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Application of Technology of Additive Manufacturing in Radiators and Heat Exchangers

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Abstract

Radiators and heat exchangers play a key role in the long-term and stable operation of the equipment. The emergence of additive manufacturing technology has released the freedom of design, enabling many innovative structures of radiators and heat exchangers to be manufactured. The paper reviews the application of additive manufacturing in new radiators and heat exchangers. The technology of additive manufacturing boosts the development of new radiators and heat exchangers, which improves heat dissipation performance and heat exchange efficiency. This paper will provide a new idea and method for the development of radiators and heat exchangers via the application of additive manufacturing.

Keywords

Radiators, Heat Exchangers, Additive Manufacturing, Heat Dissipation Performance, Heat Exchange Efficiency

1. Introduction

The traditional processes of manufacturing radiators and heat exchangers mainly have extrusion molding, casting and machining. Owing to the characteristics of this processing, the structural design of radiators and heat exchangers is greatly limited. One of the main problems is that the flow runner must be designed straight to facilitate processing, which makes the heating of the parts uneven and increases the temperature of some areas quickly. The rising temperature caused by poor heat dissipation affects both the service life and the stability and reliability of instruments and equipment. Therefore, to meet the requirement of heat dissipation properties, many portable computers, power electronic equipment and high-power LED lighting have to increase volume. This obviously cannot meet the miniaturization trend of equipment. In today's high-precision and miniaturized scientific and technological era, it is urgent to improve the heat dissipation performance of radiators and heat exchangers [1].

Additive manufacturing (often abbreviated to AM), also named 3D printing, adopts the stacking method of layer upon layer via point → line → surface → body, which releases the degree of design freedom and provides an implementation way for new structural radiators and heat exchangers [2]. Therefore, many enterprises and institutions have conducted additive manufacturing research to improve the performance of radiators and heat exchangers and achieved some innovative results [3]. This paper expounds on the application of additive manufacturing in radiators and heat exchangers. The structure of the paper lists as follows: the first part introduces the importance and existing problems of radiators and heat exchangers application. The second part focuses on the principle and process of additive manufacturing and points out the advantages of the process. The third part discusses the application status of additive manufacturing in radiators and heat exchangers, and the fourth part summarizes and points out the existing problems and development direction of additive manufacturing in radiators and heat exchangers.

2. Additive Manufacturing Principle and Typical Processes

Differently from traditional manufacturing methods, additive manufacturing starts from the CAD geometric model of parts or the scanned data, then transfers 2D slicing file through slicing software, uses special process methods (melting, sintering, bonding, *etc.*) to stack materials layer by layer to form 3D solid parts via forming equipment. The working principle of additive manufacturing is listed in **Figure 1** [4].

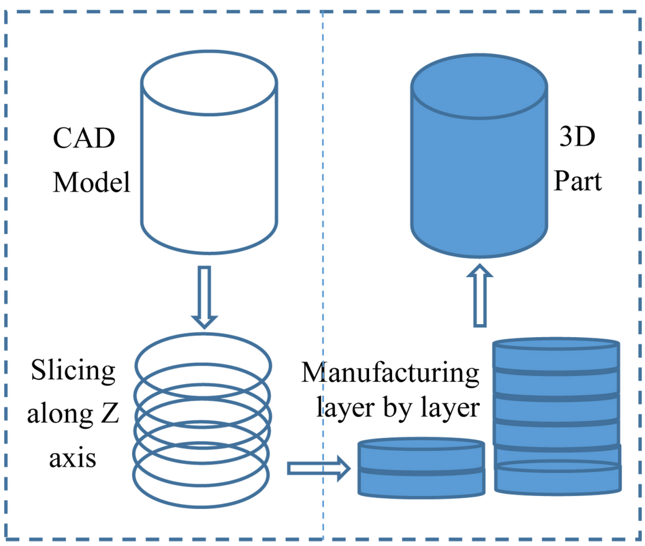


Figure 1. Working principle of AM [4].

The technology of additive manufacturing has the following characteristics:

1) It is unnecessary of tools or fixtures before the processing so it has short processing cycle;

2) It is more suitable for processing complex or integrated components;

3) The cost of personalized and small patch products is low;

4) The whole process is the information integration of manufacturing, material and NC equipment.

