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# Preparation of aluminum coating on Lexan by cold spray

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ABSTRACT

Metallization of polycarbonate is challenging by the conventional polymer metallization technologies. For the first time, this study explored an industrially practical method to deposit dense and thick metallic coating on a polycarbonate substrate. Pure Aluminum coatings were successfully deposited onto Lexan surface using cold spray technology. The powder feeding rate was examined to be a critical processing parameter for forming continuous coating on Lexan, in addition to generally studied spray temperature and pressure. The deposition behavior of Aluminum on the polycarbonate, especially the effect of powder feeding rate, was discussed. The results demonstrate that cold spray is a promisingly economical and practical metallization method for polycarbonate.



## 1. Introduction

Due to its excellent resistance to impact, abrasion, weathering and chemicals as well as the favorable physical properties like high tensile strength and low density, polycarbonate (Lexan) has been one of the most important thermoplastic polymers widely utilized in various fields, including construction, optical, medical, electronic, nuclear, and aerospace [1]. To further broaden the applications, metallization of Lexan surface could introduce electrical conductivity, improve the erosion resistance and enhance the operation temperature. However, because Lexan is much stable against surface modification, there is only one report of the Lexan metallization found by literature survey in contrast to tremendous publications on tailoring its chemical microstructure. Kumar successfully deposited copper onto Lexan substrate using PVD where delicate pretreatment and accurate processing controls were required to achieve good adhesion [2]. Apparently, the method was not industrially practical because of the unfavorable equipment costs, part size limitation, and processing complexity [3].

Cold spray (CS) is a novel coating process where metallic particles are accelerated by a supersonic gas flow towards a substrate and the deposition is build up due to the plastic deformation of the particles at the impact [4]. Compared with conventional coating techniques, CS is a near net shape process with very minimum part size or geometry limitation and it brings up less heat affects and denser coating with good adhesion. Extensive studies of CS have been conducted on the preparing of metallic coatings on metal and alloy substrates, meanwhile increasing interests in metallization of polymers by CS are emerging recently. Various polymeric substrates, as PEEK, PVC, CFRP and PP, have been experimented and it has evidenced that the CS is an appropriate and environment-friendly polymer metallization method due to the high efficiency, low energy consumption, and good coating quality [5].

With the aim to broaden the application of Lexan by enhancing its functionalities, this paper demonstrated the first successful trial of an industrially feasible metallization method using cold spray technology. Based on the comprehensive lab studies, a critical processing parameter, powder feeding rate, was examined here. The deposition characteristics and the microstructure of the resultant coating were analyzed, and the metallization mechanism of Lexan by cold spray was discussed.

## 2. Materials and methods

Commonly used 4.5 mm thick Lexan 9043 sheet, manufactured by Sabic Innovative Plastic was selected as the substrate. Pure aluminum feedstock SST-A5001 (Centerline (Windsor) Ltd., Canada) was sprayed onto isopropanol cleaned Lexan by SST-Series P Cold Spray system (Centerline (Windsor) Ltd., Canada) with UltiLife™ modular nozzle. Nitrogen was used as the propellant gas. Fig. 1 shows the powder morphology and the CS system. SST-A5001powder is in irregular shape with the particle size in the range of 10–50 μm. The compact, portable, economical SST-Series P system is a downstream injection system where powder is injected into the nozzle tube through downstream of the throat. The major benefits of this design include the ability to minimize the guns for greater accessibility and maneuverability, the easiness to manufacture practical, low cost, durable engineered nozzle tubes, and the feasibility to use an economical low pressure powder feeder. An

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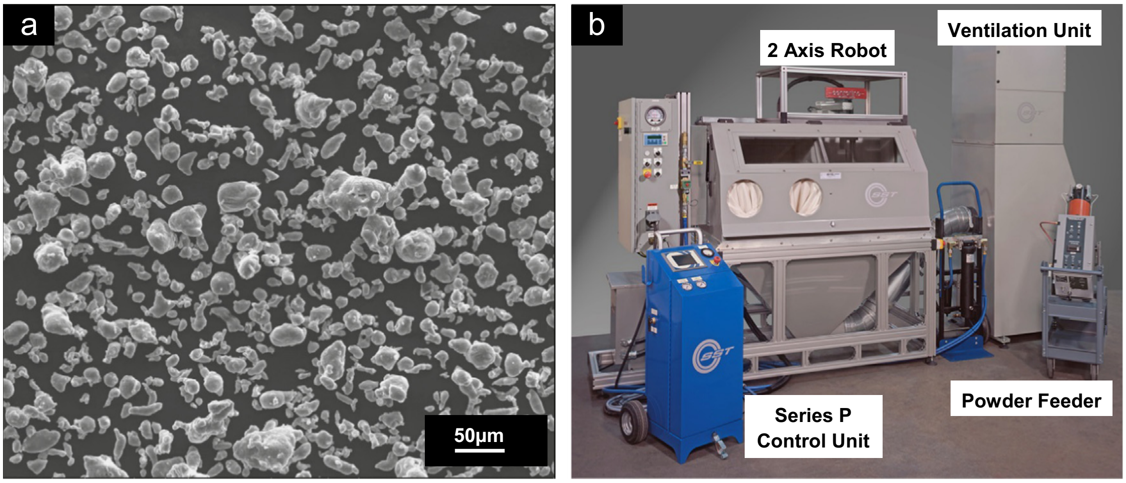


