Analysis of Geometric Modeling of Slot Die Lips

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Tungsten Carbide, which is known for its hard metal properties, is used on slot die lips for wear resistance. Computer analysis introduces a case study of lip wear for critical process control. This study helps in understanding geometric modeling of slot die lips and helps support the necessity of wear resistant material for slot die lips. Additionally this analysis shows the resulting cases of protection against corrosive fluids.

MMC Ryotec, Mitsubishi Materials first experimented and began applying Tungsten Carbide to traditional slot dies in 1975.

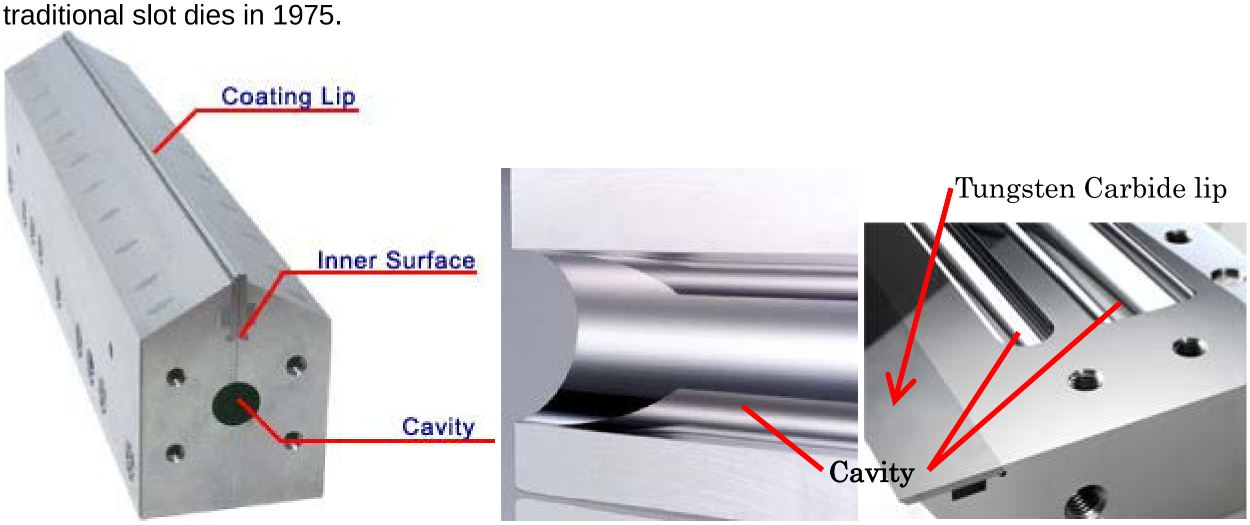


Fig. 1 Slot Die with Tungsten Carbide Lip

Tungsten Carbide for the coating lip is well known as a wear resistant and high hardness material. Therefore the shape and profile of the coating lip is maintained for an extended period of time. Generally speaking, that period of time is typically three to five times longer than the maintenance of the profile of a stainless steel lip. This benefit of wear resistance influences profile uniformity during the coating process. This paper examines tungsten carbide lip performance through computer simulation analysis and the resulting coating profiles.

Before going into the analysis and discussion it is important to highlight a key difference and point of comparison in lip corner radii between tungsten carbide and stainless steel. Figure 2 below compares the cross section of the lip edge radius of a tungsten carbide lip and the lip edge radius of a stainless steel lip both with a machine finish.

