PROSIDING SNTTM XXI 2023
Volume 21, Tahun 2023, 5 Oktober 2023
e-ISSN 2623-0313
p-ISSN 3032-1972

Investigation of wick fabrication with atomic diffusion additive manufacturing technology

Dinni Agustina[a,c], Nandy Putra[a], Dwi Marta Nurjaya[b], Sulthanaan Nashiiraa[a]
[a]Applied Heat Transfer Research Group, Dept. of Mechanical Engineering, Universitas Indonesia, Depok,16424, Indonesia
[b]Department of Metallurgical and Material, Faculty of Engineering, Universitas Indonesia, 16424, Depok, Indonesia
[c] Department of Mechanical Engineering, Universitas Riau, Riau

[a]nandy.putra@eng.ui.ac.id

ABSTRACT

A key to optimizing the performance of heat pipes is to ensure that the wick structure performs within its original design specifications. Sintering is the most commonly used technique due mainly to the economic costs. However, it presents a drawback associated with the randomness of the internal wick structure that can result from an irregular pore, penalizing its permeability and causing unsteady fluid-thermal behavior in the whole device. This research implemented 3D printing technology for the manufacturing of wick, which is known as Atomic Diffusion Additive Manufacturing. The advantage is to control the geometric size of the wick passages, aiming to achieve an optimal design according to the specified requirements. Based on this, this study aims to provide a solution in the form of a wick manufacturing process on heat pipes using 3D printing technology to overcome the unevenness of pores formed in the sintering process and can provide good performance results in thermal conductivity. The final result expected in this test is to be able to make a wick heat pipe with good performance through a 3D printing manufacturing process. For this aim, determining the sizes of pores that can be printed for the wick was the first step to investigate.

Keywords: Additive manufacturing, heat pipe, wick

Received 30 September 2023; **Presented** 5 October 2023; **Publication** 27 May 2024

INTRODUCTION

Heat pipe is a heat transfer technology that uses a pipe of a certain size and contains a special liquid to deliver heat from the evaporator side to the condenser side [1]. Heat pipes have several advantages, such as the heat transfer cycle that occurs being relatively short with dimensional compactness and a high increase in the heat transfer coefficient. There is no additional power required because fluid circulation occurs naturally, so they are widely used in industrial and electronic technology, waste heat utilization, air heating, air conditioning systems, and exhaust heat utilization in boilers [1]. Heat pipes are usually made of aluminum, copper, or nickel-plated copper [2]. The heat pipe consists of a main wall component in the form of a pipe, a capillary axis in the form of sintered powder, screen mesh or groove, and working fluid [3].

A heat pipe is a hollow pipe consisting of three sections: evaporator, adiabatic, and condenser. Both ends of the heat pipes are closed (vacuum), and there is a working fluid in them. In addition, to gain much better performance of the heat pipe as a superconductor, there is a capillary axis named wick on the inner wall as a medium through which the working fluid from the condenser end through the adiabatic section returns to the evaporator end. In other words, the working fluid flows because of the capillary force on the capillary axis [4].

The capillary axis must also work to evenly distribute the working fluid over the surface of the evaporator, which is exposed to heat when working under steady-state conditions. Both of these functions require a different shape of the capillary axis, and the choice of the capillary axis depends on many factors, such as permeability, thermal conductivity, capillary pressure, heat transfer ability, wettability, and so on [5], which depends on the internal structure from the results of the choice of the manufacturing process and the properties of the material itself [6]. There are various forms of heat pipe capillary axis, ranging from screen mesh wick, sintered metal powder wick, grooves, and wire, all of which can be made of metal, composite, ceramic, or biomaterial [7]. The sintered powder is a type of capillary axis that can carry out a high heat transfer process with a low-temperature gradient and high capillary force in anti-gravity applications so it is the technology most widely used by manufacturers. However, making the capillary axis

e-ISSN 2623-0313
p-ISSN 3032-1972

in the form of sintered powder has the disadvantage that it produces a random internal structure and can cause fluid temperature uniformity on the capillary axis [8], whereas in selecting the capillary axis the most important and recommended thing is the level of homogeneity of the pore structure and the pore sizes should be relatively small [9], so we need a new technique in the process of manufacturing the capillary axis.

The use of SLM-type 3D printers can solve this problem because they can provide full control of the pore structure on the capillary axis [10]. In addition, the use of 3d printing can overcome high costs and limitations on pore size, as well as materials that can be used and are able to provide smooth surface results [11]. J. Esarte, et. al [10] in their research, revealed that the manufacturing process of heat pipes using 3d printing gave good results in four main parameters, namely permeability, capillarity, porosity and thermal conductivity.

In heat pipes manufacturing, there are procedures and steps that must be carried out to obtain a heat pipe that can operate and function properly, which are determining the material and geometry of heat pipes, and calculating and planning the performance limit of heat pipes. and the calculation of the actual performance limit of the heat pipe [12]. In addition, in these stages, it is necessary to carry out tests such as leakage tests, cleanliness tests, performance tests, and life tests [13]. This test aims to determine the performance level of the heat pipe, namely permeability, capillarity, porosity, and thermal conductivity so that it can be categorized and applied according to the level of performance [14-17]. A series of conventional methods are required to obtain these parameter values. One of them is the Scanning Electronic Microscope (SEM) method for observing pore radius.

