# Substrate properties influence on the coating deposition by DYMET technology

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The heating of the substrate by the jet may influence on the process of coating deposition by DYMET technology. It can be observed as deposition efficiency variation at various nozzle transverse speeds. Experimental investigation of the deposition efficiency variation for different jet stagnation temperatures and different substrate thermal properties is presented and discussed. The suppression of substrate influence on the deposition process with the coating thickness growth is demonstrated.

## Introduction

The Gas Dynamic Spray (GDS) or Cold Spray (CS) process was intensively investigated last decade. The careful investigation allowed describing the details of the process of particle to substrate impact. The CS process was assumed and proved to be adiabatic [1].

At lower velocities and particle temperatures, inherent to DYMET technology [2], often called as low pressure CS, the process may become non-adiabatic.

The substrate influence to the coating deposition for low velocity processes was qualitatively described for copper and aluminum particles deposition to steel and aluminum substrates [3]. For the non-adiabatic process the heat sink to the substrate affects the coating deposition process.

The substrate heating influence on the coating deposition for CS process by air jet was described by Alkhimov et al. [4]. The rise of deposition efficiency was observed for aluminum coating at heated steel.

Recently J. G. Legoux et al. [5] investigated substrate temperature influence on the deposition of pure powders at low pressures. Both heating of the substrate by the jet and the influence of this heating to the deposition process was observed.

M. Fukumoto et al. [6] described the increase of single copper particles deposition efficiency to the preheated substrate.

Technological process of coating formation is always realized with the nozzle transverse motion along the substrate. The displacement of the heated jet determines non-stationary heating at the spraying spot. The influence of this process to the coating deposition was investigated.

The heat release and heat sink at the particle – substrate interface for non-adiabatic process may be influenced by both particle and substrate thermal properties. The influence of the substrate on the deposition process at low jet temperatures was observed up to 60 micrometers of coating thickness.

## Experimental

### Equipment

Experiments were performed with commercial portable DYMET equipment [7] with standard supersonic nozzle of 5 mm exit diameter with 130 mm diverging part length. Compressed air at 0.5 MPa was used as accelerating gas. The air consumption, determined by the nozzle critical section and stagnation air pressure and temperature, was about 6 g/s.

### Powder

Commercial powder K-20-01 (OCPS, Russia), composed of aluminum atomized powder and alumina powder with median particle sizes of 30 μm and 20 μm respectively, was sprayed.

### Substrate

Mild steel, aluminum alloy and glass plates were used as substrates. The plates dimension was 25 mm x 50 mm x 1.5 mm. The initial substrate temperature was 20°C.

### Spraying procedure

GDS gun was fixed at the X-Y robot. Only one direction motion was used at single lines experiments, and nozzle scanning was used at the multilayer experiments. Nozzle to substrate distance was always kept at 10 mm, except of the case specially mentioned. Non-stationary substrate temperature was not measured.

The DYMET produced coating density is uniform across the coating thickness because of specific “hummer” effect of ceramic particles. The typical coating structure is presented in Fig. 1 and may be found elsewhere [2, 8].

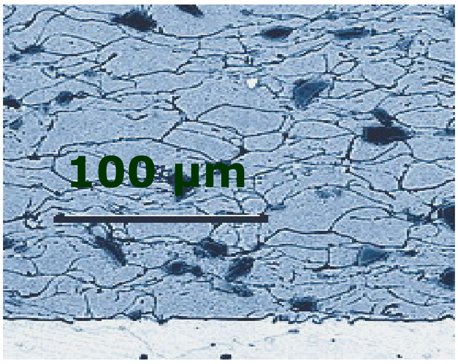

**Figure 1:** The typical coating structure of DYMET sprayed aluminum – alumina blend.

## Results and Discussion

The substrate heating by the jet depends on the jet temperature and process duration. It must be different for different nozzle transverse velocities. Because of heat sink to substrate it must also differ for substrates with different thermal properties.

Single lines experiments include coating spraying at different transverse velocities. The different stagnation temperatures produce different jet velocities along with different substrate heating by an air jet.

