %, Cu = 14.64 %, B4C = 3.37 %) on a Cu substrate using cold spray technology, and the internal structure of the coating is dense, The porosity is about 1 %, and the interface with the substrate is very good, and no obvious oxidation occurs during the spraying process. Zhang [10] and other researchers prepared a Cu-MoS2 composite wear-reducing coating on the surface of Al6060 alloy using cold spray technology. The Cu-MoS2 composite wear-reducing coating reduced the friction coefficient by 75 % compared with the pure Cu coating. Xu [11] and other researchers used cold spray technology to prepare conductive Cu coatings on the surface of Al6061 alloy using Cu as the spray material. In the cold spray technology, Cu was used as the deposition material to study the mechanical properties of the coating. Li [12] and other researchers developed a rapidly cooling Cu-4Cr-2Nb alloy layer on the rocket thrust device components using cold spray technology. Vacuum heat treatment of the coating at an annealing temperature of 350 °C, the Microhardness reaches the maximum, the coating performance can reach the performance of the coating prepared by VPS technology. Using cold spray technology to prepare the Cu coating and heat-treating the coating, research shows that the average tensile strength of the Cu coating after heat treatment and annealing increases by 34.27 % [13]. The hardness of the Cu alloy coating prepared by the cold spray technique is obviously higher than that of the pure Cu coating [14]. Huang [15]. used cold spray technology to prepare Cu coatings on the surface of Al alloys, and obtained the relationship between the bonding strength of Cu coatings and substrates and particle velocity, as shown in Figure 1.

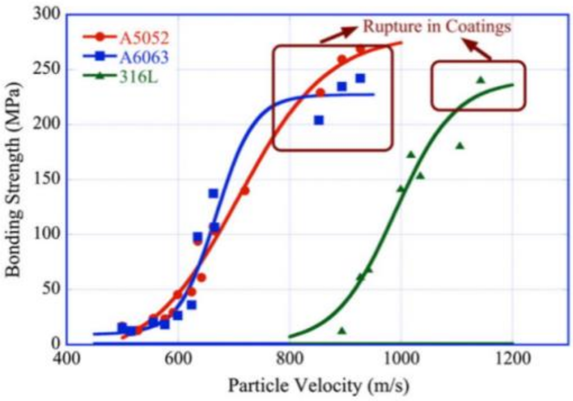

Figure 1. The relationship between the bonding strength and the speed of Cu powder particles [15]

3.2. Ti series metal materials

Ti alloys have been developed since the last fifty years of the last century. Ti alloys have such outstanding advantages as high strength, corrosion resistance, and high temperature resistance. Therefore, Ti alloys are widely used as materials for core components of aircraft. Many researchers have prepared pure Ti coatings and Ti-6Al-4V coatings by cold spray technology, and studied their Microstructure and mechanical properties. Figure 2 shows the Microstructure of pure Ti and Ti-6Al-4V coatings prepared by cold spray technology [16]. researchers such as Li [17] used cold spray technology to prepare porous Ti materials. Because Ti and its alloys have high hardness, they are not likely to deform during the cold spray process.

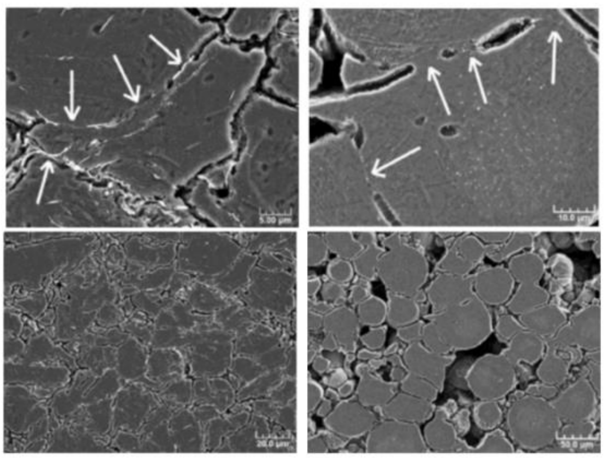

Figure 2. Microstructure of the cross section of pure Ti and Ti-6Al-4V coating [16]

Wang [18] and other researchers used cold spray technology to prepare a Ti metal coating on a 1Cr13 stainless steel substrate, and XRD analysis confirmed that there was basically no oxide phase formed in the Ti coating. Luo [19] and other researchers used in-situ Shot Peening (SP) to prepare high-density CP Ti and Ti-6Al-4V coatings using cold spray technology. The research results show that the proportion of SP powder particles increases from 0 to 70 vol. %, the porosity of CP Ti and Ti-6Al-4V coatings is reduced, and the work hardening effect is significantly enhanced, as shown in Figure 3.