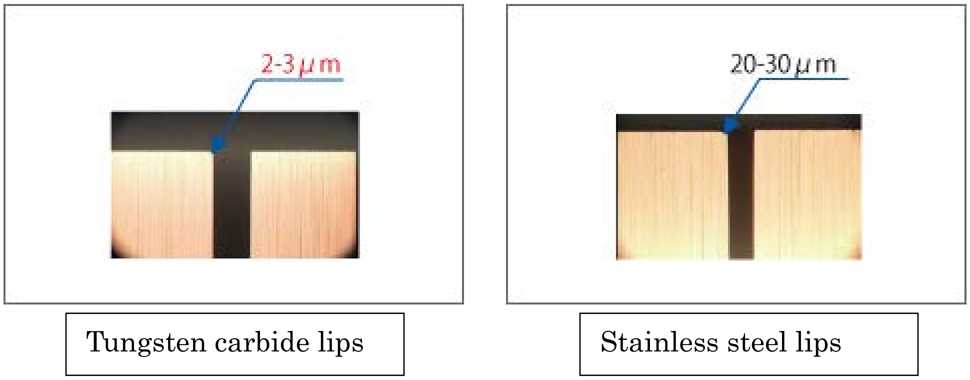


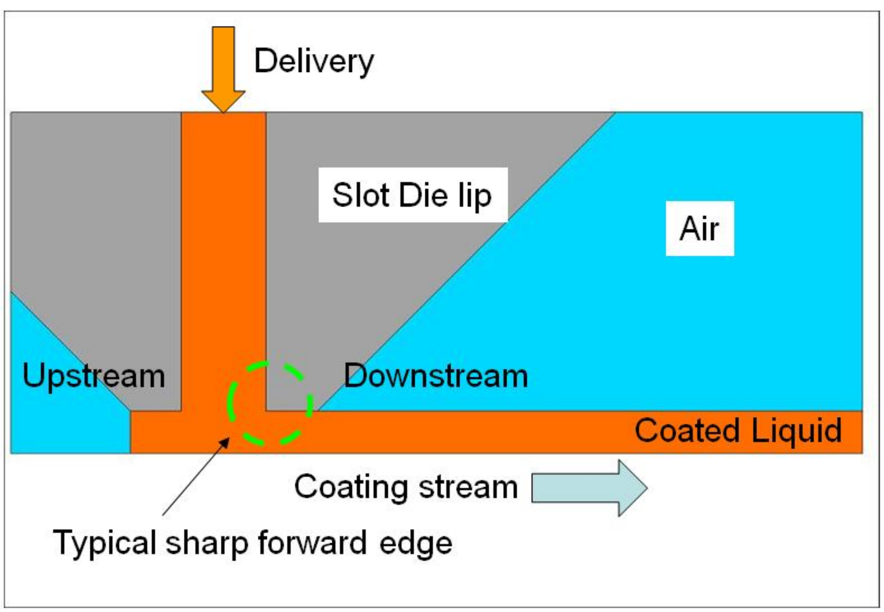
Fig. 2 – Sharpness of Slot Die lips

The tungsten carbide lip is sharper than stainless steel.
We decided to simulate both edge shapes by computer flow analysis, because coating performance is influenced by the lip edge shape.

1. Simulation

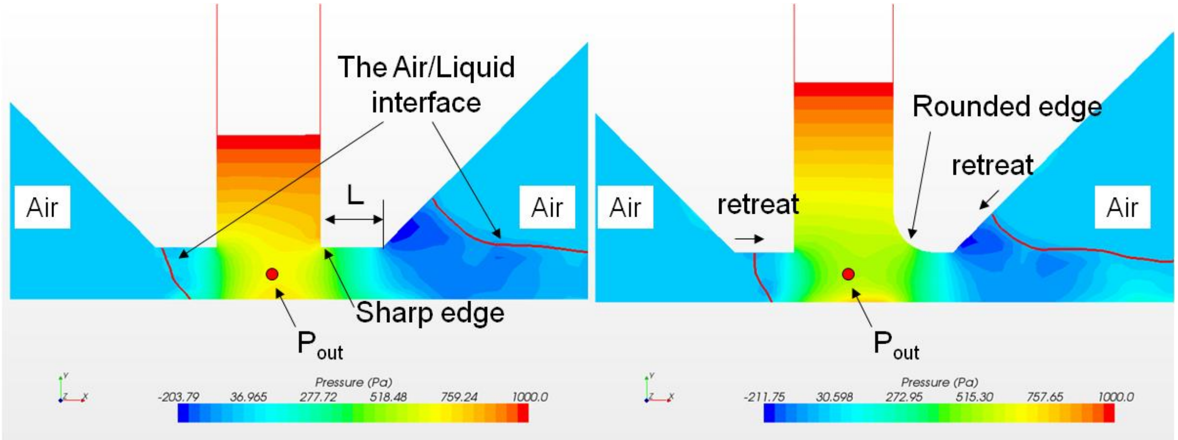
1-A. Basic Premise for Modeling

The basic premise for modeling, and the question presented is: What is the influence of the Slot Die's downstream edge?