Obviously single line coating mass *m* equals to powder feed rate $m_t$ multiplied by powder deposition efficiency DE and by spraying time, which in turn equals sample length *L* divided by transverse velocity *U*.

$$m = m_t \; DE \; \frac{L}{U}$$

So one may suppose that the coating mass dependency on the inverse transverse velocity to be linear.

The results of the coating mass measurements for the different air stagnation temperatures are presented in Fig. 2 as a function of inverse transverse speed. The substrate is mild steel.

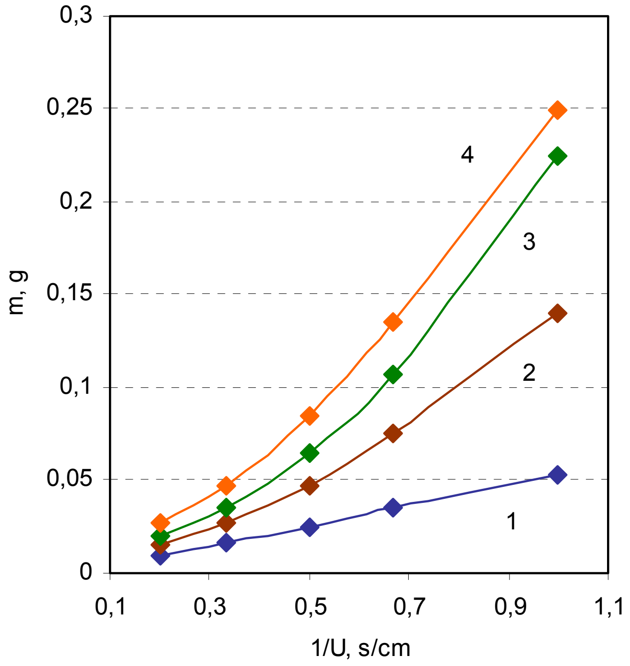

**Figure 2:** Coating mass as a function of inverse transverse speed at the jet stagnation temperatures 225 (1), 325 (2), 425 (3) and 525°C (4).

Only at stagnation temperature of 225° C the dependency is close to the linear one. At stagnation temperatures of 325, 425 and 525° C the dependencies are not linear.

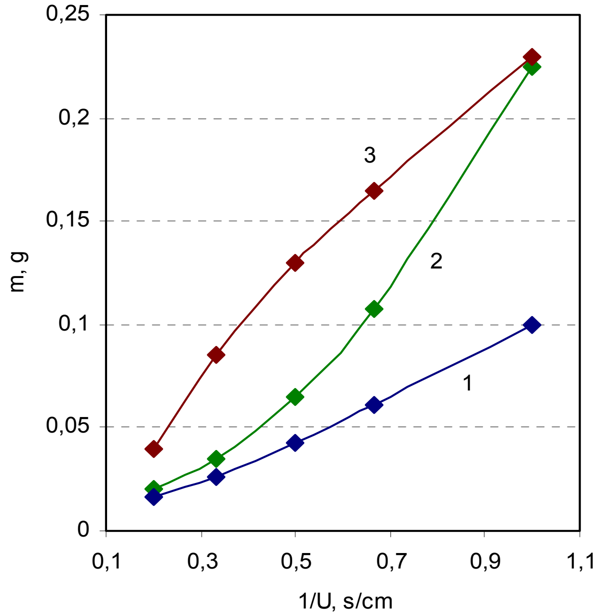

**Figure 3:** Coating mass as a function of inverse transverse speed for different substrates (aluminum alloy – 1, mild steel – 2, glass – 3) at air stagnation temperature 425°C.

Fig. 3 presents the coating mass deposition to different substrates at the same jet stagnation temperature 425°C. Thermal diffusivity of substrates used were $4.2\cdot10^{-5}$ $m^2/s$ for the aluminum alloy, $2.1\cdot10^{-5}$ $m^2/s$ for the mild steel and about $8.4\cdot10^{-7}$ $m^2/s$ for the glass. The coating mass dependency on the inverse transverse speed is close to the linear one only for the case of aluminum alloy substrate. It is not linear for the cases of mild steel and glass substrates.