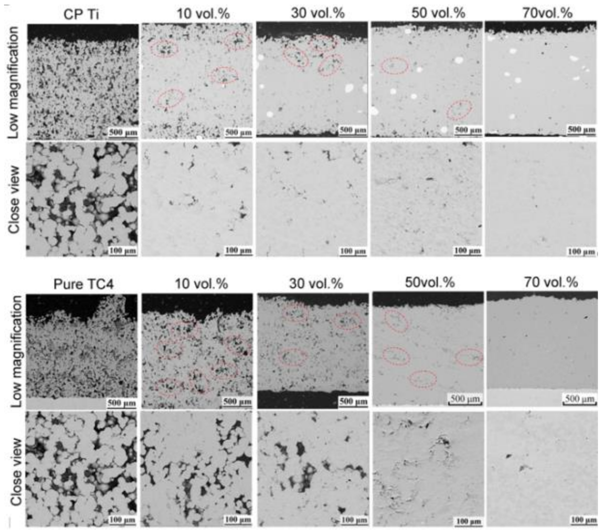

Figure 3. The change of the cross-sectional microstructure of pure Ti and Ti-6Al-4V with increasing proportion [19]

3.3. Al-based and Ni-based metal materials

Aluminum and Al alloys are widely used in aerospace, marine and automotive fields. Al has the characteristics of low density, high tensile strength, corrosion resistance and easy forming. Al is widely used as a spraying material in cold spraying technology. At present, many researchers are devoted to studying pure Al and Al alloy coatings. Compared with copper, Al powder is easier to deposit on the substrate, but its density is lower than that of Cu coating, because the density of Al is lower than that of Cu. Zhang [20] and other researchers used Al powder with a purity of 99.9 % as a spraying material, prepared Al coatings on 45 steel by cold spraying technology, and further studied the effect of spraying distance on the Al coating. The results show that when the spraying distance is 30mm, the deposition efficiency and microhardness of the Al coating are higher, and the combination effect with the substrate is better. CHAMPAGNE [21] and other researchers used cold spray technology to repair the Mg alloy crankcase shell by deposit coating with CP-Al powder as the material. The results showed that the bonding strength was 8.6 Mpa and 71.3 Mpa respectively, and the salt spray test was 336h and 610h respectively no corrosion and other phenomena occur, indicating that the Al coating has good corrosion resistance. Novoselova T. [22] and other researchers used cold spray technology to prepare the Ti-Al coating. After the heat treatment process was applied to the coating, the inter metallic compounds TiAl3, α-TiAl2, Ti-Al and Ti3 Al were generated, compared to the traditional Ti-Al coating preparation Method, cold spraying is more cost-effective.

Regarding the application of Ni as a spray material in cold spray technology, Elisa [23] and other researchers used Inconel 718-Ni (1: 1) as a spray material, and used high-pressure cold spray technology with Nitrogen as an accelerating medium on stainless steel substrates. In the coating, only 30 wt % of Inconel 718 was retained in the coating. The effect of the corrosion rate was studied by operating variables. The results show that The corrosion feed rate is 2g/min, the corrosion product size is 60 microns, the collision angle is 90° , and the corrosion rate is the smallest. researchers such as Marios [24] also used pure Ni and Inconel 718 powder as a spraying material, and used high-pressure cold spraying technology to prepare high-quality coatings on stainless steel substrates using Nitrogen as an acceleration medium. Studies have shown that by using pure Ni powder the addition of Inconel 718 powder particles can enhance the cavitation resistance of the Ni coating, and the hardness of the coating surface can be increased. The composite coating has a higher porosity, but compared with pure Ni coating, it can show excellent Anti-cavitation. Makarov [25] and other researchers used Ni-Ti composite powder and combined with nano-material WC as a spraying material. The results show that the use of cold spray technology to prepare Ni-TiWC coating can significantly improve the microhardness of the substrate surface, from 600 HV 50 Increased to 1300 HV 50. Mieczyslaw [26] and other researchers used cold spray technology to prepare Ni coatings on Al7050 alloy. The study found that the size of Ni powder material has a significant effect on the corrosion resistance of Ni coatings, and the porosity of Ni coatings will increase with the size of Ni powder increases with the increase of size. With the reduction of Ni powder diameter, the corrosion rate of Ni coating in chloride environment will decrease. The surface can be obtained by using irregular spherical or dendritic structure Ni powder as the spray material. Smooth and highly corrosion-resistant Ni coating. Wei [27] and other researchers used cold spray technology to prepare a fully dense Ni coating with a thickness of about 150 microns on the surface of AZ31B Mg alloy. After 1000 hours of immersion test and 1000 hours of NaCl salt spray test, the cold spray technology was further verified the prepared Ni coating has very good corrosion resistance.