Based on this, this study aims to provide an alternative solution in the form of a wick manufacturing process on heat pipes using 3D printing technology to overcome the unevenness of pores formed in the sintering process. Three capillary axes samples made of stainless steel with different pore sizes, namely 100-150µm, 250-350µm, and 400-500µm, will be made using the 3D printing method.

METHODOLOGY

1. Wick design

3D printing is a part of additive manufacturing technology, where in the additive manufacturing process, an object is created by placing thin layers in sequence until the object is formed according to the desired shape. Each of these layers can be seen as thin horizontal cross-sections of objects that eventually form a 3-dimensional object. Therefore, in the 3D printing process it is possible to produce complex shapes using less materials than traditional manufacturing methods [10]. The first thing to do in making this capillary axis is to make a design using CAD for various pores sizes which are 100 µm, 300 µm and 500 µm, as shown in Figure 1.

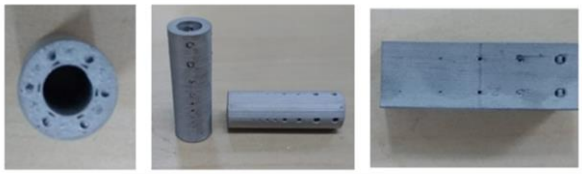


Figure 1 Various pore sizes 100 µm, 300 µm and 500 µm in vertical and horizontal printing orientation

Parameters in this 3D-Printing process, such as radius action, nozzle flow rate and material used (stainless steel) have been adjusted. Then, the results from the 3D printing process will go through a washing and sintering process in the final stage. After the capillary axis manufacturing process has been completed, the next step is to see the 3D printing results using SEM (Scanning electron microscope).

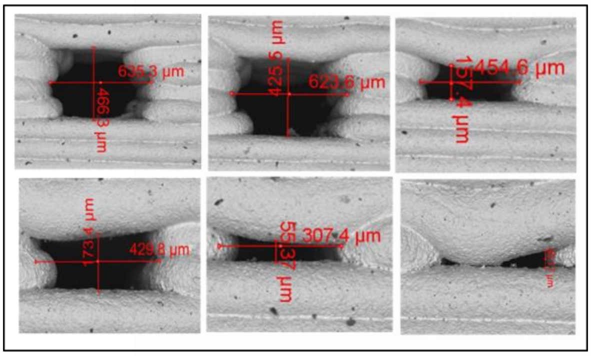


Figure 2 The result of the 3D-Printing manufacturing process with pore size 150, 300 and -500µm

The results of SEM are used to characterize and describe the surface of products produced by additive manufacturing processes. Information that can be obtained from the characteristics of the metal powder used is particle size, shape and porosity

2. Wick Fabrication

e-ISSN 2623-0313
p-ISSN 3032-1972

The tools used to make heat pipe wicks using atomic diffusion additive manufacturing technology are as follows, as shown in Figure 3. Markforged Metal X with 125µm layer printed the wick samples. This printer has two nozzles, each of which releases metal material and ceramic material (release material).

The next process is debinding the samples with Markforged Wash-1, which converts the "green part" printed by the printer METAL X into a completely solid metal called the "brown part". The debinding process uses a special low-emission method that dissolves the main binding agent. Meanwhile, the part becomes semi-porous, and the remaining binder material can easily burn during sintering. This process purifies the resulting part and helps keep the sinter furnace clean.

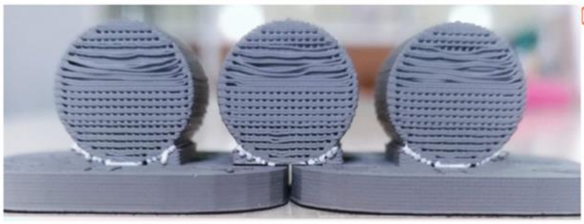
The Markforged Sinter-1 is a high-performance furnace ideal for small batch production. Sinter-1 converts the washed part into a high-quality solid metal form in approximately 26 hours with the type of gas used being Argon and an Argon-Hydrogen mixture.

Figure 3 Markforged Metal X, Markforged Wash-1 dan Markforged Sinter-1 (from left to right)

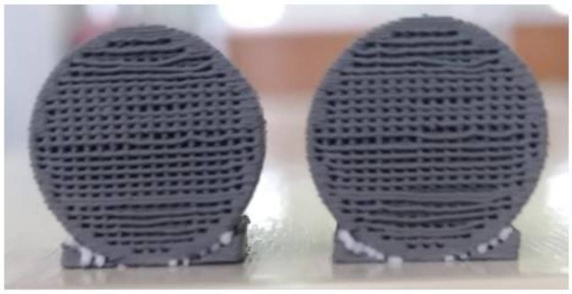
RESULTS AND DISCUSSION

Based on the SEM results of pore size samples of 500µm, 300µm and 150µm in Figure 2 it can be seen that the pore size of the printed results will be significantly different from the design because the printing layer does not match the design. For the next stage, the pore placement in the sample design will be adjusted to the printing layer, which is 125µm as the default of Markforged Metal X.