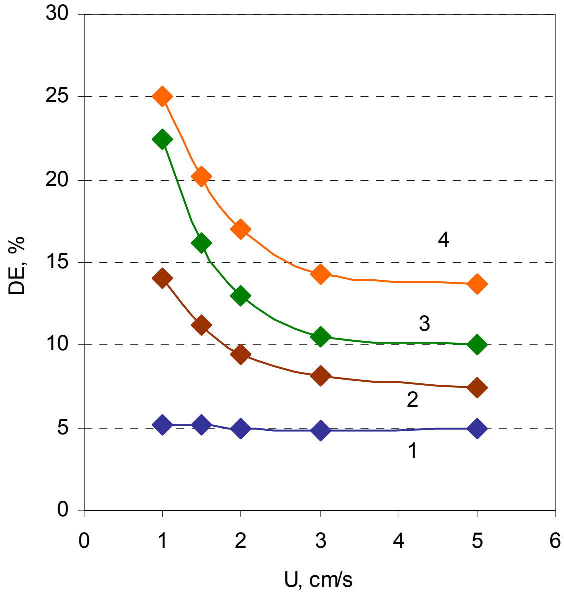

**Figure 4:** Coating DE as a function of transverse speed for air stagnation temperatures 225 (1), 325 (2), 425 (3) and 525°C (4).

As both powder feed rate $m_t$ and sample length $L$ are kept constant it is only the deposition efficiency to be responsible for the deviation from the linearity. Calculating the DE from experimental data one may observe DE dependency on the transverse velocity. It is presented in Fig. 4 for the case of different jet stagnation temperatures. The DE rise with the transverse velocity $U$ decrease is obviously connected with the substrate heating by the jet.

For the jet stagnation temperature 525°C DE differs almost twice in the transverse velocity range concerned. The decrease of the jet temperature is followed by the decrease of the substrate temperature at the spraying spot. It causes the weakened non-stationary heating influence on the DE. The influence becomes negligible at the jet stagnation temperature of 225°C in this case.

Because of substrate temperature is determined by both the heat input and the heat sink, the more the heat diffusivity of the substrate the higher the heat input required to observe the effect. The DE dependencies, presented in Fig. 5, demonstrate the great influence of heat sink to the deposition process.

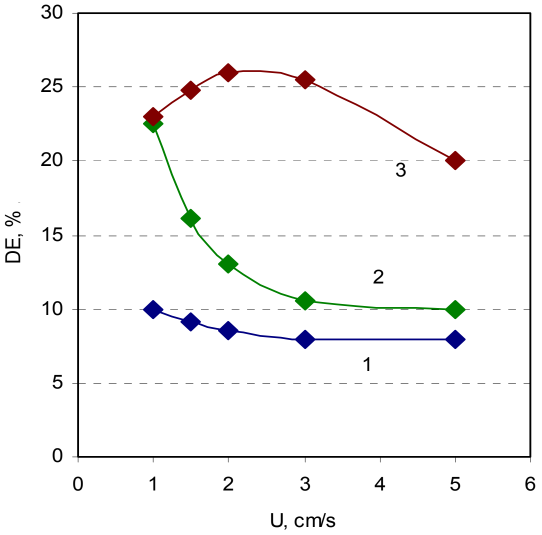

**Figure 5:** Coating DE as a function of transverse speed for different substrates (aluminum alloy – 1, steel – 2, glass – 3) at air stagnation temperature of 425 °C.

Two extreme situations of heat sink are observed in Fig. 5. High heat diffusivity of aluminum alloy prevents the rise of the surface temperature at the spraying spot during the process time interval. It causes the weakening of the DE dependency on the transverse speed.

Low heat sink to the glass substrate changes the main heat sink trajectory from the substrate surface to the already deposited coating line. The total heat sink is rather low because of small coating line thickness, but the rise of coating line thickness increases the value of the heat sink from the spraying spot.

The increase of the heat losses with the coating thickness increase leads to the weak DE dependency on the transverse speed along with the total DE increase at the glass surface.

The substrate influence weakening with the coating thickness increase may be observed in Fig. 6. The increase of feed rate from 0.2 g/s to 0.6 g/s at the same circumstances for the same steel substrate will produce thicker coating, but, because of the increase of the heat think to the thicker aluminum coating, respective DE values turned out to become less.