3.4. Tungsten series, Tantalum series and Niobium series metal materials

Tungsten is an extremely refractory metal with a melting point of up to 3400 ° C and a density of $19.3\ g/cm^3$, and it has the characteristics of high hardness, low expansion coefficient, low saturation vapor pressure and good conductivity [7]. If cold spraying technology is used to prepare tungsten coating on the surface of aircraft engine turbine blades as a high temperature resistant coating, it will be a very important breakthrough. Aaron [28] and other researchers used Cu-plated tungsten powder as a spraying material to prepare a composite high-temperature resistant coating by cold spraying technology. The concentrations of tungsten-Cu were 80W-20Cu wt %, 85W-15Cu wt % and 90W-10Cu wt %, The research results show that the content of tungsten in the composite coating after spraying is far less than the amount of the original spray powder. The Microstructure evidence shows that the Cu coating and tungsten particles are separated during the spraying process, as shown in Figure 4.

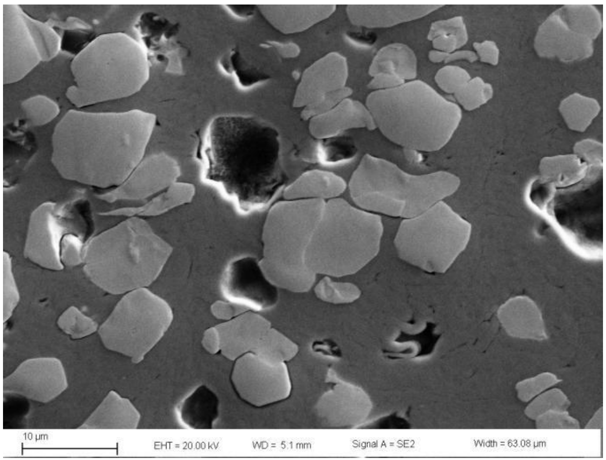

Figure 4. Magnified 80W-20Cu wt % coating sample by microscope [28]

Resulting in a decrease in the content of tungsten on the coating, indicating that tungsten is a metal material that is extremely difficult to prepare the coating by cold spray technology. Kang [29] and other researchers used tungsten / Cu mixed powder as the spraying material, and used cold spraying technology to deposit the tungsten / Cu composite coating on the low carbon steel substrate. The research results show that the porosity will change with the presence of tungsten. No oxidation was found in the Cu in the composite coating. researchers such as Jones [30] used Supersonic Laser Deposition (SLD) to prepare a fully dense tungsten coating on a Mo substrate, as shown in Figure 5.

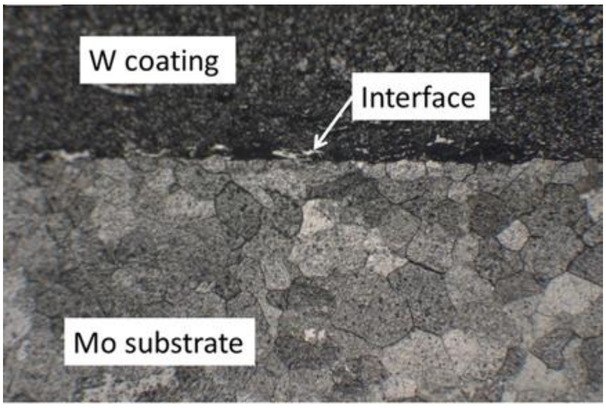

Figure 5. Tungsten coating and molybdenum substrate under optical micrograph [30]

The results show that the tensile strength of the tungsten coating is 724 Mpa, and the tensile strength of forged tungsten is comparable; it is worth noting that the working principle of Supersonic Laser Deposition (SLD) technology is similar to cold spray technology.