The wick sample was designed and then built by using the atomic diffusion additive manufacturing method to manufacture all of the parts. This process generates internal passages into the wick of the desired geometrical size. In the manufacturing process, the first step was to generate the CAD file of the wick. The software used for setting material types, layer slicing, and so on is Eiger Cloud, which Markforged provides. Then, this file was loaded into the 3D printer. Figure 4 shows the results of the 3D Print with a pore size of 250µm before the sintering process.



(a)



(b)

(c)

Figure 4 Wick samples from 3D printing with pore size of 250 microns (a) distance between pores 250 µm (x-axis), (b) distance between pores 300 µm (x-axis), (c) distance between pores 325 µm (x-axis)

Figure 4(a) shows that 250 µm pores with a distance between pores 250 µm were not able to hold their shape. The same condition happened for 250 µm pores with a distance between pores of 300 µm. The best wick sample that was feasible to print was 250 µm pore with a distance between pores of 320 µm.

CONCLUSION

1. The pore placement in the sample design should be adjusted to the thickness of the printing layer, 125µm. Therefore, the best diameter for designing the pore is 250 µm.

e-ISSN 2623-0313
p-ISSN 3032-1972

2. The smallest size of pores without blockage was 250 μm with a 325 μm distance between the pores on the x-axis.

ACKNOWLEDGMENT

This study was supported by Universitas Indonesia through funding in Hibah Publikasi Terindeks Internasional (PUTI) Q2 2020.

DAFTAR PUSTAKA

[1] L. L. Vasiliev, "Heat pipes in modern heat exchangers," *Applied Thermal Engineering, 2005*., vol. 25, 1, doi.org/10.1016/j.applthermaleng.2003.12.004.

[2] Harris J, "Modeling, Designing, Fabricating, and Testing of Channel Panel Flat Plate Heat Pipes., *2008*, doi: 10.1016/j.csite.2020.100767

[3] Reay D, Kew P, McGlen R. "Heat Pipes: Theory, Design and Applications: Sixth Edition." *2013*:1-251.

[4] Ariantara B, Putra N, Supriadi S., "Battery thermal management system using loop heat pipe with LTP copper capillary wick.," *IOP Conference Series: Earth and Environmental Science*. *2018*;105:012045.

[5] Kiseev VM, Vlassov VV, and Muraoka I., "Experimental optimization of capillary structures for loop heat pipes and heat switches," *Applied Thermal Engineering*, *2010*;30:1312-9.

[6] Xu J, Zou Y, Fan M, Cheng L., "Effect of pore parameters on thermal conductivity of sintered LHP wicks." *International Journal of Heat and Mass Transfer*. *2012*;55:2702-6.

[7] Li J, Zou Y, Cheng L., "Experimental study on capillary pumping performance of porous wicks for loop heat pipe." *Experimental Thermal and Fluid Science*. *2010*;34:1403-8.

[8] Ranjan R, Murthy JY, Garimella SV., "A microscale model for thin-film evaporation in capillary wick structures." *International Journal of Heat and Mass Transfer*. *2011*;54:169-79.

[9] Nandy Putra WNS., "Teknologi Pipa Kalor: Teori, Desain dan Aplikasi." *2014.*

[10] Esarte J, Blanco JM, Bernardini A, San-José JT., "Optimizing the design of a two-phase cooling system loop heat pipe: Wick manufacturing with the 3D selective laser melting printing technique and prototype testing." *Applied Thermal Engineering*. *2017*;111:407-19.

[11] Conner BP, Manogharan GP, Martof AN, Rodomsky LM, Rodomsky CM, Jordan DC, et al., "Making sense of 3-D printing: Creating a map of additive manufacturing products and services." *Additive Manufacturing*. *2014*;1-4:64-76.

[12] D. Reay RM, and P.Kew., "Heat Pipes: Theory, design and applications." *2013*.

[13] Putra N, Saleh R, Septiadi WN, Okta A, Hamid Z., "Thermal performance of biomaterial wick loop heat pipes with water-base Al2O3 nanofluids." *International Journal of Thermal Sciences*. *2014*;76:128-36.

[14] Putra N, Septiadi WN, Rahman H, Irwansyah R., "Thermal performance of screen mesh wick heat pipes with nanofluids." *Experimental Thermal and Fluid Science*. *2012*;40:10-7.

[15] Zohuri B., "Chapter 5 - Heat pipe heat exchanger opportunities and industrial applications." *In: Zohuri B, editor. Functionality, Advancements and Industrial Applications of Heat Pipes: Academic Press; 2020*. p. 275-305.

[16] Jafari D, Wits WW, Geurts BJ., "Phase change heat transfer characteristics of an additively manufactured wick for heat pipe applications." *Applied Thermal Engineering*. *2020*;168:114890.

[17] Yan D, Gu M, Zou L., "Numerical analysis of the heat transfer in a naphthalene heat pipe based on the modified Nusselt model." *Applied Thermal Engineering*. *2020*;167:114730