The thinner is the aluminum coating line the less is its contribution into the total heat sink with respect to that of to the steel substrate. The decrease of coating line thickness with transverse speed increase leads to aligning of DE values at different powder feed rates.

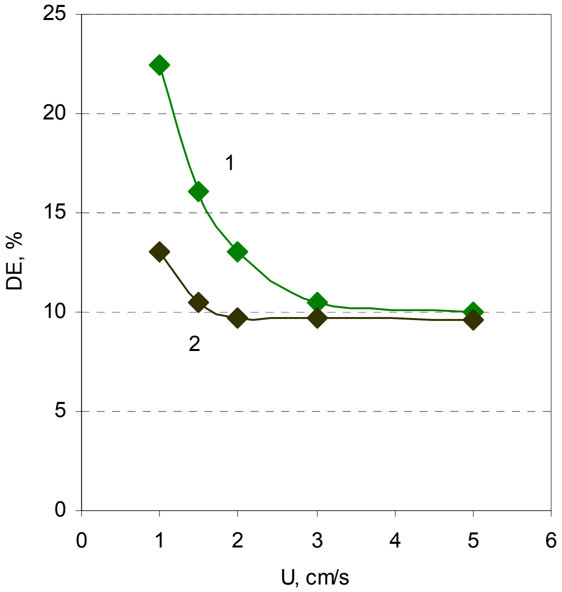

**Figure 6:** Coating DE as a function of transverse speed for different powder feed rates 0.2 g/s (1) and 0.6 g/s (2).

The heat sink to the coating with the coating thickness increase may become dominant and hide the substrate influence on the deposition process. It means that at some coating thickness the substrate properties will become "forgotten". Multilayer coatings experiments were performed to reveal the flat coating thickness influence on the coating deposition process.

Nozzle scans with transverse velocity of 5 cm/s and about 1 mm displacement were used to spray aluminum coating to the mild steel substrate. To reduce the influence of the total sample heat capacity the jet stagnation temperature of 325°C was used. The initial sample temperature for each successive coating layer was kept at 20°C. Powder feed rate of 0.4 g/s was maintained. The results of the coating thickness measurements at successive passes are presented in Fig. 7.

The coating thickness dependency on the passes number is linear, but shifted at the Y-scale. It indicates to the almost equal terms for deposition at the coating thicknesses above 200 µm. The same time the first coating layer was deposited with the higher efficiency. So, it makes it clear that the heat sink to the aluminum coating exceeds that of to the steel substrate at the coating thickness above 200 µm at least.

To reveal the sequential change of deposition conditions with coating thickness increase another multilayer experiment with thinner coating layers was performed. The results of this experiment are presented in Fig. 8.

To reduce each layer thickness the transverse velocity was increased to 10 cm/s and powder feed rate reduced to 0.1 g/s. The nozzle to substrate distance was also changed to 30 mm.

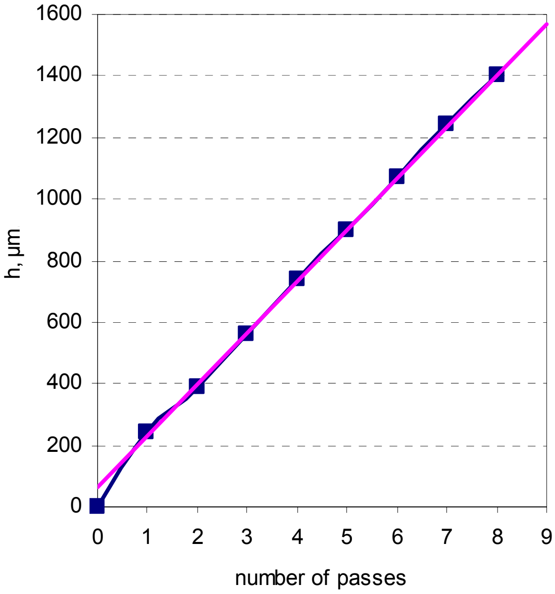

**Figure 7:** Coating thickness as a function of a number of passes for aluminum deposition.

The thicknesses of the first five layers in Fig. 8 are monotonically decreasing. The coating hides the substrate completely only above 60 µm thickness. It clearly demonstrates that the deposition of thin coatings may be more efficient then that of the thick ones.