Tantalum metal has a melting point of up to 3033 °C and a density of $16.68\ g/cm^3$. It is better than tungsten and molybdenum at room temperature in process ability, weld ability, ductility and oxidation resistance. It is an important material for high-temperature structures required in the aerospace industry. Tantalum and its alloys have poor oxidation resistance, and oxidation begins at 600 °C [31, 32]. The plasticity of tantalum is very suitable for use as a spray material for cold spray technology. Koivuluoto [33] and other scholars used cold spray technology to prepare tantalum coatings, and found that the purity and density of tantalum coatings are very high under scanning electron microscope, Under two different temperature conditions of normal temperature and 80 ° C, the corrosion test was carried out in 3.5 wt % NaCl and 40 wt % H_2SO_4 solution. The tantalum coating performed well in all corrosion tests, which further indicated that the tantalum coating was dense. researchers such as Koivuluoto [34] also used cold spray technology to prepare tantalum coatings on steel surfaces. The results of electrochemical tests in 1 M KOH solution showed that the tantalum coatings prepared by cold spraying technology were better than those prepared by plasma spraying. The layer has more stable passivation performance. In 1wt % HF solution, the performance of tantalum coating prepared by cold spraying technology is better than bulk tantalum. Bolelli [35] and other researchers prepared a tantalum coating on the surface of steel and Al using cold spray technology, and further studied the stress and strain behavior of the coating using the depth-sensing spherical and sharp (Berkovich) indentation testing method. The size of the tantalum material does not affect the mechanical properties of the coating. The layered structure has a direct relationship with the mechanical properties of the coating, and the density of the tantalum coating is good. Kumar [36] and other researchers prepared the tantalum coating by cold spray technology, The tantalum coating is heat treated at different temperatures to further optimize the mechanical properties of the coating, The study found that the tantalum coating was found when the heat treatment temperature was 1500 ° C the mechanical properties of the layer are comparable to those of tantalum blocks. At the same time, the author also conducted a test evaluation and electrochemical test of the corrosion performance of the tantalum coating in 1 M KOH solution. The study found that the tantalum coating is very dense.

Niobium has a melting point of 2467 °C and a density of $8.57\ g/cm^3$. It has good ductility, stable physical and chemical properties and high-temperature mechanical properties. It is very stable in corrosive media and is widely used in the aerospace field. It can be used to make liquids and orbit control rocket engine nozzle [7]. Although the limit working temperature of niobium alloy is higher than that of Ni-based and cobalt-based super-alloys, the oxidation resistance of niobium alloy is poor. When the temperature exceeds 600 °C, pure niobium will appear powdering failure, which seriously restricts the preparation of niobium-based materials and development [37].

Niobium powder is used as a spraying material, and cold spraying technology is used to prepare a niobium coating with air as an acceleration medium. After that, heat treatment is used to eliminate the gap of the niobium coating and the interface between the deformed particles, thereby improving the mechanical properties of the coating. The porosity of the coating is reduced to 0.1 %. When the heat treatment temperature reaches 1500 °C, the elastic model of the niobium coating reaches 103 Gpa, while the elastic modulus of the niobium block is 105 Gpa, and the strength of the grain boundary of the niobium coating is increased by 750 %; The corrosion rate of the coating is 0.443 MPY and 0.498 MPY of the niobium block material. It can greatly improve the corrosion performance of the coating under the annealing process. The research results also found that when the recrystallization temperature of niobium is close to 1250 °C or annealed at a higher temperature, the niobium coating can almost achieve the performance of niobium block [38]. Kumar [39] and other researchers can obtain a good combination of deposited coatings when the spray speed of niobium particles is 515 m/s through numerical simulation of multiple particles.

3.5. Polymer materials

The techniques commonly used to prepare polymer coatings are: plasma spraying, arc spraying, flame spraying and cold spraying [40-43]. As a spray materials

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of cold spray technology, polymer materials have remarkable characteristics, good elastoplasticity, light weight, insulation and heat insulation. The materials usually used to prepare polymer coatings are mainly near spherical, as shown in Figure 6 [43].