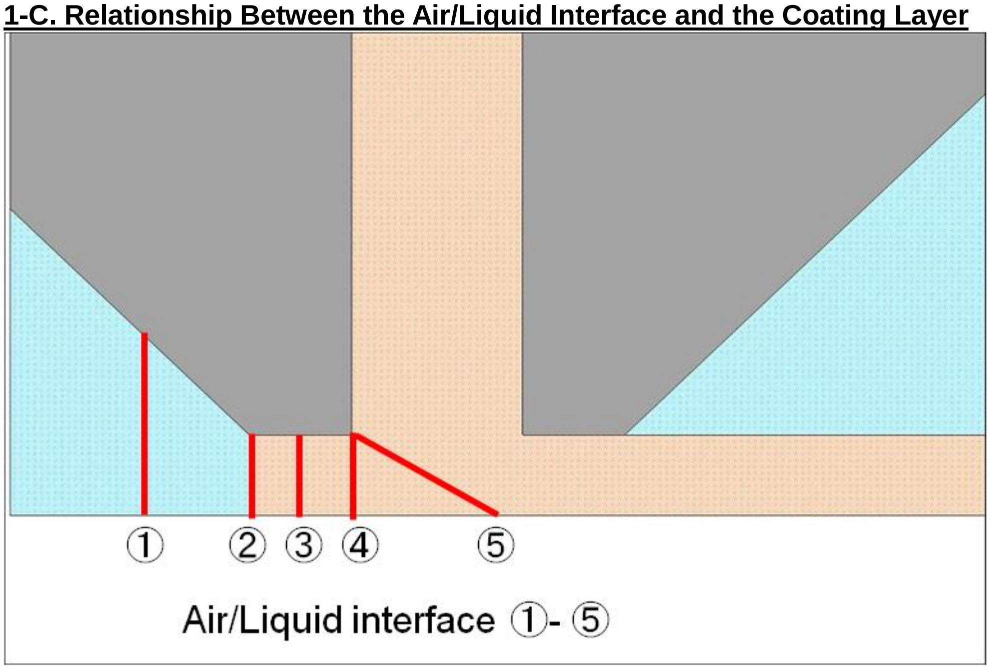
We examined the coating bead, forming part of the initial coating layer.
→ How does the forward edge of the Slot Die influence the source material flow and the subsequent bead being coated?

1-B. Pressure distribution at the Coating Bead



By analyzing the pressure distribution and the interface position between the air and the liquid we see the following.
The influence of the rounded edge resulted in:
> Decreased pressure at point P_{out}.
> The Air/Liquid interface positions retreated at both the upstream and downstream sides.
The reason: By reducing ‘L’ h the pressure at P_{out} was decreased which consequently made the pressure differential between atmosphere and P_{out} become smaller.

1-C. Relationship Between the Air/Liquid Interface and the Coating Layer



From past experiences it can be determined that coating problems are due to the position of the Air/Liquid interface. Examining the position of the coating bead, as in the figure above, the following can be assumed:

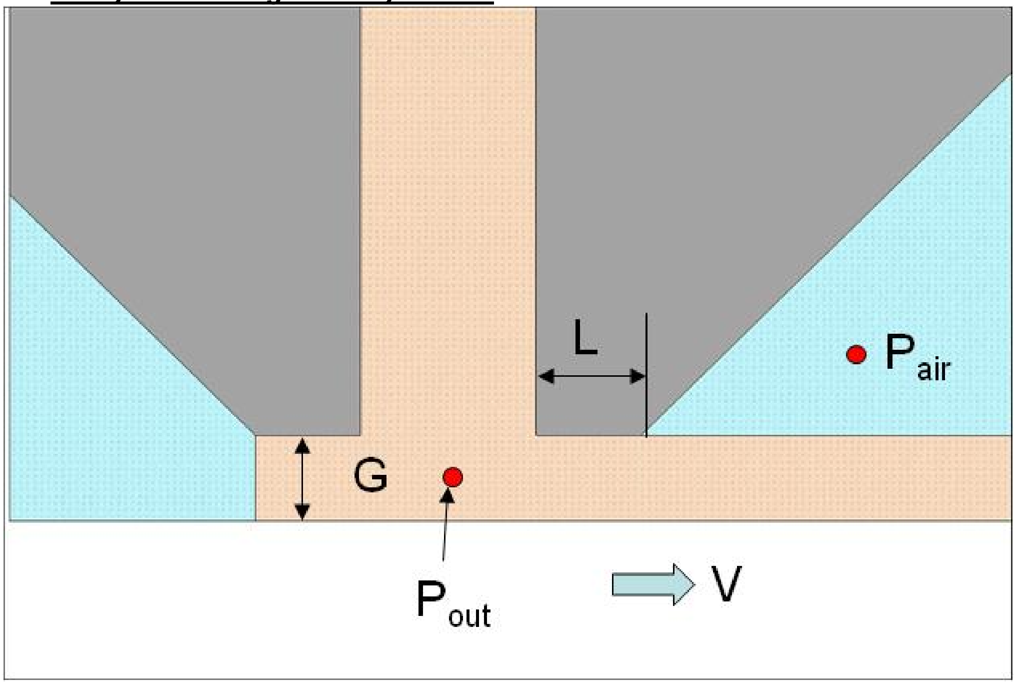
①: Higher coating height at the upstream: Thinner coating thickness.