**Fig. 1.** SST-A5001 SEM morphology (a) and Supersonic Spray Technologies Series P cold spray system (b).

**Table 1**
Successful operating parameters for cold spray and powder feeding.

| Cold spray | | Powder feeding | |
|---|---|---|---|
| Pressure (MPa) | 1.24 | Carrier gas | Air |
| Temperature (K) | 413 | Flow rate (cfh) | 20–30 |
| Standoff distance (mm) | 15 | Wheel type | Standard-Slotted |
| Step-over (mm) | 1.2 | Rotation speed (rpm) | 2–16 |
| Spray area (mm × mm) | 40 × 40 | | |
| Traverse speed (mm/s) | 40 | | |
| Number of pass | 1 | | |

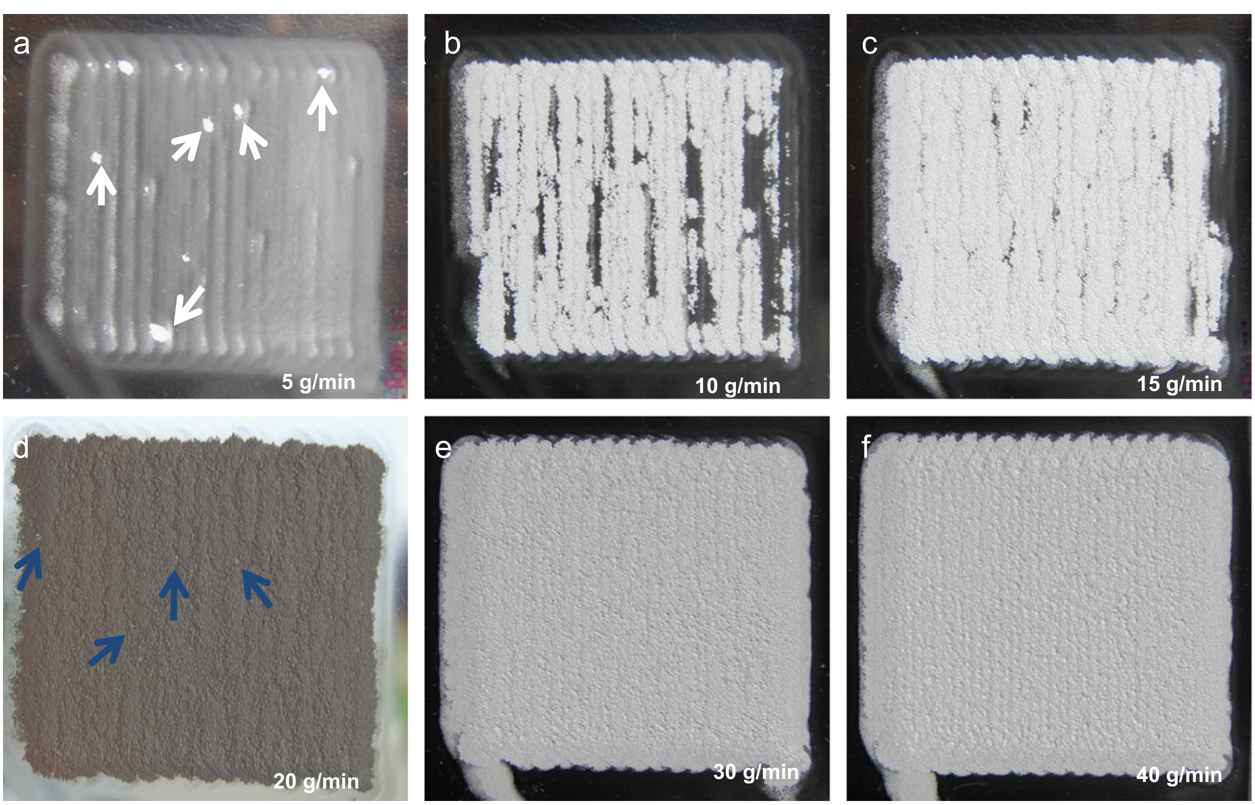


**Fig. 2.** Surface morphology of Al deposition on Lexan at different powder feeding rates. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

external low pressure powder feeder (Thermach Inc., USA) was used to feed the powder at different powder feeding rates (PFRs). The successful operating parameters were listed in Table 1. During CS, the deposition efficiency (DE) and deposition rate (DR) were recorded as the weight gain of the sample over the effective sprayed powder weight and over the effective spray time, respectively. The sprayed samples were sectioned and metallographically prepared through multiple steps of grinding and polishing. The coating microstructures were observed by FEI Quanta 200 SEM equipped with EDX.