The higher heat diffusivity of the coating with respect to that of the substrate leads to DE decrease with the coating thickness increase. One may expect another rate of substrate hiding for the coating and substrate materials with another thermal diffusivity ratio.

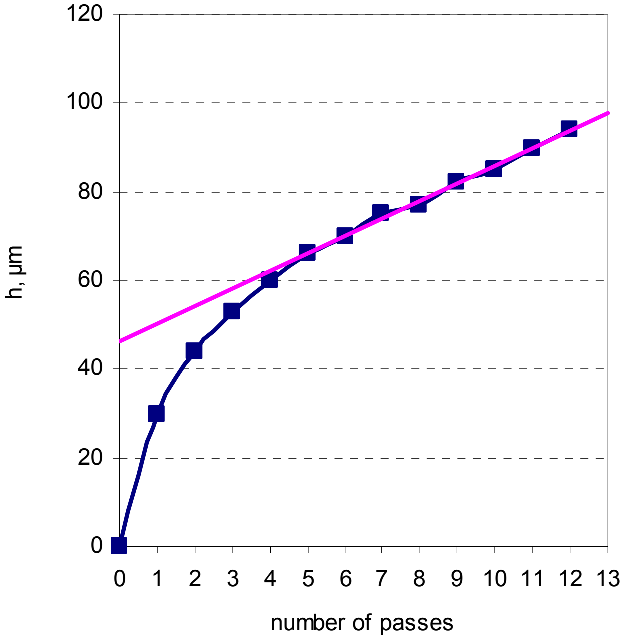

**Figure 8:** Coating thickness as a function of a number of passes for aluminum deposition at reduced deposition rate.

The multilayer experiment with the zinc coating at the mild steel was performed. Nozzle scans with transverse velocity of 5 cm/s and about 1 mm displacement were used to spray zinc coating at stagnation temperature 325°C with powder feed rate 0.4 g/s. Commercial powder K-00-11, composed of zinc and alumina powders, was used. Zinc coating thickness at successive passes is presented in Fig. 9.

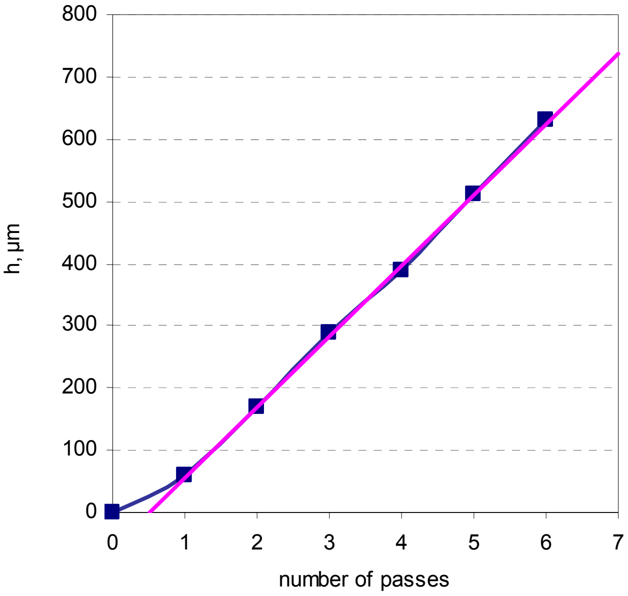

**Figure 9:** Coating thickness as a function of a number of passes for zinc coating deposition.

One may observe that the linear thickness dependency on the passes number is shifted at Y-scale to the opposite direction with respect to that of in Fig. 7. Reduced thickness of the first coating layer indicates that the heat sink to the coating is less then that of to the substrate. Lowered heat diffusivity of the zinc coating may be determined by the particle boundaries structure, the extent of particle deformation and other coating intrinsic properties. Anyway, the result shows that substrate influence may both increase and decrease the DE, depending on the substrate and coating properties.

## Conclusion

The efficiency of gas dynamic spraying may be influenced by the substrate heating by the jet. This influence is efficient for the low pressure spraying process.

The deposition efficiency may differ for the different thickness coatings of the same material under the influence of substrate thermal properties.

The substrate influence may both increase and decrease the deposition efficiency of thin coating with respect to that of the thick coating.

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