Sealing up the holes by gas dynamic spraying

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High density and low porosity of gas dynamic sprayed coatings may provide gases and liquids impermeability. But jet deflection and stagnation in the narrow splits and reach-through holes prevent from sealing up the deep substrate defects by gas dynamic spray. The correct choice of powder blend makes the gas dynamic spray process applicable to the splits and holes sealing up. The approaches to the defects sealing up by gas dynamic spray and some applications are presented and discussed.

Introduction

Gas Dynamic Spraying (GDS) process is characterized by high velocity jet of solid particles. The jet may be stagnated or deflected in the narrow splits or holes and particles loose the velocity necessary for bonding. The substrate defects like narrow split or pin hole will remain uncoated by GDS process. In contrast to welding or low velocity liquid metal spraying by some thermal spray processes with liquid surface tension capable to seal the hole, GDS process may be applied to only relatively smooth substrate.

The restoration processes often requires the coating deposition to the surfaces with defects. To achieve uniform GDS coating in this case one needs to cut off defects and create smoothed substrate profile. It may be the solution for the case of small defects, but it does not work with the through defects.

The only possible way to seal the through defect in the metal part is to fill it by glue or by liquid metal by welding. The first approach is not applicable to the parts subjected to the high operating temperature, and the second one is not applicable to the heat-strengthened metals or to the very thin metal parts.

The advantage of the GDS process to build up metal with relatively small substrate heating seems can't be applied to eliminate the deep narrow defects at the substrate. The scope of this paper is to describe possible approaches to the sealing up the splits and holes in the metal parts by GDS process and to demonstrate their realization by DYMET technology [1].

GDS coatings gas permeability

One of the GDS process advantages is low coating porosity. This is due to the high value of deposited particle deformation at the impact. The high density of the coating leads to its low gas permeability.

Presented in Fig. 1 are the results of gassing in vacuum measurements, fulfilled at the Vacuum Systems Laboratory of the Joint Institute of Nuclear Research (Dubna, Russia). The columns present values of gassing G for uncoated flat mild steel sample and the same sample coated by copper and by aluminum both as sprayed and polished respectively. The aluminum and copper coatings may substantially reduce the gassing in vacuum from the flat mild steel surface. Polished coatings demonstrate an order of magnitude decrease of the initial value.

The coating gas impermeability looks promising for hermetic sealing of leakages in metal parts. With the nozzle axis positioned perpendicularly to the surface the dense and hermetic coating may be effectively deposited. However for any defect at the flat substrate the defect internal walls are always positioned at the angle to the substrate surface. The nozzle axis will be directed on-the-miter to the defect walls in this case.

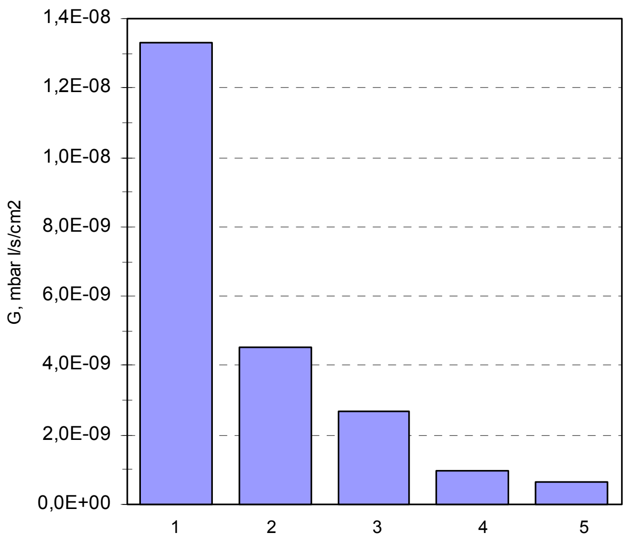

Figure 1: Gassing in vacuum from the surface of mild steel sample, mbar·liter/s/cm^2 (1 - uncoated, 2 - coated by copper, 3- coated by aluminum, 4 - coated by copper and polished, 5 - coated by aluminum and polished).