## 3. Results and discussion

The Lexan coupons cold-sprayed at different PFRs are shown as Fig. 2. In all, with the increase of PFR, the Al deposition was getting more continuous, denser, and thicker. At PFR of 5 g/min, the sprayed area was more like sandblasted, with some isolated Al powder agglomerations formed on the surface (Fig. 2a, white arrows). When the PFR was 10 g/min, more Al particles were deposited onto Lexan, but the coating (Fig. 2b) was still discontinuous and about 18% of the surface was uncovered by image analysis via GNU Image Manipulation Program. Further increase of PFR to 15 g/min decreased the uncoated area to about 4% (Fig. 2c), and only a few narrow fissures (Fig. 2d, blue arrows), about 0.2% area, could be observed through light at PFR of 20 g/min. CS at PFR of 30 g/min (Fig. 2e) and 40 g/min (Fig. 2f) would fully cover the substrate, with about 450 μm and 550 μm thick Al coating, respectively.

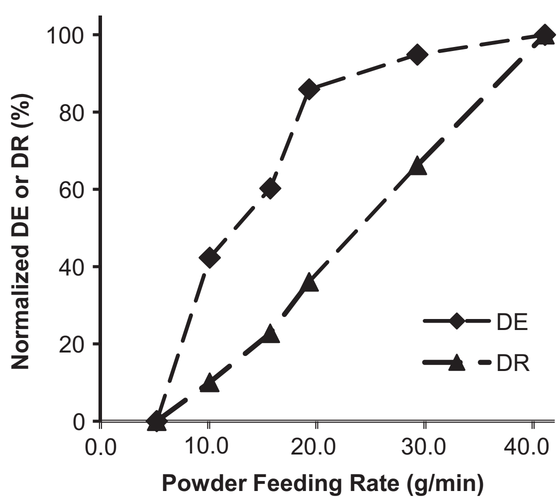


**Fig. 3.** Normalized deposition efficiency and deposition rate at different powder feeding rates.

The DE and DR measurements echoed the evolution of coating morphology at different PFRs. Fig. 3 displays the normalizing relations between DE, DR and the PFR, where DE and DR at various PFRs were normalized against those at 40 g/min PRF. The normalized DE and DR at 5 g/min PFR were 0%, indicating there was no weight increase occurred during CS. The normalized DE was improved dramatically from 0% up to 86% with the increase of PFR to 20 g/min. Further increase of PFR to 40 g/min only boosted about 14% of the normalized DE at 40 g/min. In comparison to the change of DE, DR was more linearly and steadily improved with the PFR increase.

The SEM micrographs of Lexan coated at 40 g/min PRF are presented in Fig. 4. Fig. 4a shows a typical dense and uniform cross-section of the Al powder coatings on Lexan by CS. The coating thickness was about 550 μm and no cracks or any other defect were observed. Close examination of the interface exhibits the original smooth Lexan surface became uneven and Al particles were embedded into the substrate. In the meantime, some polymeric particles were splashed from Lexan and entrapped in the adjacent Al coating, as evidenced by the EDX spectrum, where carbon and oxygen peaks were obviously detected (Fig. 4b). The deformation of the Lexan interface by Al particle impact and embedment ensured a good bonding between the coating and substrate.

The mechanisms of coating formation and bonding between metallic particles and metallic substrates have been well established [6–9]. Studies suggested that particle deposition depends on the impact velocity and only the particles with a velocity higher than a critical velocity can be deposited [7]. Bonding is generally attributed to adiabatic shear instability at the local interface caused by high-velocity impact of the supersonic metal jet. Mechanical interlocking and metallurgical bonding are two forms of the bonding mechanism [8]. However, the deposition behavior of the metal particles on polymeric substrate is poorly understood even though various combinations of powders and substrates have been investigated