These technical characteristics of additive manufacturing determine that it plays a significant role in complex product manufacturing, innovation and personalized customization. It helps designers to realize the goal of "free design and rapid manufacturing".

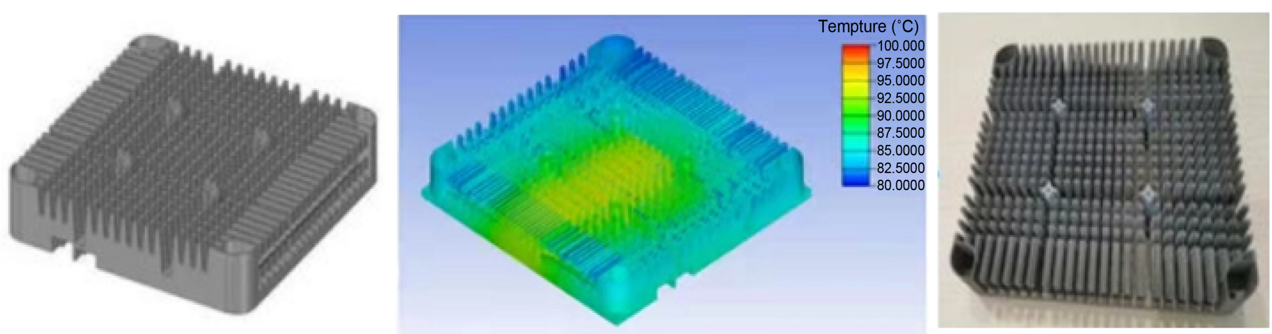
There has a variety of additive manufacturing processes. The typical processes list as follows: Stereo Lithography Prototype (including SLA, DLP, and LCD), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS), Fused Deposition Manufacturing (FDM), and Three Demension Printing (3DP, including spray bonded 3DP and inkjet 3DP) [5]. Each process has its own characteristics. The metal additive manufacturing via SLS is mainly applied in radiators and heat exchangers.

3. Application of Additive Manufacturing in Radiators and Heat Exchangers

3.1. Radiators and Heat Exchangers with Complex Structure

Additive manufacturing releases the freedom of designing complex structure of radiators and heat exchangers. The new type of radiators and heat exchangers with special-shaped pipe or different shape chips to build mirco-passageway, can be successes fully manufactured via AM instead of welding.

Figure 2 shows the scheme of a new radiator in 5G micro base station via AM technology [6]. The new radiator with Jiugong grid is adopted to change the fin shape and increase the fin height. It was made from DLM-280, which is a metal 3D printing system based on selective laser melting technology. The above scheme



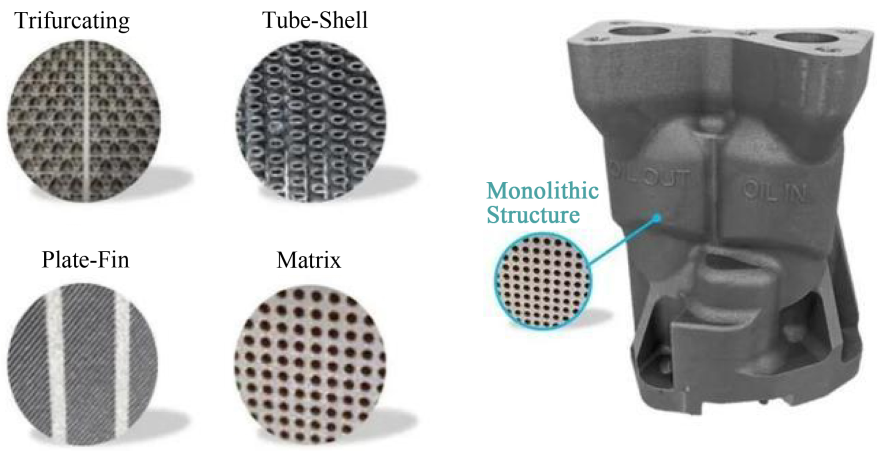
(a) Design (b) Simulation (c) Product

Figure 2. The AM scheme of new radiator in 5G micro base station [6].

effectively solves the problems of compact structure and low heat dissipation performance of the new heating radiator in 5G mirco base station.