On-the-miter spraying

On-the-miter spraying is always less effective then normal spraying. It is obviously connected with the reduced normal particle velocity and the enlarged tangential rebound force.

The deposition efficiency dependency on the angle to the surface is rather strong. The sample of dependency, taken from [2], is presented in Fig. 2.

The deposition process drops drastically with the angle decrease and ceases completely below some jet defined angle.

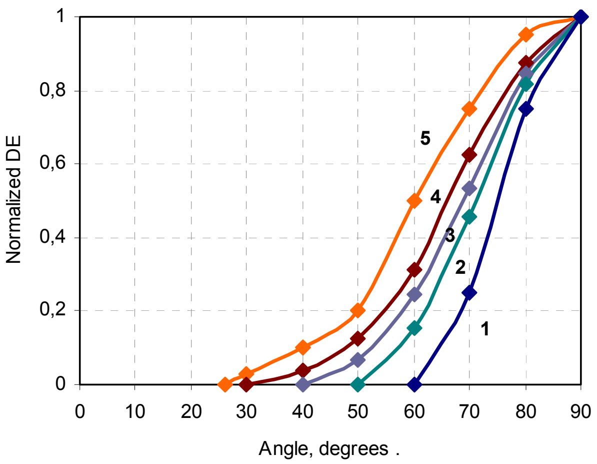

Figure 2: The normalized copper deposition efficiency dependency on the jet to the substrate surface angle at different air stagnation temperatures (1 – 500 °K, 2 – 600 °K, 3 – 700 °K, 4 – 800 °K, 5 – 900 °K).

Gas dynamic spraying to the surface region with a split or a hole always keeps unfilled volume over the through defect. The defect walls will rise up to the limiting angle and coating never fills the reach-through defect (Fig. 3 and Fig. 4).

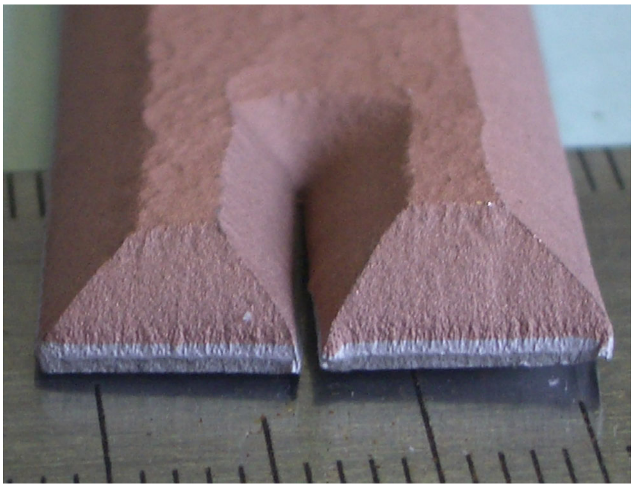

Figure 3: Copper coating at the aluminum substrate with the reach-through split. Coating forms canyon at the split.

The limiting angles of 30 – 40 degrees are observed at both figures. The angle value will remain constant with the coating thickness growth.

The stagnation of the jet inside the narrow splits and pin holes always causes the formation of the defect in the coating. The rise of coating thickness leads to the defect size increase. The gas dynamic spraying process enlarges the defects instead of sealing them up.

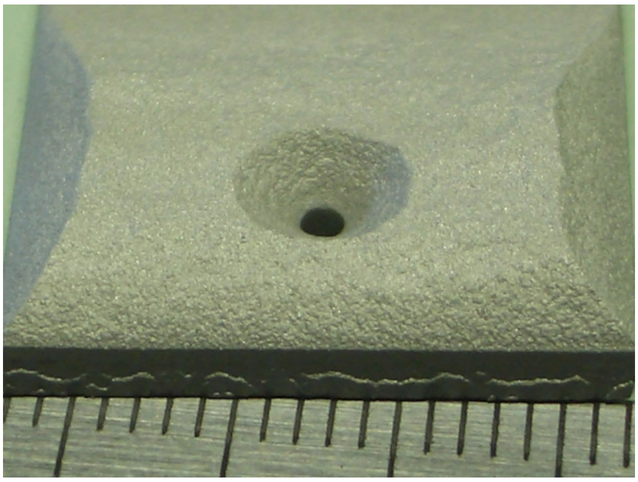

Figure 4: Aluminum coating at the steel substrate with the hole. Coating forms crater at the hole.

