Diffusion Welding of Wire Micro Heat Pipe Arrays

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Abstract

One of the main challenges in the design of micro heat pipes is to obtain the porous media that is able to provide the necessary liquid pumping from the condenser to the evaporator. Usually, the sharp corners of the grooves, where the liquid flows, work as the porous media. One of the fabrication processes consists of the union of cylindrical wires between two thin plates. The edges formed between the wire and the plate provides the capillary pressure. In this work, the procedures involving the diffusion welding process used in the fabrication of wire micro heat pipes arrays is presented. The first one comprises of stretching the wires over one of the copper plates, using an auxiliary support that maintain the spacing of the metal wires under control. Second, contacting surface solid state copper diffusion welding was used to joint the wires with the thin plates. In this process, the mass transfer mechanism that takes place fills the empty spaces between the materials in contact. Therefore, the continuous contact between the plate surfaces and the wires provides the necessary sealing to the proper operation of the device. In this work, the welding diffusion technique is detailed. Also, thermal experimental data of prototypes constructed through this process are presented and compared with data of micro heat pipes constructed using other technique.

Key Words: Micro heat pipe, diffusion welding

1. INTRODUCTION

The physical operation principles of micro heat pipes are similar to those of the large conventional heat pipes. The heat applied to the evaporator region vaporizes the working fluid within the porous media and the resulting vapor flows to the condenser through the central region of the heat pipe. The vapor then condenses, releasing the latent heat of condensation. Due to the evaporation and condensation processes, the meniscus liquid-vapor interface varies continuously from the condenser to the evaporator in the capillary media. This results in a pressure difference between both regions that promotes the flow of the working fluid from condenser back to the evaporator.

Many different techniques can be employed in the manufacture of micro heat pipes. One of them consists of the machining of triangular and trapezoidal grooves on flat plates that are welded together in their edge [1]. Due to the very small dimensions of the grooves necessary to provide the capillary pumping of the working fluid in micro heat pipes, machining is a delicate process because the capillary structure dimensions are too small. Very especial wises, high qualified technicians and sharp diamond

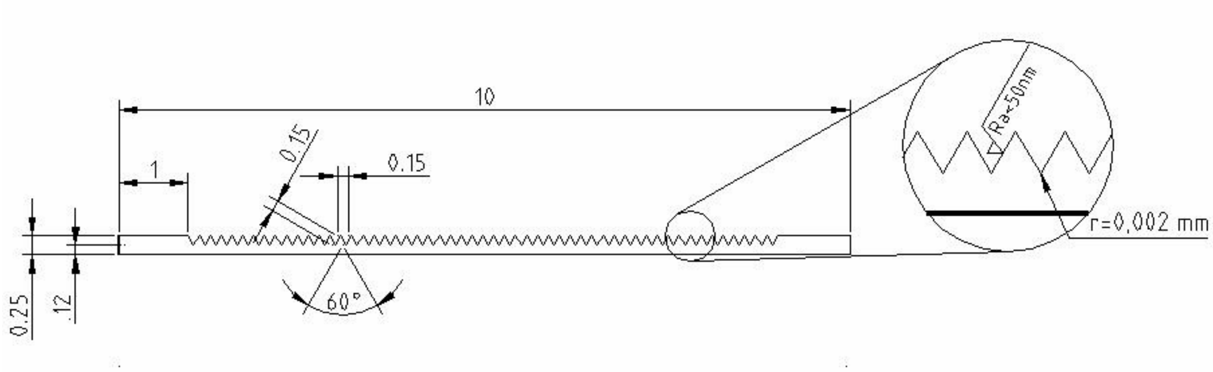

Figure 1- Grooves dimensions resulting from the machining fabrication process (in mm).

tools are necessary for the high precision narrow tolerance machining, making this process very expensive and time consuming. The Mechanical Precision Laboratory (LMP) of the Federal University of Santa Catarina (UFSC), Brazil, machined some plates that were used in some of the micro heat pipes constructed and tested in the Satellite Thermal Control Laboratory (NCTS), of this same University. As they present similar dimensions to those reported in this work, the results will be used for comparison purposes. Even though the thermal results of this process were very satisfactory, this procedure was left aside for the moment, due to the high costs involved.