Another typical application example is the heat exchanger in GE9X. Traditionally, this kind of heat exchanger is composed of dozens of thin metal tubes. In order to improve the heat management performance, GE adopts four kinds of completely different additive manufacturing heat exchanger structures, as shown in **Figure 3(a)**: trifurcating, tube-shell, plate-fin and matrix. Through simulation, the heat exchanger with matrix structure is adopted. The heat exchanger is then manufactured through metal 3D printing. The new heat exchanger decreases with weight loss of 45% and has no brazing joint. The heat exchanger has been certified and used in Boeing 777X aircraft, as shown in **Figure 3(b)** [7].

In cooperation with Renishaw, HiETA Technologies adopted Inconel additive manufacturing to produce a thin and impermeable thin-walled manifold annular heat exchanger with a thickness of 150 microns. This product is usually 40% lighter and smaller than any similar product on the market. **Figure 4** shows a ring-shaped heat exchanger which is designed and manufactured by HiETA engineers. The heat exchanger contains an integrated manifold ring and is a more compact overall system [8].



(a) Four different structures (b) Heat exchanger with matrix

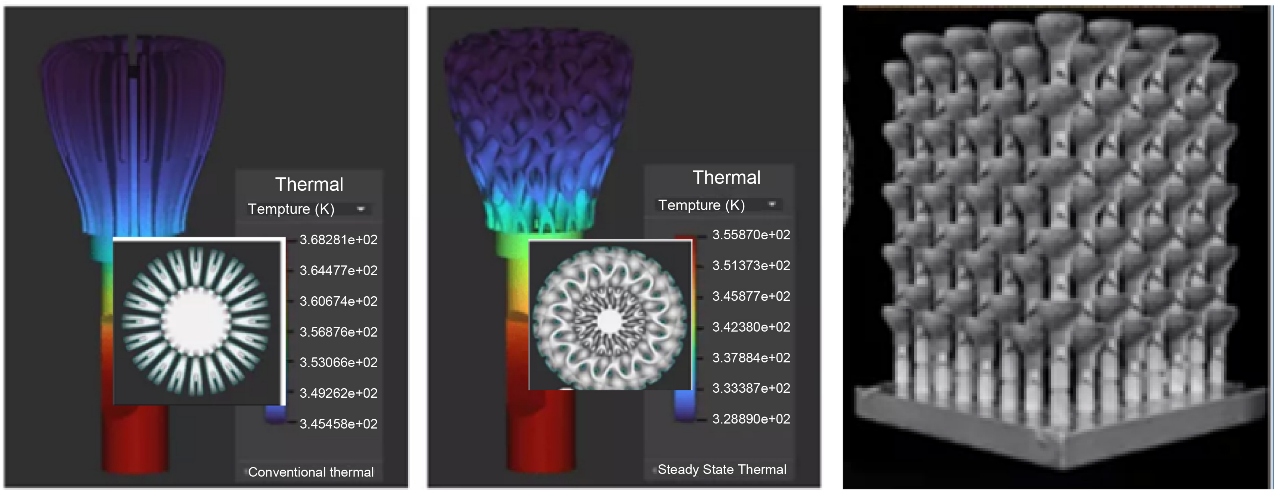
Figure 3. Heat exchanger in GE9X [7].

Figure 4. Manifold ring heat exchanger via AM [8].

One new kind of automotive LED headlamp radiators developed with topology design method, as shown in Figure 5(a). The surface area of the new radiator increased 27% than the traditional product, and the thermal change is high up to 130˚C. At present, the LED radiator of aluminum alloy can be mass produced by powder bed selective laser melting equipment, as shown in Figure 5(b) [9].

On the basis of traditional aviation fuel oil heat exchanger, the optimization of heat exchanger structure is realized through parameter design and CFD simulation, as shown in Figure 6. The new heat exchanger is made by SLM technology of metal additive manufacturing. The heat exchanging efficiency of the new heat exchanger is increased by 80% and the pressure loss is reduced by 52% [7].

Similarly, the heat exchangers with internal spiral structure were adopted for significantly improving the heat dissipation efficiency. This kind of the heat exchangers was manufactured via melting metal of SLS, as shown in Figure 7 [10].



(a) The original & new LED headlamp radiator (b) Processing via AM

Figure 5. LED headlamp radiators [9].

