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FLEXIBLE POLYMERIC PULSATING HEAT PIPES: FABRICATION TECHNIQUES AND THERMAL PERFORMANCE INVESTIGATION

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1. ABSTRACT

This extended abstract presents an overview of recent research on flexible polymeric pulsating heat pipes (PPHPs). Two promising fabrication techniques are explored - selective transmission laser welding and stereolithography (SLA) 3D printing. The thermal performance of PPHPs manufactured using these methods is experimentally investigated, including the impact of microgravity conditions and bending on the laser-welded design. Key findings show that the SLA technique enables precise control over complex geometries, while the laser-welded PPHPs demonstrate effective thermal performance even in microgravity. Non-uniform channel configurations are found to promote fluid circulation and enhance heat transfer. This work highlights the potential of polymeric PHPs for flexible electronics cooling and disposable applications.

2. INTRODUCTION

Pulsating heat pipes (PHPs) are highly efficient passive cooling devices that utilize thermally-induced oscillating fluid motion to transfer heat [1]. The development of flexible PHPs is gaining interest to meet the thermal management needs of emerging applications like wearable electronics and deployable systems [2]. Polymeric materials offer promising properties for flexible PHP designs, such as low weight, adaptability, and cost-effectiveness. However, research on polymer-based PHPs is still limited. This work investigates two fabrication methods for PPHPs and analyzes their thermal performance under various conditions.

3. METHODOLOGY

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Selective Transmission Laser Welding: A multi-turn flat polymeric PHP (260x98x1.5 mm3) was fabricated at the University of Liverpool by selective laser welding of three polypropylene sheets (1.5 mm total thickness) [3], following the method described by Der et al. [5]. Rectangular channels with 0.7 mm height and either 3 mm (11 turns) or 5 mm (7 turns) width were formed. The transparent material enabled flow visualization. An example is shown in Fig 1(a).

Stereolithography (SLA) 3D Printing: SLA 3D printing was utilized to manufacture PPHPs (185x85x2 mm) with varying channel configurations (parallel, asymmetric, diverging-converging) using a flexible UV-curable resin. The PPHPs were primarily based on an 8 turn configuration with base channels' dimensions of 1 mm high and 2.3 mm width for the parallel channel configuration and 1.8 to 2.8 variation for the asymmetric or diverging/converging configurations. An Anycubic Photon printer achieved high resolution, with dimensional errors of only -10 to -60 µm. This technique allowed precise control over complex geometries in a single piece [4], as illustrated in the example shown in Fig 1(b).

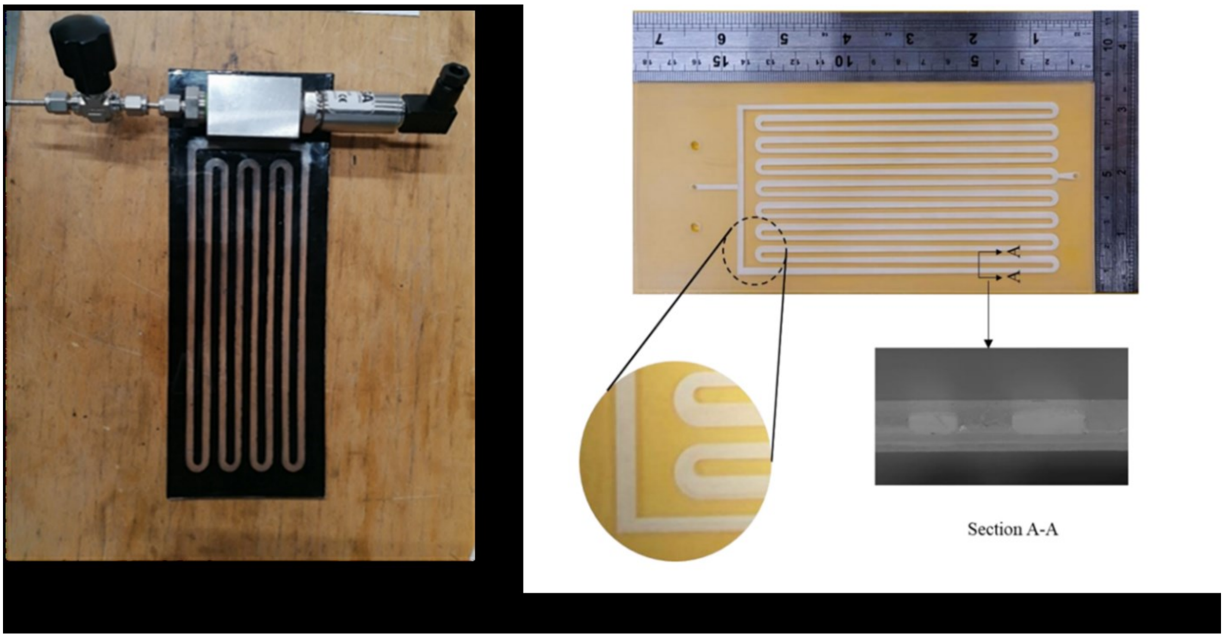

Fig 1: (a) Laser-welded polypropylene PPHP; (b) SLA-printed PPHP [4].

4. RESULTS

4.1 Laser-Welded PPHP Tests

The laser-welded PPHP was tested during the 77th ESA parabolic flight campaign to evaluate the impact of microgravity and bending on thermal performance and flow dynamics. Working fluids were FC-72 and ethanol at a 50% fill ratio. A high-speed visible camera and IR camera recorded the flow at 100 Hz [3]. A particle tracking velocimetry algorithm was developed to analyze bubble motion from the IR images.

Key findings:

- Thermal resistance increased slightly from 2.1 K/W in hypergravity to 2.2 K/W in microgravity
- Vapor bubble velocity distribution narrowed significantly in microgravity, indicating slower flow
- Minor impact of bending (up to 75°) on thermal performance and flow dynamics

4.2 SLA-Printed PPHP Tests

The thermal performance of SLA-printed PPHPs with different channel geometries was investigated experimentally, using FC-72 as the working fluid at a 50% fill ratio and heating powers from 5-30 W. Thermal resistance and evaporator temperature were compared [4].

Key results:

- All designs had similar start-up at 10 W, with thermal resistance decreasing as heat input increased
- Non-uniform channels (asymmetric and diverging-converging) promoted bubble nucleation and fluid circulation
- Diverging-converging configuration induced additional pressure difference, enhancing heat transfer
- Effective thermal conductivity of PPHP was 1016 times higher than a solid polymer sheet at 30 W

5. CONCLUSIONS

This research demonstrates the successful application of laser welding and SLA 3D printing techniques to fabricate PPHPs. The laser-welded design showed effective operation even in microgravity, with minimal impact from bending. SLA printing enabled precise control over complex geometries, with non-uniform channels enhancing heat transfer. The high thermal conductivity enhancement compared to solid polymer highlights the potential of PPHPs for flexible electronics cooling. Future work should explore methods to reduce gas permeability for improved long-term performance.

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