Micro-leakages sealing

Due to the particles for gas dynamic spraying process are in the size range of 5 – 50 micrometers, there is the probability of large particle to be driven into the pin hole or narrow slit. This may be useful for the hermetic sealing of microscopic leakages at welding lines.

The sample of spraying to the contact line of two clenched pieces of steel is presented in Fig. 5. Some points of narrow split are coated but some are not.

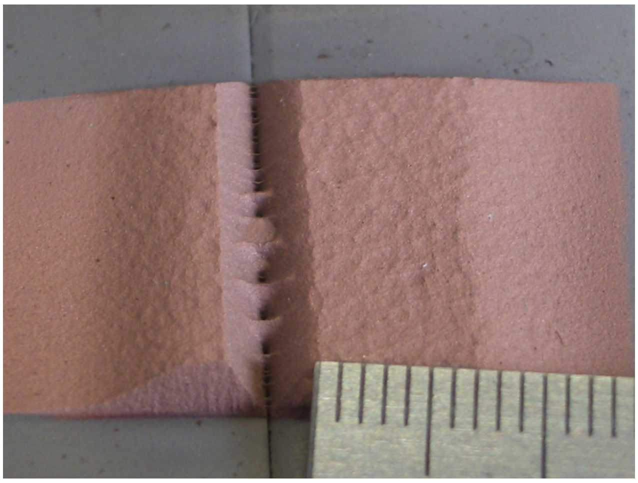

Figure 5: The sample of copper spraying to the contact line of steel plates. Narrow split is partially overlapped by the coating.

The particle driving in depends on the defects profile and powder size distribution. This approach obviously can't satisfy most of the practical applications because of large powder losses and unpredictable result. Anyway this approach is applied in special cases to protection against the microscopic leakages at welding lines by gas dynamic spraying of aluminum coatings [3].

Sealing up small holes

The holes and splits of the size of 0.1 mm and larger can't be sealed by driving in particles because of the powder spectrum limitation. So, to close the hole with coating crater rising one needs to deposit the coating to the hole or crater walls. It would become possible if the particle trajectories to be close to the perpendicular to the wall surface.

While rejecting from the crater inside, the jet turns, and some particles may impact close to the normal to the walls surface. If the velocity of those particles will be high enough to create efficient bonding the crater will become overlapped. Only soft fusible metals may be deposited at low velocities. The most convenient metal for low velocity deposition in practical applications is zinc.

Zinc particles of the size of 8 – 10 micrometers easily stick to the surface at relatively low velocities and may be deposited to the crater walls. To improve the coating bonding other material particles have to be added to the jet. Zinc particles fix at the wall first. Then other material particles deposit at the zinc created impurities and form dense layer. The sample of zinc, copper and alumina powder blend deposition to the almost vertical cavity wall is presented in Fig. 6. The zinc oversaturated layer and the alterations of the jet trajectory may be observed.

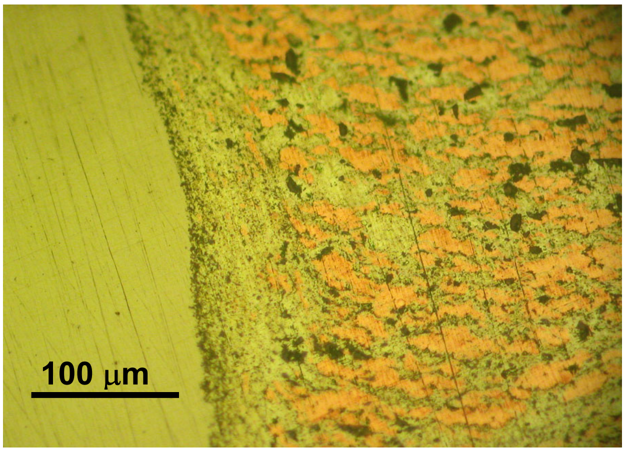

Figure 6: The cross-section of coating deposited to almost vertical wall of cavity in steel piece by spraying zinc, copper and alumina powder blend.