②, ④: Coating thickness is stable.

③: Air/Liquid interface moves unstably with the vibration: The coated surface is uneven.

⑤: Various coating defects. Ribbing, air bubbles, failure of the coating layer.

2. Analysis Utilizing Flow Dynamics



Flow analysis between P_{out} and P_{air}. This region is built by two following flows.
>Shear force flow and pressure flow between two layers.
(q: flow rate, V: Coating speed, μ : viscosity)

$$q = \frac{1}{2}VG + \frac{G^3}{12\mu L}\left(P_{out} - P_{air}\right) \quad \text{.........(1)}$$

From equation (1),

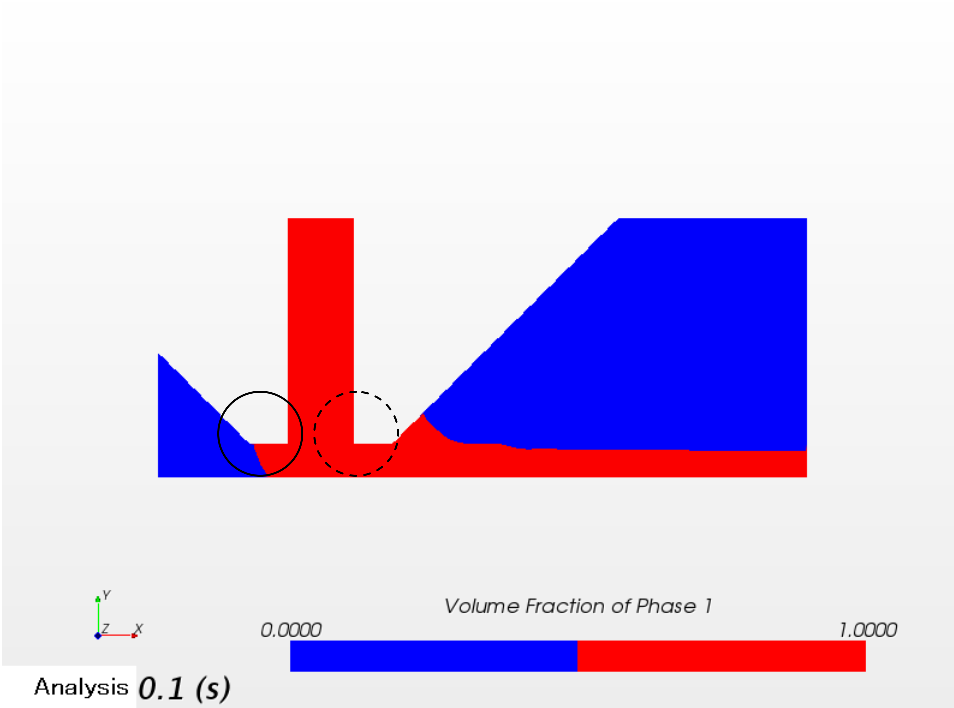
$$\left(P_{out} - P_{air}\right) = \frac{12\mu L}{G^3}\left(q - \frac{1}{2}VG\right) \quad \text{.........(2)}$$

A/L interface is positioned by P_{out}. P_{air} = 0.

$$P_{out} = \alpha\mu L \quad , \left(\alpha = \frac{12}{G^3}\left(q - \frac{1}{2}VG\right)\right) \quad \text{........(3)}$$

3. <u>2D simulation by CAE</u>

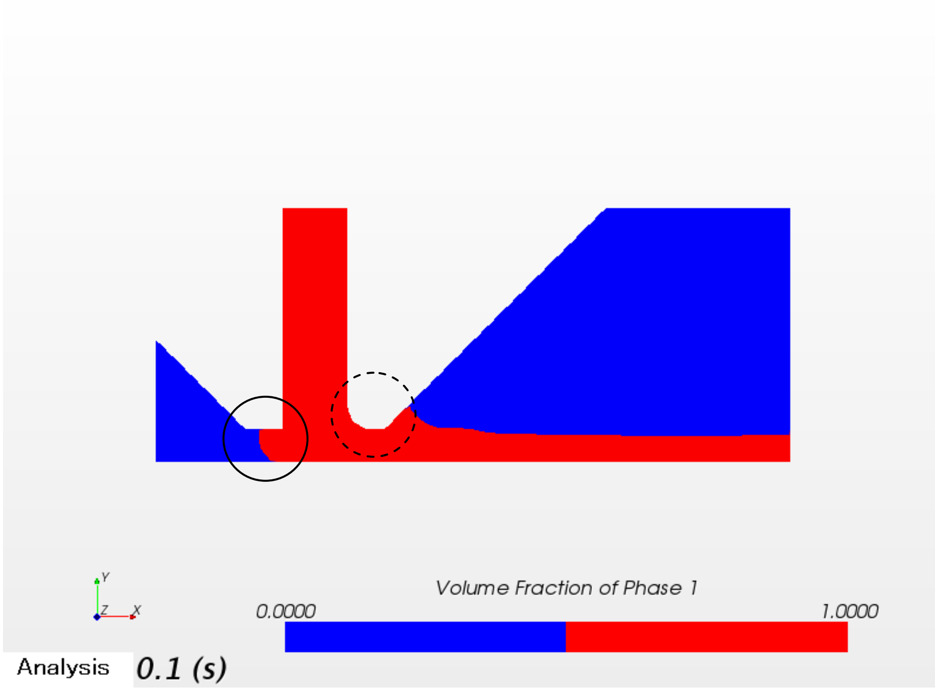
3-A. Sharp edge simulation (2-3 μm radius)