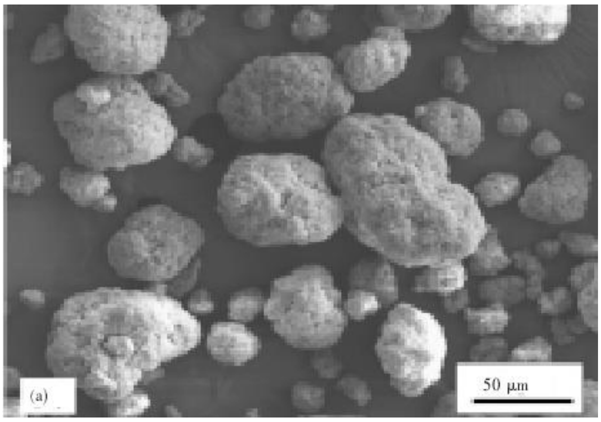

Figure 6. LIMA C near-spherical UHMWPE particles [43]

Cold spraying technology is a low-temperature spraying technology, so that the polymer material can maintain its own characteristics and structure when deposited on the surface of the substrate, reducing the porosity caused by thermal degradation [44]. Shah [45] and other researchers used high-density polyethylene powder particles as the spraying material, and deposited a coating on the surface of the semi-infinite high density polyethylene substrate by cold spraying technology. The impact speed of the sprayed material, temperature, diameter and particle composition of this series the influence of parameters on the impact dynamics of the particles, the study found that high-density polyethylene powder particles are easier to deposit on harder substrates. Xu [46] and other researchers used polyolefin powder particles as the spraying material, and prepared amphetamine alcohol coating on the surface of polyethylene and aluminum substrates by cold spraying technology, as shown in Figure 7, the research results show that: the heating temperature is lower than the polymer temperature in order to ensure that the polymer will not melt, the powder particles are closely combined through the interaction of plastic deformation. Tillmann [47] and other researchers used cold spray technology to prepare a 450 µm polyamide-12 / Al_2O_3 composite coating on the surface of steel substrates. Studies have shown that Al_2O_3 ceramic powders particle can accelerate the fluidity of polymer powders and simultaneously to shot peening. RAVIK [42]. Used super-hydrophobic polymers as the spraying material, and prepared a coating on the surface of the 316 stainless steel substrate by cold particle spraying single particle deposition to improve the surface performance of the substrate. The results showed that the surface of the substrate was coated with a layer of papillae the Micro-nano-structured hydrophobic Nano-ceramic layer of the same structure also improves the deposition efficiency of the particles.

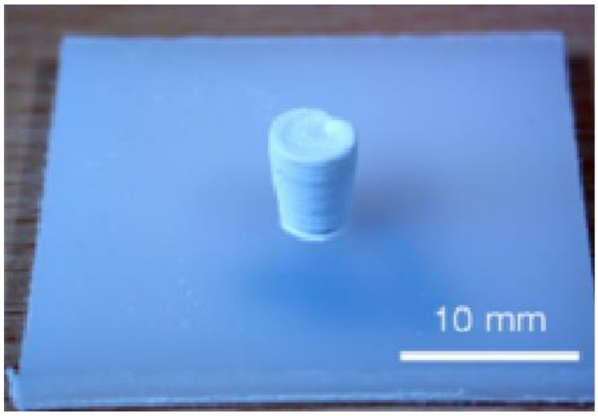

Figure 7. Amphetamine coating [46]