The zinc oversaturated layer thickness depends on the jet to substrate angle. It decreases with the deposition angle increase and almost disappears at normal spraying (Fig. 7).

So the spraying of zinc containing powder blend to the split or hole may cause the coating deposition at the defect walls. The internal coating cone forms inside the crater and the defect overlaps at some level. The view of the overlapped hole is presented in Fig. 8.

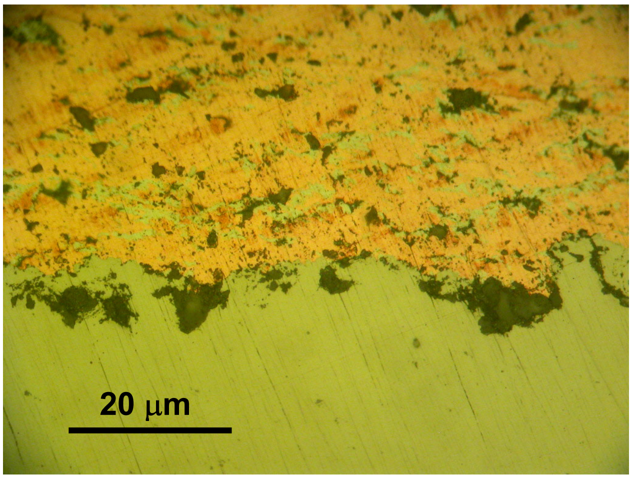

Figure 7: The cross-section of coating deposited at the normal to surface jet direction. Zinc, copper and alumina powders blend sprayed to steel.

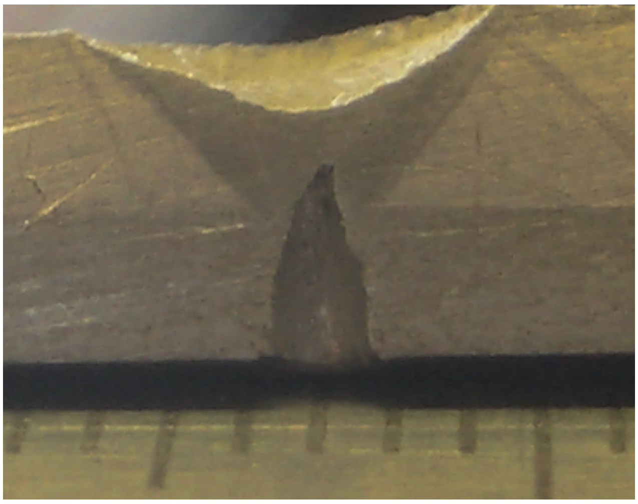

Figure 8: The cross-section of the aluminum coating at the steel substrate with the hole from Fig.4 with the crater sealed up by zinc – aluminum – alumina powder blend. The initial holes shape was cylinder.

This process of crater overlapping may be applied for the sealing up small holes, not more than 1- 2 mm in size.

Sealing up large holes

In the case of large holes one may apply the approach mentioned above, but it is necessary to fill the entire hole by any metal plug to reduce the holes dimension. The large hole changes into the narrow slit then.

In many cases it does not matter what is the material of the plug. The plug should be the substrate for coating deposition. The example of sealing up the 8 mm hole in aluminum plate with copper plug is presented in Fig. 9.

The use of proper plug and proper powder with portable spraying equipment allow quick and easy elimination of a defect. The entire procedure of elimination of unneeded hole in the aluminum case, presented in Fig. 10, takes few minutes and few grams of powder.

In some cases, like deep vacuum systems, the restriction to zinc presence at the object surface may arise. Two stages defect elimination should be used to satisfy this requirement. The defect has to be eliminated by the zinc containing powder and machined first. The coating of appropriate content may be sprayed over the already smoothed surface then.