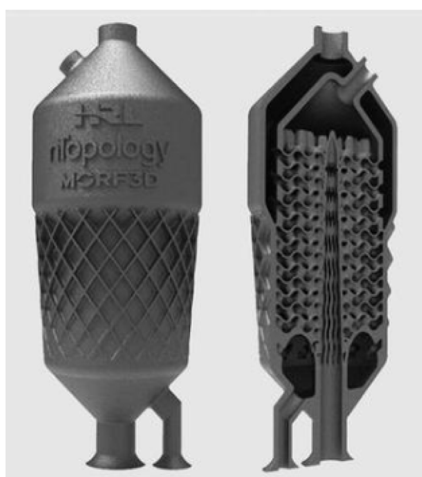


Figure 6. New kind of heat exchanger [7].

Figure 7. Internal spiral heat exchangers via AM [10].

3.2. Integrated Heat Exchangers

One of the advantages of additive manufacturing is that the core and manifold of heat exchanger can be produced in a single integral part. Traditionally, individual fins or plates are firstly produced and then manually bonded or welded together to form a heat exchanger. Breakdown between any of these welded joints may result in failure of the heat exchanger. With AM application of copper, the new and integrated heat exchanger in CPU is developed by TheSys, as shown in Figure 8 [7]. The new heat exchanger saves 81% of the space. It greatly shortens the opening time and cost and makes the computer be smaller.

Autodesk Company designed the automobile chassis, which the heat exchanger with the Gyroid structure was integrated into, as shown in Figure 9 [7]. The integrated chassis was manufactured by additive manufacturing on the least support. The integrated chassis significantly improves the thermal efficiency and decreases the overall volume.

In the process of additive manufacturing multilayer circuit board, the cooling system can also be integrated inside the circuit board. Figure 10 shows the new radiator on a board cooling system with 0.8 mm thickness developed by IQ in Germany. The new radiator is made by nickel alloy via AM. The whole thickness of the integrated multilayer circuit board is only up to 1.3 mm.

3.3. Thin Wall Microchannel Heat Exchangers

Metal additive manufacturing can be widely used in microchannel heat dissipation structure of electronic products. The thin-wall heat exchanger was successfully made by 3D Med lab with a fin thickness of 0.2 mm, a bend thickness of 0.5 mm, and overall size of 100 × 120 × 25 mm. Other heat exchangers developed by AddUp in cooperation with Sogeclair and TEMISTh has the thin wall (<0.5 mm) and thin fins (0.15 mm) with no leakage, which is made from Inconel 718. Figure 11 shows two kinds of microchannel coolers via AM [7].

3.4. Multi Material Heat Exchangers via Additive Manufacturing

Figure 12 shows a heat exchanger made from the mixed copper and stainless

Figure 8. Heat exchanger in CPU (from EOS) [7].

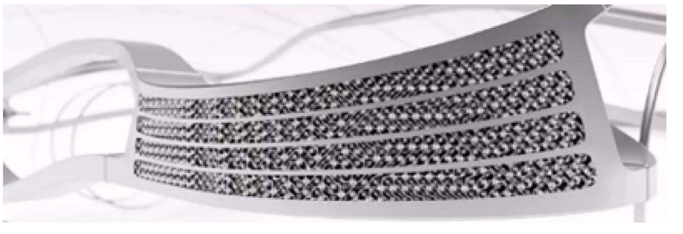


Figure 9. The chassis with heat exchanger [7].

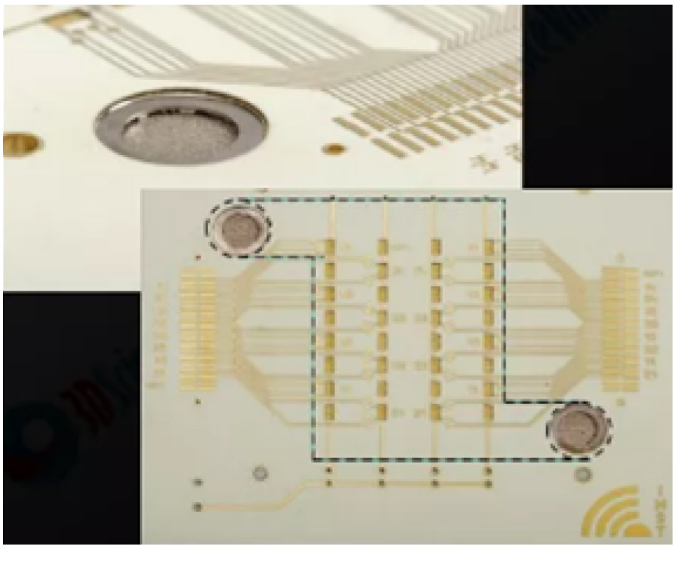


Figure 10. Radiator built-in circuit board made by AM [9].