Upstream A/L interface is on position ②. That means coating thickness is stable.

3-B. Rounded edge simulation (20 – 30 μm radius)

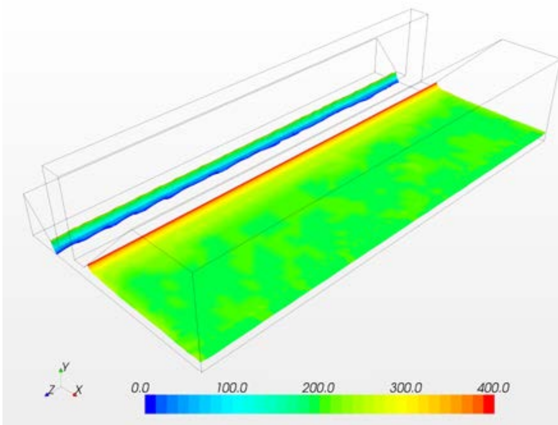
Downstream A/L interface is on position ③. That means A/L interface moves unstably with the vibration: The coated surface is uneven.

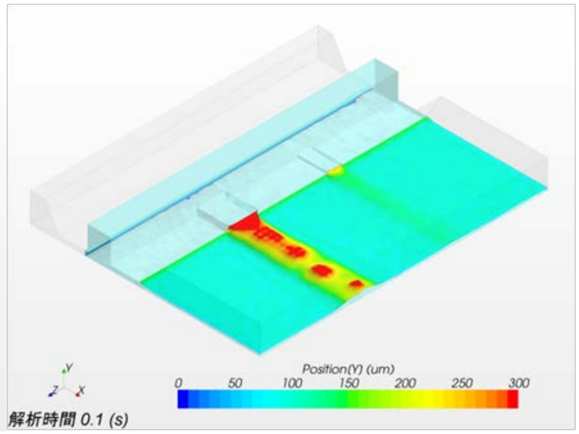


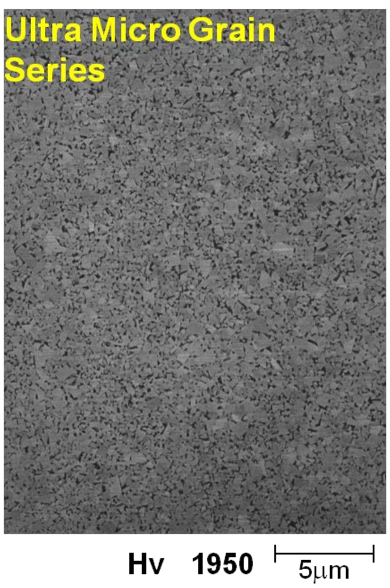
Those simulation results will be shown by motion picture at the conference.

4. 3D Simulation

2D simulation is very useful in understanding the expected process result. However, it is only a partial analysis, therefore we simulate with a 3D analysis. 3D analysis flow models will be presented in real time videos at this conference. 3D simulation explains the scratch issue on the top surface of the lip. Those results are a reason to use Tungsten carbide comparing to Stainless steel for the lip.







Conclusion

Through fluid modeling in both the 2D and 3D simulations above it can be concluded that wear on the slot die lip inversely affects the stability in the coating bead. A solution is to use a higher hardness material with a finer grain structure to maintain the sharpness of the slot die lip, providing more consistent and stable coating at the exit P_{out}, where fluid meets substrate. Through the use of tungsten carbide the working life of the slot die is increased and with the diminished need to re-sharpen and regrind the lips, machine downtime is decreased. Both resulting in efficiency and increased productivity.