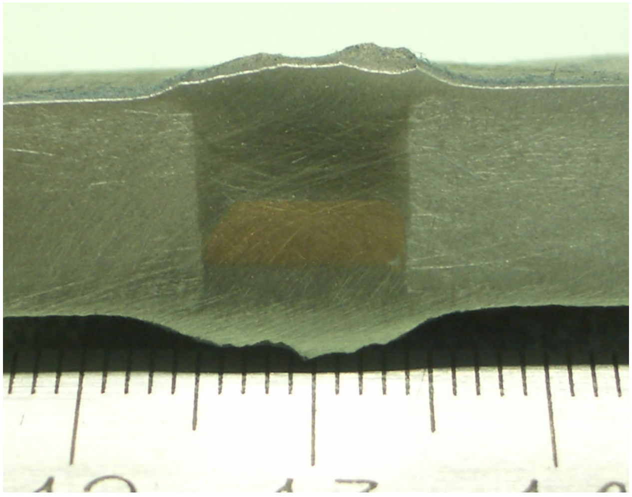

Figure 9: The cross-section of 8 mm hole with the copper plug in the aluminum alloy plate sealed up by zinc–aluminum–alumina blend.

Figure 10: The steps of the holes elimination.

Applications

Certainly process of holes sealing is not applicable to the mass production needs. It is mainly applied to the restoration problems. And it is of great demand in service and restoration of various expensive pneumatic, hydraulic, cooling and vacuum systems.
Typical problem difficult to solve by welding is the restoration of the thin walls cooling system. The use of GDS proves to be one of the best solutions in this case. Shown in Fig. 11 leakage elimination is often applied at car service shops.

Because of a coating may be applied to various substrates it does not matter what materials contact line have to be sealed. Hermetic joint of unweldable materials may be created by GDS (Fig. 12).

Figure 11: The leakage sealing at the thin wall aluminum tube of cooling system.

Casting defects, reach-through holes, revealed only at the final complex machining of a very expensive parts may become “headache” in small series production. In many cases the use of GDS can eliminate this problem.

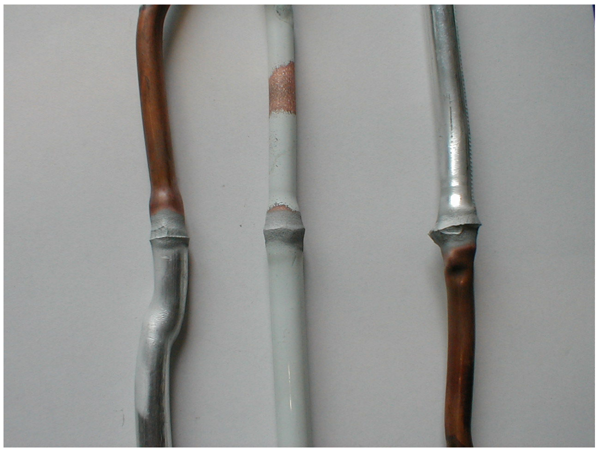

Figure 12: The hermetic joint of aluminum and copper tubes.

In some cases the same solution may be applied even to the moulds restoration. The mould cracks elimination may be realized by GDS of nickel based powder. The restored mould, presented in Fig. 13, endured few thousands extra castings.

The most exotic application of the defect sealing by GDS took place at the Scientific Center “Kurchatov Institute” (Moscow, Russia). The vacuum leakage in the cyclotron copper wall occurred as the result of metal burnout under the arc exposure.

Figure 13: The mould lifetime prolongation by the mould cracks elimination.

High heat sink to the large few tones weight copper element has prevented to the leakage welding. The cyclotron part was successfully sealed and recovered by gas dynamic spraying.

Conclusion

Because of the jet deflection and stagnation in the narrow splits and reach-through holes, the sealing up such defects by gas dynamic spraying may become hard to manage problem.

The use of zinc containing powder blends allows to fill substrate defects and to seal up splits and holes in metal objects by gas dynamic spray.

The possibility of the sealing up the leakages broadens out the applications of portable equipment for gas dynamic spraying in the restoration processes.

References

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