Another technique consists of brazing aluminum wires between plates [2]. A more sophisticated welding procedure, the diffusion welding, presents better thermal performance considering that some of the brazing material can block regions of the grooves formed between the wire and plates. The main concern of the present work is to describe diffusion welding fabrication processes developed for wire plates micro heat pipes. Also, a brief explanation about the machining process is presented. The thermal performance of the heat pipes fabricated with this technique will be compared with the micro heat pipes fabricated with the machining procedure.

2. FABRICATION PROCESSES

2.1. Machining

The cross section of the micro heat pipe, fabricated through the machining process is presented in Figure 1. In this figure, the triangular groove geometry and the achieved dimensions are also shown. The micro heat pipes constructed have approximately *10 x 83 mm* by *2 mm* of thickness and should transport up to *10 W* of heat power. The usual literature method [2] [3] [4] was used to determine its geometry taking into account the thermal and geometrical parameters. It is not the scope of the present paper to describe the calculation developed. To achieve the necessary working fluid pumping capacity through the heat pipe, *53* grooves were machined in a copper plate of *0.3 mm* of thickness, in the axial direction. *1 mm* was left in the four edges for welding, so that all the parallel grooves were machined within *8 mm* in the width direction. The triangular grooves presented $130\mu m$ of depth and $150\mu m$ of width, as shown in Figure 1.

One should note that the only geometry possible to be drilled by the machining process is triangular. More than that, the curvature of the active corner cannot be very sharp, because the diamond tool to be used in the machining would very fragile and expensive, making the process unfeasible. This is the reason why so many and small groves were necessary. The resulting plates with the grooves are shown in Figure 2.

Figure 2- Grooved plates, resulting from the machining process.

2.2. Diffusion Welding

When a plate and a cylinder touch each other, a very sharp edge between then is observed. If these surfaces can be welded without blocking the groove, these edges can work as efficient porous media for heat pipe applications. The diffusion welding is able to provide these grooves.

The solid-state diffusion is a welding union process in which atomic diffusion, activated by high temperature levels and controlled pressure applied between the surfaces, induces a very strong junction. The main disadvantage of the welding diffusion, when compared to the traditional welding processes, is that the thermal cycle necessary for the proper welding can be too long. As a consequence, the production is limited and its costs can increase. Another limitation is concerned to the geometry of the surfaces to be welded [5] [6].

Typically, the diffusion welding is realized between *0.5 – 0.8* T_f , where T_f is the melting temperature of the basis material. For the copper (Cu), the process shows optimum results, for temperatures ranging between *450 ºC* and *820 ºC*, depending on the geometry of the samples, the applied specific pressure and the welding time [7]. The atmosphere is also an important parameter. Usually, Cu plates are welded at high-vacuum environment, but an inert or reduced atmosphere can also be used.

In this work, the temperature diffusion welding cycle adopted is presented in Figure 3. The vacuum level adopted was about 10^{-4} *mbar*. The pressure to be applied depends on the geometry of the micro heat pipe and a special device, for the load application, was designed and constructed especially for the micro heat pipe welding. This device takes advantage of the difference between the thermal expansion properties of the copper and of the stainless steel, so that, as the temperature increases, the pressure applied also increases. Figure 4 shows the charge pressure device, highlighting the side view with the micro heat pipe inside.

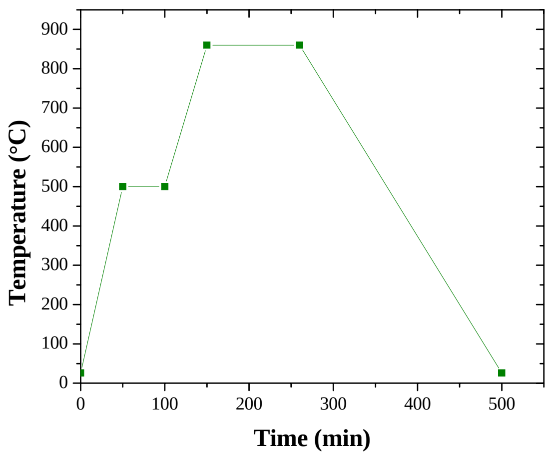

Figure 3- Diffusion welding temperature cycle.

