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Additive Manufacturing for Thermal Management applications: advantages and current limitations

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1. ABSTRACT

Additive Manufacturing opens novel frontiers in thermal science but it also comes with several challenges, This work presents a few applications of the metal additive manufacturing to different heat transfer problems: single phase forced convection, pool boiling, and solid-liquid phase change.

2. INTRODUCTION

Additive Manufacturing (AM) is a technology process, which intrinsically shows many advantages and a few limitations. For many years, it has found wide use in fast prototyping, due to its versatility and limited costs per unit. More recently, this technology has involved the manufacturability of new components, using metallic materials, for example in aerospace and automotive applications, where the compactness and lightness are mandatory [1-5]. One remarkable advantage of AM technology is the possibility to realize complex channels directly inside the component without assembling external cooling pipes. The direct integration of the cooling channels in the final component is becoming a key enabling technology in many different applications, among those: aerospace, automotive, biomedical, electronic thermal management, robotics, and energy.

This work investigates the possible application of AM in thermal science showing different case studies to present advantages and challenges that this novel design and manufacturing approach revealed during the experimental campaigns.

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3. A NOVEL FRAMEWORK FOR ADVANCED HEAT TRANSFER DESIGN

Either in single phase and two phase heat transfer, the AM allows to re-think the heat transfer surfaces using advanced topological optimization tools to re-design the heat transfer surfaces. Fig. 1 and 2 show two different case studies. Fig.1 presents the design of a prototype with internal cooling channels for the thermal management of critical component for fusion energy application capable to reject up to 6 MW/m^2 (Fig. 1) while Fig. 2 shows the sample printed via laser bed fusion of a novel 3D structure for pool boiling of dielectric fluids developed using an in-house developed tool.

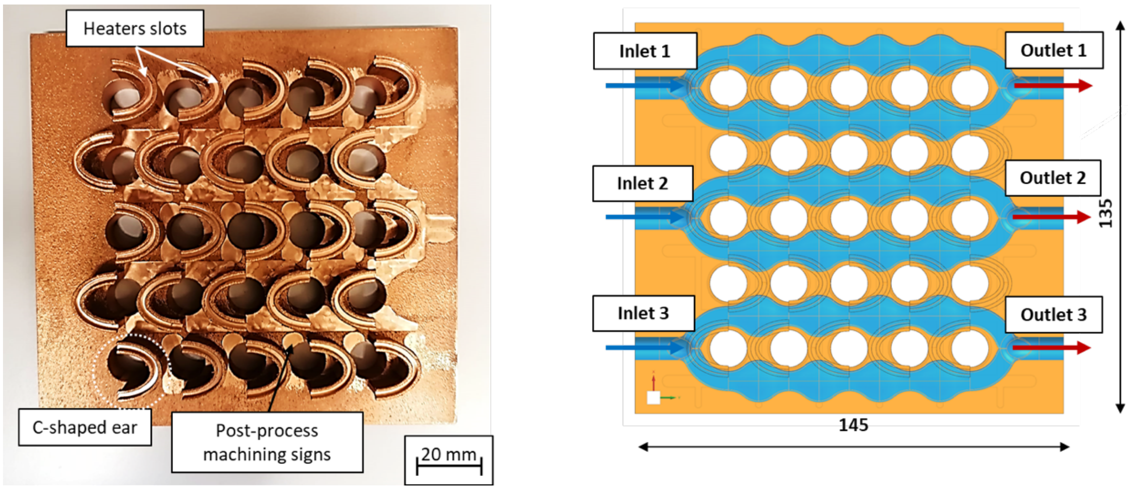

Figure 1. The top view of the prototype is reported. The post-process machining signs are visible because of the support removal (left); drawing of the prototype (left) [1].

Figure 2. Topologically optimized 3D surface for pool boiling applications [2]

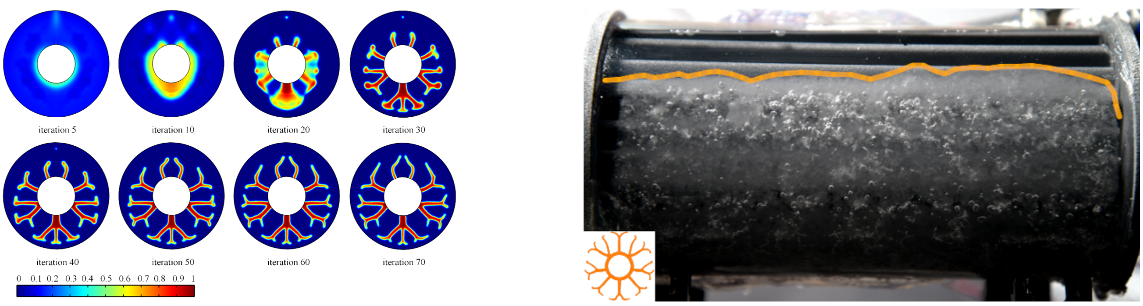

Figure 3. Topologically optimized 3D surface for solid-liquid pahse change [3]

Fig. 3 shows the application of the topological optimization to design advanced heat transfer surfaces to enhance the heat transfer during the solid liquid phase change process.

4. CURRENT LIMITATATIONS

The friction factor *f* of the reference straight channel can be evaluated from the measured values of pressure drop and water flow rate with the Fanning equation, considering the flow length equal to the distance between the two pressure taps, l=54 mm and computing nominal velocity u on the basis of cross sectional area A=26.09 mm^2. In Fig. 3, the values of the experimental friction factor as a function of the Reynolds number are reported for the straight channel. On the same diagram, the friction factors calculated with the well-known Blasius equation are reported.

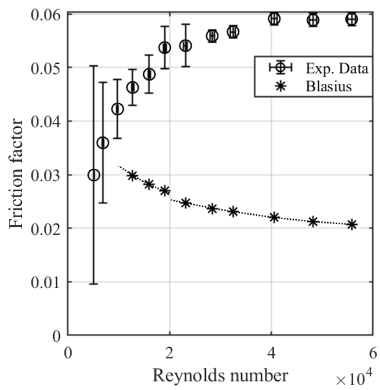

Figure 3. Photo of the three samples at the end of the AM process (left); comparison the experimental friction factors measured for the 3D straight channel and the ones calculated using the Blasius equation.

It clearly appears that the experimental friction factors show a completely different behaviour as compared to those computed for smooth straight channels. As described before, this is due to the fact that the channel obtained via AM is not "smooth" and presents a non-negligible surface roughness, which deeply affects the fluid flow. The Reynolds number varies from 5000 to 50000; in this range for rough channels, the transition between laminar to turbulent implies an increasing of the friction factor, which then tends to a constant value that depends on the value of the relative roughness, as also reported in Moody diagram. The surface roughness can deeply affect the performance of the 3D printed samples and lead to unpredictable results of the optimization tools, which usually consider the channel smooth. Currently, this remains the most important drawback and a challenge that must tackled to make the AM reliable and feasible.

5. CONCLUSIONS

This work presents different case studies to show the capabilities of the additive manufacturing in thermal science but it also highlights its current limitations.

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