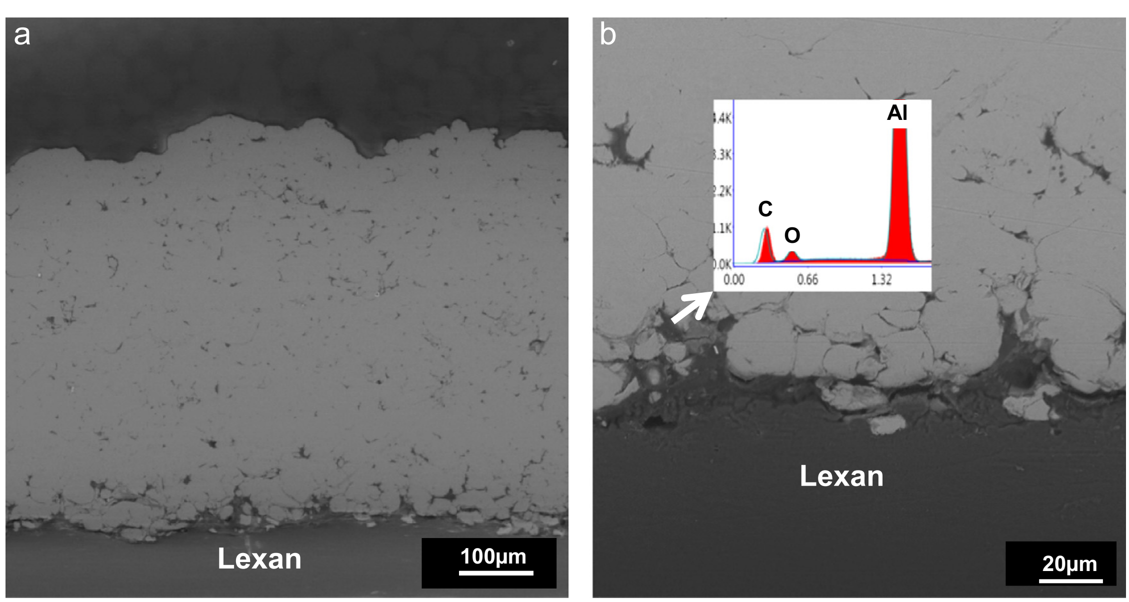


**Fig. 4.** Microstructures of the coating and interface achieved at 40 g/min powder feeding rate.

[2]. Spray temperature and pressure were generally addressed in the reports as the key processing parameters as they directly affected the softening of the polymeric substrate which resulted in surface distortion and initial powder entrapment [3,4]. King sprayed copper onto Makrolon polycarbonate at 2.5 MPa and little copper particles were entrapped at 150 °C [10]. High hardness and its proneness to brittle fracture under Cu particle stream were regarded as the major factor resulting in the shallow penetration and inability to capture particles.

For the first time, our study achieved thick dense Al coating on polycarbonate substrate and demonstrated the critical effects of powder feeding rate on Lexan metallization by CS. At given temperature and pressure, influence of the PFR or loading effect on the particle velocity was negligible in a certain range and negative-linearly related above the limit [6,11]. Therefore, the improvement of DE with PFR in Fig. 3 was not caused by the increase of particle velocity or impact energy. During CS, Lexan substrate was blasted by Al particles and some polymeric material was squeezed out, where the irregular Al particles could anchor into the fresh surface by high-velocity impaction. When the PRF was as low as 5 g/min, the weight gain by Al entrapment was similar to Lexan mass loss of erosion caused by particle impact, and there were Al particles implanted into the substrate without coating formation. Increase of PFR enhanced the density of the particle cloud impacting the substrate, which would hammer more particles into the substrate and subsequent impacting of dense particles eventually generated a uniform and continuous metallic coating (Fig. 2a–d). In this process, the high hardness and erosion resistance of Lexan helped the coating build-up by preventing further erosion of the substrate. The Lexan interface deformation by Al particle impaction and embedment ensured good bonding between the coating and substrate. Furthermore, the dense particle cloud would also entrap eroded polymeric materials in the coating adjacent to the interface (Fig. 4b).

## 4. Conclusion

Pure Aluminum coatings were prepared onto Lexan surface using cold spray technology at different powder feeding rates. The Al deposition efficiency was improved dramatically with the increase of powder feeding rate at the given spray temperature and pressure. Continuous coating could only be built up at feeding rate over 20 g/min, which would enhance the functionality of Lexan. The microstructures at the cross-section and interface of the deposition achieved at 40 g/min indicated the coating was uniform, dense, free of defects, and good adhesion was formed between Al and Lexan substrate. Increase of powder feeding rate could improve both initial and subsequent coating formation on Lexan, and the high erosion resistance of Lexan helped the coating build-up by preventing further substrate erosion. This study, for the first time, presents a promising industrially practical technique to deposit dense and thick metallic coating onto a polycarbonate substrate.

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