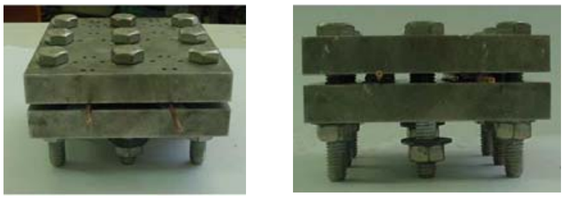

Figure 4 - Stainless steel matrix.

To guarantee a good welding, the wires and the flat plate must be cleaned with 10% sulfuric acid solution to remove any oxidation that could block the copper diffusion, before the thermal cycle. Flowing water was used to rinse the wires and the plate, for about *10 min*. After the welding, acetone was introduced in the micro heat pipe to wash the grooves, which are filled with the working fluid.

2.3. Experimental study

After the fabrication process is concluded using any of the techniques described in this work, the micro heat pipe is leak tested using an Edwards Leak Detector. Then, they are charged with distillated water, the selected working fluid, and sealed. The volume of working fluid is equivalent to the volume of all the grooves plus 40%.

After the charging, the micro heat pipe fabrication can be considered concluded and it is ready for the experimental measurements. Three different configurations were tested in the present work: grooved heat pipes, wires plate heat pipes and a unfilled heat pipe. All of them presented *83 mm* of length, *10 mm* of width and *2 mm* of thickness. The thickness of the wires used was *1.45 mm* and of the plate was *0.3 mm*. The test lasted about one hour, but the steady state conditions were achieved after about *5 min*.

Figure 5- Micro heat pipes manufactured at NCTS.

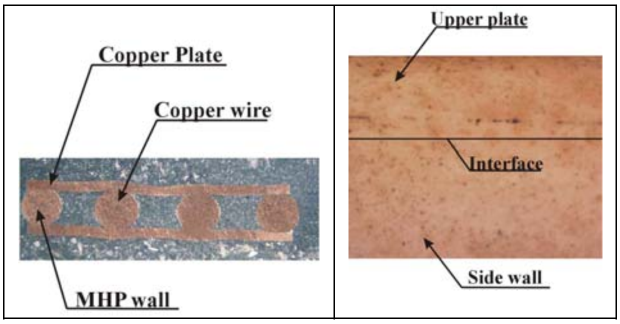

Figure 6- Micro heat pipe cross section and its interface.

Figure 5 shows a picture of all the micro heat pipes constructed in the laboratory. Figure 6 shows a micrography image of its cross section, highlighting the sharp edges obtained between the wire and the plates and the almost unidentifiable welding at interfaces.

The micro heat pipe is divided in three parts: evaporator, adiabatic section and condenser. It is desirable to test the micro heat pipe in a horizontal position, where the effect of the gravity force can be neglected. Figure 7 shows a schematic of the experimental apparatus mounted.

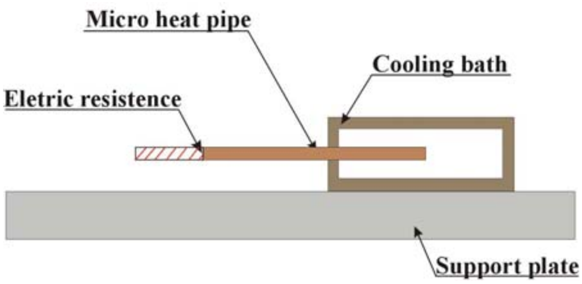

Figure 7- Experimental apparatus.

The evaporator has *25 mm* of length. The heat is generated and delivered by means of an electric resistance, wound around the evaporator. The adiabatic section, of *20 mm* of length, was thermally insulated with fiber glass.

The length of the condenser is about *38 mm*. The cooling water flows through a PVC tube, as shown in Figure 8, so that the condenser is in direct contacted with the cooling fluid, during the tests. The cooling water temperature, controlled by a thermal bath, is 25°C ± 0.01.

The temperature along the tube is monitored by means of six thermocouples (see Figure 9) that are attached to the micro heat pipe surface through Kapton tapes.

Figure 8- Condenser device.

