Present Status and Future Prospects of Cold Spraying

Frank Gaertner[1,a], Tobias Schmidt[1,b] and Heinrich Kreye[1,c]

[1]Helmut Schmidt University, University of the Federal Armed Forces Hamburg, Holstenhofweg 85, D-22043 Hamburg, Germany
[a]frank.gaertner@hsu-hh.de,
[b]tobias.schmidt@hsu-hh.de, [c]heinrich.kreye@hsu-hh.de

Abstract

Cold spraying is a fairly new coating technique, which within the last decade attracted serious attention of research groups and spray companies. As compared to thermal spraying, the low process temperatures in cold spraying result in unique coating properties, which promise new applications. Since particles impact with high kinetic energy in the solid state, new concepts to describe coating formation are requested to enable the full potential of this new technology. The present contribution gives a brief review of current models concerning bonding, supplying a description of the most influential spray parameters and consequences for new developments. With respect to spray forming by cold cold spraying, microstructures and thick, further machineable structures are presented.

Keywords : cold spraying, bonding mechanisms, microstructures, spray forming

1. Introduction

Cold spraying was developed more than twenty years ago by a group of scientists at the Institute of Theoretical and Applied Mechanics, Novosibirsk, Russia. Nowadays, experimental equipment is commercially available meeting all requirements for industrial applications. The principle of cold spraying is quite simple, using a highly pressurized and preheated gas, which by passing through a converging diverging DeLaval type nozzle accelerates powder particles to supersonic velocities [1]. Heating of the process gas is requested to reach higher gas and thus particle velocities. Even that the gas is heated, the term cold spraying is still justified since particles on their way through the nozzle and the free jet attain only temperatures below their melting temperatures, in clear contrast to thermal spraying in which at least a part of the feedstock is molten before the impact on the substrate.

As compared to thermal spray processes, cold spraying offers several advantages. Heating and acceleration of the feedstock material only happens in the environment of an inert gas, typically nitrogen, in some instances helium, operated at comparably low temperatures. Thus oxidation is limited down to a minimum. Moreover, the well determinable process temperatures and exposure times make the process very suitable to prevent other undesired phase transformations.

Whereas thermal spraying requires a certain amount of heat to melt at least a part of the feedstock material to obtain welding to the substrate or to already adhering particle layers, cold spraying just uses the kinetic energy upon impact to assure bonding. For successful bonding, spray particles have to exceed a critical velocity, which is strongly dependant on the type of feedstock material, but also on the substrate properties. Recently developed and already well established models explain bonding by shear instabilities at particle-substrate or particle-particle interfaces that occur under high strain rate deformation [2,3].

One of the major goals within the last five years was to optimize particle acceleration, resulting in optimized nozzle geometries with respect to expansion ratios, contours and lengths of expanding sections. Newer attempts aimed for increased particle impact temperature, supplying a well defined amount of heat to support bonding by shear instabilities [3,4]. Since the creation of heat by deformation during impact is localized to the particle interfaces, the heat transfer to the inside of spray particles also has to be taken into account. Recent investigations demonstrated that heat flux is more prominent for smaller particle sizes and increases critical velocities for bonding. To obtain high deposition efficiency or a maximum amount of bonded interfaces, the particle impact velocity should be significantly higher than the critical velocity for bonding. The particle impact velocities are as well highly dependant on size. Small particles are decelerated in the bow shock, means the compressed gas in front of the substrate, whereas large particles by their large momentum not reach high velocities. Superimposing both dependencies shows that a well tuned medium range powder size cut supplies conditions under which nearly all particles adhere to the substrate and result in optimum coating performance.

Up to present, most interests aimed to customize cold spraying for well established engineering materials by retaining the feedstock properties. Already that could open new applications for powder spray techniques, complementary to thermal spraying. Typical cold sprayed coating thicknesses range from about less than 50 μm, corresponding to a couple of monolayers of spray particles, to some tens of millimeters. Within this range, the comparably thin coatings are interesting with respect to especially designed functional materials. Building up thicker structures is of particular interest for repair work or rapid protyping. Morover, the compressive stresses present in the cold sprayed coatings by the deformation upon solid state impact can be benifcial for coating performance.

2. Results and Discussion

With respect to applications, the present paper focusses on examples of copper, steel 316L, titanium and aluminium-alumina composite coatings.

As revealed by etching of coating cross sections, microstructures of copper coatings, as processed by using nitrogen as process gas and recently optimized spray conditions, show no remarkable differences between grain boundaries and particle-particle interfaces. The good resistance against the chemical attack demonstrates the quality of metallurgically bonded particle-particle interfaces. Building up thicker coppers coating does not restrict coating performance or adherence. The final product is well machinable and can be polished to similar standards as highly cold worked copper bulk material. Spraying thick copper coating on tubes results in parts that in the polished state can be used used as print roll.

By using stainless steel 316L powders as feedstock material, currently attainable conditions by cold spraying result in coatings with very low porosities far less below 1 vol. % and a high strength suitable for further maching. The cross sections demonstrate the low porosity of the as sprayed coating. Thicker coatings or structures can be finished and prepared for further construction as conventional, highly deformed steel 316L.

Under currently available conditions of cold spraying with nitrogen as process gas, pure titanium coatings can be processed with porosities of less than 1 vol. %. As compared to steel 316L or copper as spray material, the slightly higher porosity can be attributed to the low deformability of titanium. Nevertheless, particle-particle interfaces are well bonded and thick coatings can be processed, which allow further maching and final finshes.

Also feedstock blends of metallic and ceramic powders can be used for building up dense coatings and thick structures. The detailed view into coating cross sections reveals only a minimum amount of porosity. Nevertheless, it must be noted that by using a powder blend containing about 50 vol. % of ceramics results in a coating hard phase content of only about 15 %. Nevertheless, that comparatively small hard phase contents reduced the abrasive wear by 30 to 50 %, as compared to bulk alumiunum alloys. By cold spraying, thick coatings of such aluminum – alumina composite coatings can be processed, which can be further machined by conventional techniques.

3. Summary

Bonding in cold spraying can be attributed to the occurance of shear instabilities at particle surfaces and recently developed concepts allow predicting impact conditions for successfully building up coatings. By optimized nozzle design to reach high particle velocities and by well tunable process temperatures, the technique meets all requirements for industrial applications. The present investigation demonstrates that cold spraying can be used to build up thick coatings or free standing forms of various metals or metal-ceramic composites that can be further machined and finished. Next future demands will most probably affect the implementation of cold spraying into production lines, requiring the definition of the most effective spray parameter sets and quality assurance of spray powders, so far mainly based on well known commercial but heat sensitive alloys. Apart from that, cold spraying also offers a very high potential to deposit new types of materials, as amorphous or nanocrystalline alloys.

4. References

1. T. Stoltenhoff, H. Kreye, H.J. Richter, J. Therm. Spray Technol., 11, p. 542(2002).
2. H. Assadi, F. Gärtner, T. Stoltenhoff, H. Kreye, Acta Mater., 51, p.4379(2003).
3. T. Schmidt, F. Gärtner, H. Assadi, H. Kreye, Acta Mater., 54, p. 729(2006).
4. H.J. Kim, C.-H. Lee, S.Y. Hwang, Materials Science and Engineering A, 391, p 243(2005).