3.6. Ceramic powder materials

Generally, nano/sub-Micron ceramic particle powders are used as a spray material for cold spray technology. A few micron-sized powders are formed by agglomeration of nano-powders by sol-gel method [48], which is deposited on the surface of the substrate driven by a high subsonic acceleration medium. Compared with polymer powder and metal powder, the biggest feature of ceramic powder is that it has no plasticity at low temperature, so it is more difficult to deposit on the surface of the substrate. Ceramic powder particles have many advantages as a spray material for cold spray technology: low temperature, economy, and simple operation. Wang [49] and others researchers found that the deposition mechanism of ceramic powder particles is divided into two types, one is the bonding of ceramic powder particles to the substrate, the way is mechanical occlusion; the other is the deposition inside the ceramic powder coating, the way divided into grain refinement, plastic deformation and grain refinement-compaction mechanism. Liu [50] and others researchers found that using TiN ceramic powder particles as the spraying material, during the VCS (vacuum cold spray) spray deposition process, the TiN ceramic powder particles showed obvious cracks and plastic deformation, because the TiN ceramic powder particles were in the process of high-speed impact Induced strain occurs in the powder particles. The density of the individual particles is $\sim 5 \times 1017\ /m^2$. The density of the TiN ceramic powder particles will form an amorphous layer with a width of 3-4 nm. The reason for the misalignment is the high density of the individual powder particles. High stress and strain cause amorphization at the TiN interface, as shown in Figure 8. Sung [51]. Found that using cold spray technology to spray mixed powder particles of different diameters on the surface of the fluorine-doped tin oxide electrode, the results showed that the sprayed coating can generate a porous TiO_2 layer, which was compared with the sample after annealing , Conversion efficiency increased by 62 %.

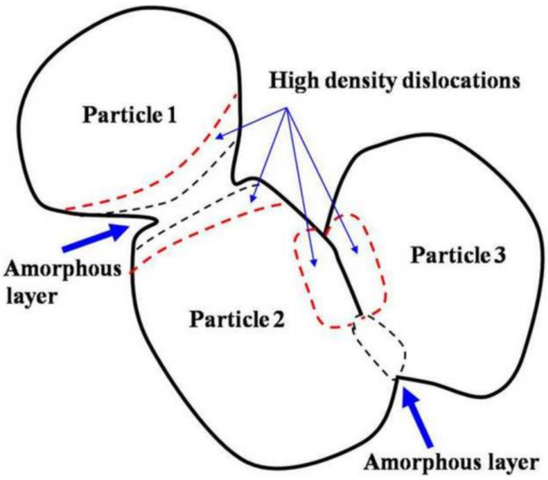

Figure 8. Schematic diagram of the amorphous layer at the TiN interface [50]

Conclusion

This article reviews the application of cold spray technology in spray materials and summarizes the literature on cold spray research. It mainly summarizes the existing conventional metals, rare metals and non-metallic materials. At present, Cu, Ti, Al and Ni-based metal materials are commonly used in cold spraying technology, but the main research is focused on Al, Cu and Ti-based metal materials, and the research of Mg-based metals is still in the initial exploration period, although Titanium's there are many studies, but due to its own high hardness, the compactness and mechanical properties of the deposited layer restrict its own use in the industrial field. The application of rare metal tungsten series, tantalum series and niobium series metal materials in the field of cold spraying technology is still in its infancy. Non-metallic materials are mainly polymer materials and ceramic powder materials. As a new spraying material, this material has the characteristics of surface modification and strengthening technology. It also has low oxygen content, low thermal stress, high density, and combination. The strength is good, and the advantages of itself and the physical structure of the substrate will not be changed during the deposition process.

At present, the reliability of rare metal coatings is still a problem worthy of study, how to improve the reliability of rare metal coatings and thus improve the mechanical properties of the coatings. The mechanical properties of the joint between the coating of the non-metallic material and the substrate are poor and the bonding mechanism is unclear, especially in the case of low bonding force. The use of ceramic powder as a cold spray material for deposition on metal substrates, especially for the preparation of high-temperature coatings, has very little application research, which will be the focus of future research.

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АНАЛІЗ ПОРОШКОВИХ МАТЕРІАЛІВ ДЛЯ ХОЛОДНОГО ГАЗОДИНАМІЧНОГО НАПИЛЮВАННЯ ТА ОБЛАСТЕЙ ЇХ ЗАСТОСУВАННЯ

