Proceedings World Geothermal Congress 2026, Calgary, Canada, June 8—11, 2026

Novel In-pipe Deposition Method for Low-Adhesion Diamond-like Carbon Coating against Silica accumulation

Yuya Nakashima[1]*, Shinya Ui[1], Kanato Sato[2] , Risako Imai[2], Hiroyuki Kousaka[2]
Fuji Electric Co., Ltd.[1]*, Gifu University[2]

INTRODUCTION

Back ground

- Silica scale is one of biggest problem in the geothermal plant such as in the heat exchanger causes a output drop (Fig.1).
- In our previous research, Diamond-like Carbon coating (DLC) which could suppress the silica scale accumulation has been developed[1-3](Fig.2). However, it's difficult to deposit inside of pipes (Fig.3).

Aim of this study

- Development of in-pipe deposition process of DLC coating (Fig.3).

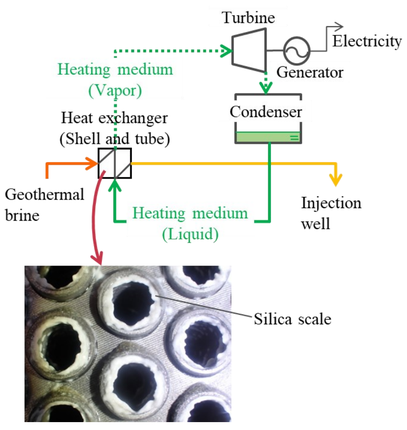


Figure.1 Example of Scale accumulation

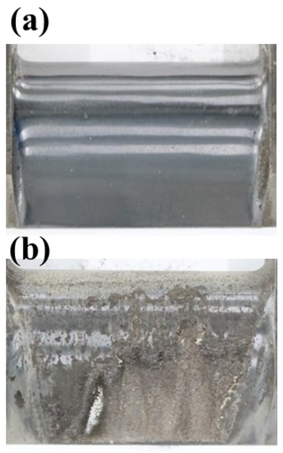


Figure.2 (a)DLC coated and (b)non -coated turbine blades

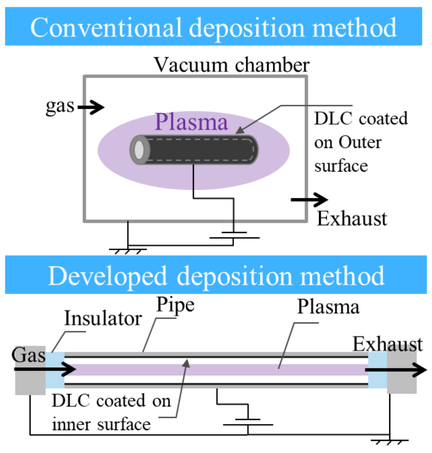


Figure.3 Coating process of DLC

METHODS

Materials and coating process (Fig.4).

- Stainless steel pipe (AISI 304, I.D.:16 mm, O.D.:19 mm, L:500 mm),
  plate (AISI 420, 10×10×1mm, for analysis)
- DLC coating: deposited by the in-pipe deposition equipment (Table 1)
  Without gas flow : To avoid pressure drop between inlet and exhaust. Inlet and exhaust valve was closed after gas filled into pipes
  (Δp generally affect uniformity of DLC chemical structure)
  With gas flow : To generate Plasma along entire length of pipes. DLC was deposited under continuous gas flow.
- Chemical property analysis for DLC: Elastic recoiled detection analysis (ERDA)

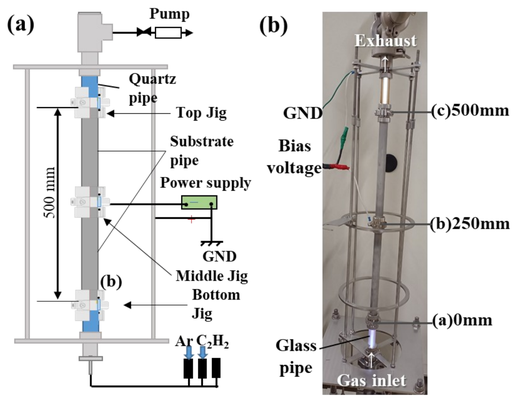


Figure.4 In-pipe coating equipment

Table.1 Deposition conditions

Type	No flow	Gas flow
Gas	C_2H_2	
Bias voltage [V]	-840	
Deposition time [min]	80	
Inlet pressure [Pa]	40	76
Exhaust pressure [Pa]	40	39
Gas ratio(C_2H_2/Ar)	0.2	
Total gas flow rate [sccm]	94	

