ACHIEVING FULL-COVERAGE LIQUID GAINSN FILM FLOW UNDER STRONG MAGNETIC FIELDS: SYNERGISTIC EFFECTS OF WETTABILITY OPTIMIZATION AND DUAL-LAYER STRUCTURAL DESIGN

[1]Y.M. WANG, [1]X.J. ZHANG

[1]Southwestern Institute of Physics, Chengdu, China

Email: wangym@swip.ac.cn

1. INTRODUCTION

In future fusion reactors (DEMO) to produce electricity, a major challenge is how to exhaust high heat flux and control impurities for quasi or true steady state operation [1]. The solid high-Z metal plasma facing component (PFC) first wall/divertor designs such as those employing tungsten (W) or molybdenum (Mo) will not meet the requirements for PFCs to be used in DEMO reactors [2]. Employing flowing renewable liquid metal as the PFC material in fusion reactors demonstrates significant advantages including absence of thermal stress, resistance to neutron irradiation damage, unlimited service lifetime, recyclability, and high steady-state thermal load capacity, potentially providing innovative solutions for DEMO PFC[3]. However, in the tokamak fusion environment, the strong magnetic field will generate a Lorentz force that hinders the forward flow of the flowing liquid metal. This force acting on the fluid can induce magnetohydrodynamic (MHD) instabilities on the free surface of the liquid metal, altering the velocity distribution and flow characteristics of the liquid metal film [4]. So resolving the MHD instability of liquid metals and achieving full-coverage, stable, and uniform flow under strong magnetic fields remain critical challenges for liquid metal applications.

2. EXPERIMENT AND SIMULATION

The paper employs a combined approach of simulation and experimentation to analyze the spreading characteristics of the liquid metal GaInSn first-wall film flow, with a particular focus on the effects of wettability, magnetic field strength and flow velocity on the spreading characteristics. The simulation utilized VOF (Volume of Fluid) model in FLUENT to analyze the spreading of GaInSn film flows on stainless steel chute under various conditions, including different inlet velocities, and wettability parameters. The experiments were conducted using the liquid metal loop at the Southwestern Institute of Physics. The liquid metal flows along a chute (see figure below), performing film flow spreading tests under different flow velocities (0.051-0.676m/s) and magnetic field strengths (0-1.8T).

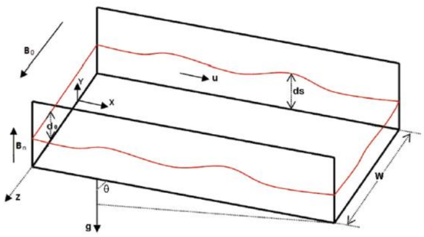

Fig. 1-Sketch of liquid metal flows along a chute

3. CONCLUSION

By comparing the simulation and experimental results, the reliability of the simulation results was verified. Through analysis, the influence patterns of the above parameters on the spreading of GaInSn film flow were obtained (some of the results are shown in figure below), laying the foundation for improving the spreading area and stability of GaInSn film flow on stainless steel (SS) surfaces. The following main conclusions are drawn from the simulation and experimental results: (1)When the magnetic field strength is constant, as the inlet flow velocity increases, the spreading area of the film flow becomes larger. (2) When the inlet flow velocity is constant, under the action of the magnetic field, the surface of the film flow gradually changes from a relatively disorderly state without a magnetic field to a smooth one. This indicates that the magnetic field can suppress surface waves, and the higher the magnetic field strength, the greater the suppression effect. No obvious obstruction of the magnetic field on the GaInSn film flow was observed, and there was no hysteresis or thickening of the film flow in the magnetic field - covered section.

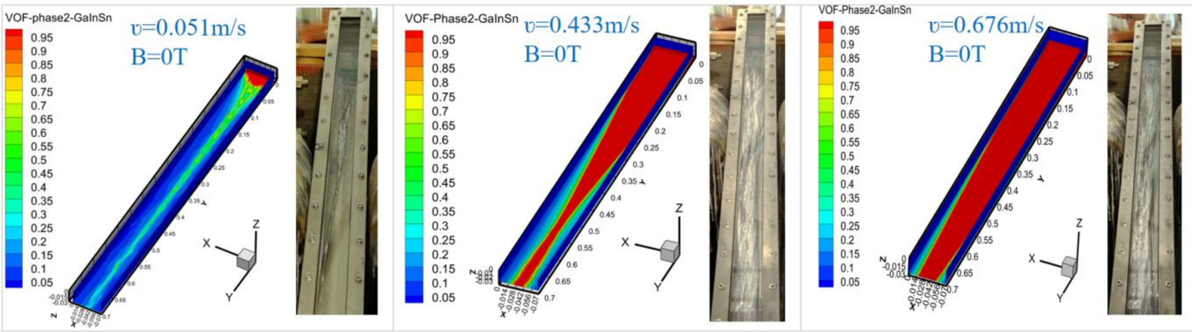

Fig.2-Simulation and experimental results of GaInSn film flow under different flow velocities with contact angle~135°and without open wave BC

4. NEXT STEPS PLAN

The current experimental and simulation results indicate that full-coverage liquid GaInSn metal film flow cannot yet be achieved, primarily due to insufficient wettability of GaInSn on stainless steel (SS) surfaces. In the next phase, we will continue integrating experimental and simulation approaches while exploring two strategies to enhance the spreading area of GaInSn film flow under magnetic field:
1) Optimizing substrate wettability: Investigating substrates with superior wettability to GaInSn (e.g., pure copper and organic glass/PMMA) to elucidate the mechanism of wettability effects on film spreading dynamics.
2) Innovative film flow configuration: **I.** Develop a dual-layer film flow structure to actively guide liquid metal distribution across the substrate surface, aiming for full-coverage liquid GaInSn metal film flow. This investigations are currently underway, with anticipated results within the next two months. **II.** Develop the serrated bottom wall structure. Here's the very first step result showing that full-coverage film flow has been achieved by using the serrated bottom wall.

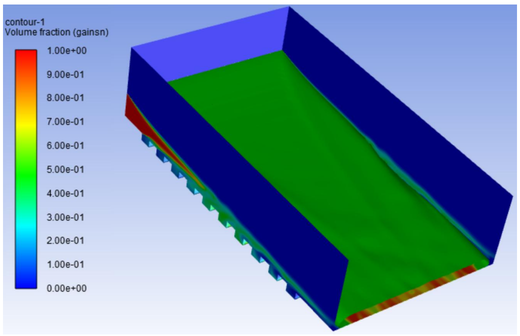

Fig. 3-Simulation results of GaInSn film flow using a serrated bottom wall structure (ISO surface VOF=0.5)

Key Words: Liquid Metal; Film Flow; First Wall; MHD; Wettability

REFERENCES

[1] Zohm H , Angioni C , Fable E, et al. On the physics guidelines for a tokamak DEMO[J]. Nuclear Fusion, 2013, 53(7):073019.
[2] J.E. Menard, S. Gerhardt, M. Bell, et al. Overview of the physics and engineering design of NSTX upgrade[J]. Nuclear Fusion 52(8) (2012).
[3] Y. Nagayama. Liquid lithium divertor system for fusion reactor[J]. FED. 84 (7–11) (2009) 1380–1383.
[4] Hu J S , Zuo G Z , Li L ,et al. Recent progress in the development of liquid metal plasma facing components for magnetic fusion devices[J]. Nuclear Materials and Energy, 2024, 41.