steel via additive manufacturing by DMG Precision Machine Co. In the exchanger, the part requiring higher heat exchange efficiency is made of copper instead of stainless steel, which improves the heat exchange efficiency and saves the cost.

3.5. Costumed Heat Exchangers

Additive manufacturing can be used to manufacture costumed heat exchangers

(a) Micro cooler for high power laser diodes (a) Transistor cooling device, 1000Watt

Figure 11. Two kinds of microchannel coolers [7].

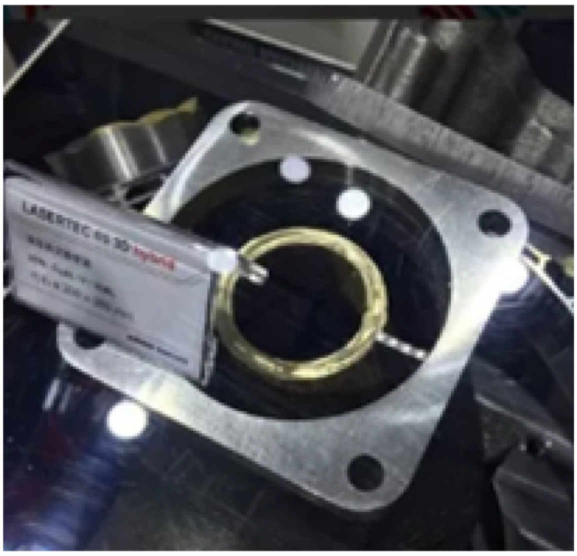


Figure 12. The heat exchanger mixed copper and stainless steel via AM [9].

at lower cost. It is common in industries such as motor sports, where many components are encapsulated in a compact volume. The additive manufacturing technology is very suitable for these kinds of customized products.

4. Summary

Additive manufacturing brings higher freedom of design optimization for radiators and heat exchangers, so that the structure of radiators and heat exchangers can meet the development trend of compact, efficient, modular and multi-material products. In the successful application example, metal additive manufacturing has been used to process radiators and heat exchangers with special-shaped, structural integration, thin-wall, thin warping, microchannel, very complex shape, lattice structure, *etc*. The use of additive manufacturing in radiators and heat exchangers has significantly improved heat dissipation performance and heat exchange efficiency. Meanwhile, it makes be possible to miniaturize structure. The advantages of using additive manufacturing for radiators and heat exchangers are summarized as follows [10]:

1) High performance in small size;

2) Possibility to integrate multiple parts into one and avoid welding;

3) Optimized performances;

4) Weight saving to 85%.

It is estimated that the global radiator market will be up to US $119.1 billion in 2026, with a Compound Annual Growth Rate (CAGR) of 4.5% [11]. Therefore, the market for radiators and heat exchangers is very large and the demand for radiators and heat exchangers is very urgent. The application of additive manufacturing technology makes the innovation of radiators and heat exchangers more possible. The possible breakthrough points of using additive manufacturing technology to manufacture radiators are as follows:

1) Plastic radiators and heat exchangers will replace the metal ones. Although plastic material has extremely poor thermal properties, plastic radiators and heat exchangers can be made into a larger surface area by additive manufacturing. The new products can achieve better heat exchange performance, because the heat transferring sensitivity to surface area change is about 160 times higher than the heat conductivity.

2) More mixed materials can be used in additive manufacturing to overcome the disadvantages of a single material. At present, one disadvantage of metal additive manufacturing is very expensive, and the efficiency of heat exchangers made of plastic is lower. However, heat exchangers made of a mixture of plastic and grapheme or ceramics can be used to deal with this potential problem.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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