RESULTS

Uniformity of DLC coating

- Different appearance of DLC on each position from deposition gas inlet has observed (colour of DLC corresponds thickness of DLC)(Fig.5).
  On no gas flow condition, gas inlet(a:0 mm) and exhaust (c:500 mm) has looks same DLC thickness, but middle position (b:250 mm) has thinner thickness. It indicates DLC is not uniform.
  In contrast, on gas flow condition, colour of DLC is similar from position (a')-(c'). It indicates the thickness of DLC is relatively uniform compared with no gas flow condition.

>in-pipe deposition process has different trend from conventional deposition process (no gas flow, no pressure difference, should get uniform DLC based on previous studies of conventional method)

- Plasma emission intensity, it corresponds brightness of emission, also reflected with thickness of DLC(Fig.6).
  Positions where similar DLC thickness obtained at (a),(c),(b'),(c'), has similar intensity of plasma emission. Emission at position (b), which has thin DLC, is darker than others, and (a'), which has bit thicker DLC, is bit lighter than others.

>Plasma uniformity is dominant factor for DLC uniformity. Plasma intensity get uniformed by gas flow even it has pressure difference between gas inlet and exhaust.

- Hydrogen content, it can reduce silica accumulation amount to less than 1% if it has >27at% on outermost surface[3], is almost same regardless position of pipes (Fig.7).
  Hydrogen content on the outermost surface(0.1nm) at all position is in >27at%, it indicates this DLC coated pipe can suppress silica accumulation along whole length of pipe.

>Uniformity of DLC is improved by getting uniformed plasma intensity along length of pipe by gas flow deposition.