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Технологія холодного газодинамічного напилювання - перспективна та багатообіцяюча технологія формування покриттів. Дана технологія має багато переваг в порівнянні з іншими технологіями газотермічного напилювання, а саме: можливість отримання товстих покриттів, мінімальні значення пористості, відсутність окислювальних процесів матеріалів покриття й підкладки, задовільні фізико-механічні характеристики й високі значення коефіцієнта використання порошку. Холодним газодинамічним напилюванням можливо отримання корозійностійких, теплозахисних, зносостійких та інших функціональних покриттів. Розвиток і вивчення процесу напилювання дозволяє отримувати покриття з широкого діапазону металевих порошків, а також інших метало-керамічних порошкових сумішей. Технологія холодного газодинамічного напилення добре зарекомендувала себе в процесах відновлення пошкоджених поверхонь, а також при необхідності забезпечення спеціальних експлуатаційних властивостей поверхонь деталей. У даній роботі розглядається застосування технології холодного напилення з точки зору порошкових матеріалів: металів, як пластичних (мідь, алюміній, цинк та ін.), так й важкооброблюваних (наприклад, титан), а також метало-керамічних композиційних порошкових сумішей на основі карбідів і оксидів. З проведеного аналізу літературних джерел можна зробити наступні висновки. У разі пластичних металів, процес формування покриттів і їх застосування в промисловості в достатній мірі вивчені. Позитивні результати по нанесенню покриттів з титанових сплавів були отримані при холодному газодинамічному напилюванні з використанням дорогих систем високого тиску та гелію в якості робочого газу. Що стосується тугоплавких металів (наприклад, вольфрам, тантал, ніобій), а також керамічних порошків (оксид алюмінію, оксид кремнію та ін.), то їх напилювання можливо лише за наявності металевої зв’язуючої компоненти. В даний час особливий практичний інтерес має застосування технології холодного напилювання металевих покриттів на композитні матеріали, пластики та інші неметалеві поверхні. Технологія холодного газодинамічного напилювання не обмежується представленими в статті результатами аналізу порошкових матеріалів і областями застосування, а дає загальне розуміння широких можливостей даної технології і конкуренції традиційним методам газотермічного напилювання.

Ключові слова: холодне напилення; авіація; металеві матеріали; полімерні матеріали; керамічні порошкові матеріали.

АНАЛИЗ ПОРОШКОВЫХ МАТЕРИАЛОВ ДЛЯ ХОЛОДНОГО ГАЗОДИНАМИЧЕСКОГО НАПЫЛЕНИЯ И ОБЛАСТЕЙ ИХ ПРИМЕНЕНИЯ

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Технология холодного газодинамического напыления - перспективная и многообещающая технология формирования покрытий. Данная технология обладает множеством достоинств в сравнении с другими технологиями газотермического напыления, а именно: возможность получения толстых покрытий, минимальные значения пористости, отсутствие окислительных процессов материалов покрытия и подложки, удовлетворительные физико-механические характеристики и высокие значения коэффициента использования порошка. Холодным газодинамическим напылением возможно получение коррозионностойких, теплозащитных, износостойких и других функциональных покрытий. Развитие и изучение процесса напыления позволяет получать покрытия из широкого диапазона металлических порошков, а также других металло-керамических порошковых смесей. Технология холодного газодинамического напыления хорошо зарекомендовала себя в процессах восстановления поврежденных поверхностей, а также при необходимости обеспечения специальных эксплуатационных свойств поверхностей деталей. В данной работе рассматривается применение технологии холодного напыления с точки зрения порошковых материалов: металлов, как пластичных (медь, алюминий, цинк и др.), так и труднообрабатываемых (например, титан), а также металло-керамических композиционных порошковых смесей на основе карбидов и оксидов. Из проведенного анализа литературных источников можно сделать следующие выводы. В случае пластичных металлов, процесс формирования покрытий и их применение в промышленности в достаточной степени изучены. Положительные результаты по нанесению покрытий из титановых сплавов были получены при холодном газодинамическом напылении с использованием дорогостоящих систем высокого давления и гелия в качестве рабочего газа. Что касается тугоплавких металлов (например, вольфрам, тантал, ниобий), а также керамических порошков (оксид алюминия, оксид кремния и др.), то их напыление возможно лишь с наличием металлической связующей компоненты. В настоящее время особый практический интерес имеет применение технологии холодного напыления металлических покрытий на композитные материалы, пластики и другие неметаллические поверхности. Технология холодного газодинамического напыления не ограничивается представленными в статье результатами анализа порошковых материалов и областями применения, а дает общее понимание широких возможностей данной технологии и конкуренции традиционным методам газотермического напыления.

Ключевые слова: холодное напыление; авиация; металлические материалы; полимерные материалы; керамические порошковые материалы.

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