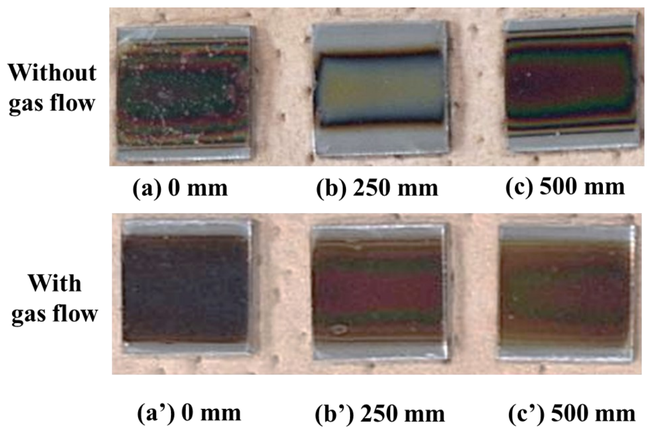


Figure.5 Appearance of DLC at each position

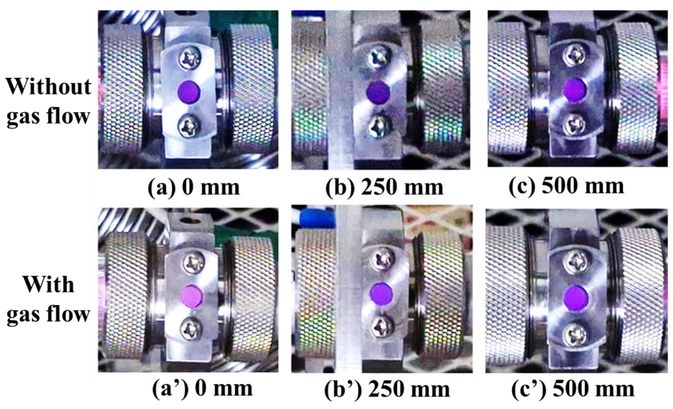


Figure.6 Plasma emission at each position

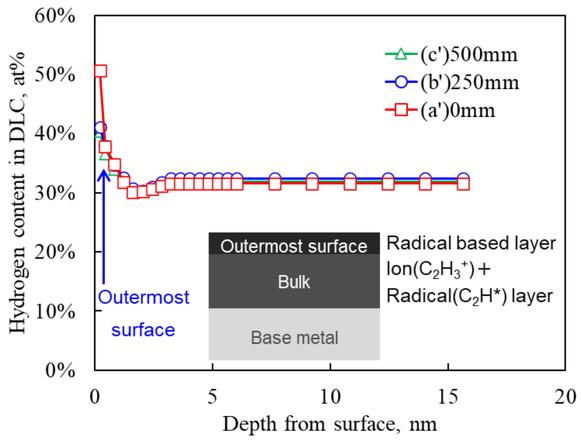


Figure.7 Depth profile of hydrogen content with gas flow deposition

DISCUSSION

- According to plasma jet theory, plasma can be transported by gas flow since plasma is ionized gas by bias voltage[3]. It means plasma is also kind of gas. Plasma is generated where electric potential difference occurred. That position can be transported by gas flow since plasma is the one kind of gas state (Fig.8).
  Hence, Plasma is transferred by gas flow and get uniformed along length of pipe as shown in Fig.9.

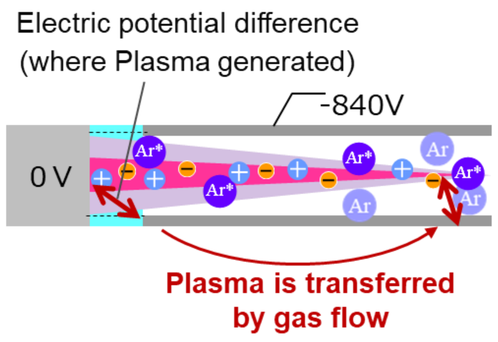


Figure.8 Schematic illustration of ionized Ar gas based on plasma jet theory

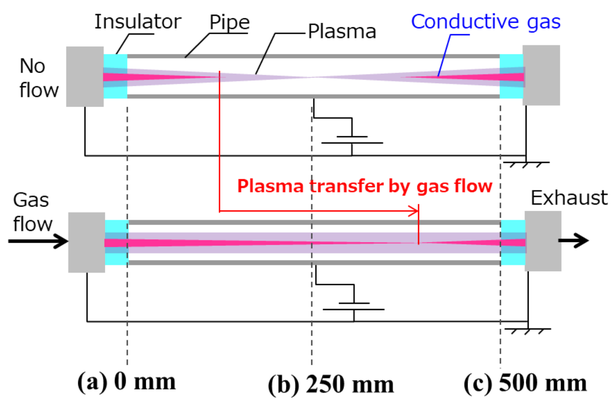


Figure.9 Schematic illustration of plasma transport by gas flow

CONCLUSION

- Pipes with inner diameter 16mm, length 500mm is used as the in-pipe DLC deposition substrate and DLC was deposited in the entire length of pipe. Based on conventional DLC deposition theory, no gas flow deposition is performed to suppress pressure difference which affect DLC uniformity. With gas flow deposition is also performed for novel in-pipe deposition.
- No gas flow deposition has non-uniform DLC through the each position with gas inlet to exhaust although it has no pressure difference. In contrast, gas flow deposition obtains uniform DLC on each positions although it has much pressure difference between gas inlet and exhaust. Plasma emission intensity is also corresponds with DLC uniformity. Uniformity of DLC is improved by getting uniformed plasma intensity along length of pipe by gas flow deposition.
- From the results of hydrogen content in DLC with gas flow deposition, DLC at the position of gas inlet to exhaust has almost same hydrogen content profile, it indicates this in-pipe deposition with gas flow can deposit an uniform DLC.

Future work

- Improvement of deposition method to adopt DLC coatings to longer pipes
  (final target should be 10 m)

Acknowledgements
We would like to thank for quantitative analysis of Hydrogen content profile in DLC at Kobelco research institute Inc.

REFERENCES

[1]Nakashima Y, Umehara N, Kousaka H, Tokoroyama T, Murashima M, Mori D. "Carbon-based coatings for suppression of silica adhesion in geothermal power generation", Tribology International, (2023), 177
[2]Nakashima Y, Hirota M, Yamada S, Dela Cruz R C. , Sanggalang M A. ,"Development of carbon-based coating to suppress silica scale accumulation on geothermal turbine blades" GRC transaction, Vol.47(2023)
[3]Nakashima Y, Ui S, Yamada S,Imai R, Kousaka H."Development of Carbon-based coating to suppress silica scale accumulation on the inner surface of pipes", GRC transaction, Vol.48(2024)
[4]Liu X Y, Pei X K, Lu X P, Liu D W. " Numerical and experimental study on a pulsed-dc plasma jet". Plasma Sources Science and Technology, 23(3), (2014) ,035007.