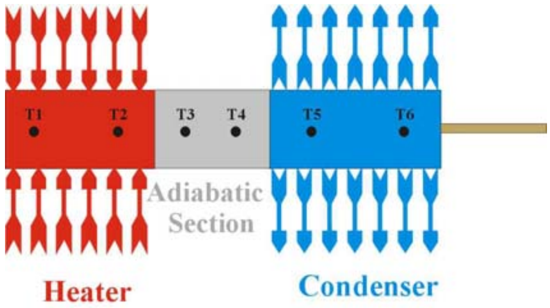

Figure 9- Thermocouple locations.

2.4. Results

The experimental temperature distribution of the micro heat pipes fabricated through the two procedures presented, grooved and wired, is compared with a configuration with no working fluid. The tests conditions were the same in all tests. Two kinds of plots are shown: temperature x position (Figure 10) and temperature x time (Figures 11, 12 and 13). The performance of a micro heat pipe can be associated with its capacity to transfer heat power from the evaporator to the condenser. The better its performance, the lowest temperature difference between the evaporator and the condenser. Using this criteria, it can be observed that the grooved heat pipe presents the best performance. It presented an overall resistance (ratio of the difference between the evaporator and condenser temperatures to the power input) *3.5* times smaller than that obtained for the heat pipe without working fluid. For the case of the micro heat pipe with wires, the overall thermal conductivity showed to be *1.8* times that without working fluid. From these figures, one can observe that the three sections of the micro heat pipe presents three different temperature levels. One can also observe that the steady state conditions is reached faster for the grooved (around *200* seconds) than for the wired heat pipes (around *500* seconds).

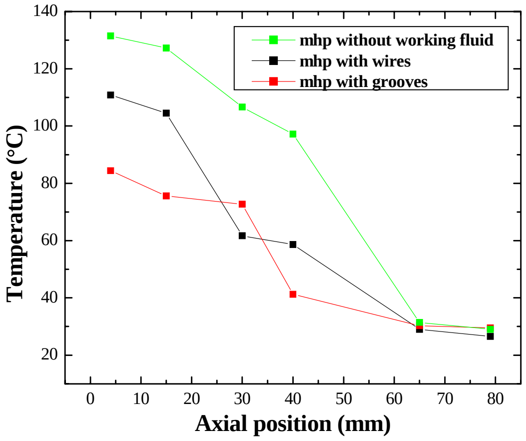

Figure 10- Three micro heat pipe configurations tested with 10W.

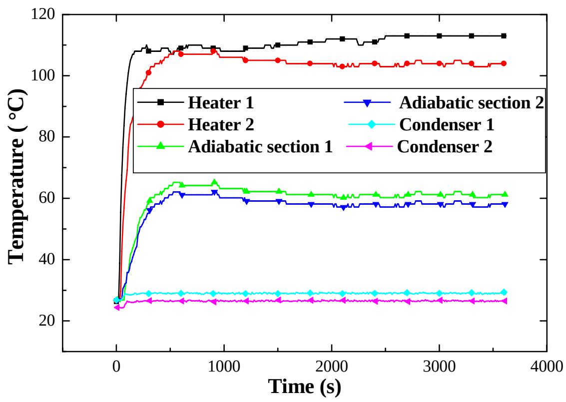

Figure 11- Micro heat pipe with wires, for 10 W of heat dissipation.

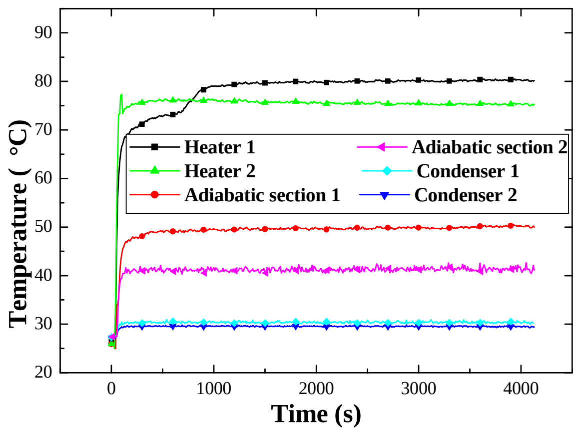

Figure 12- Micro heat pipe with grooves, for 10 W of heat dissipation.

3. CONCLUSION

In this work, two different techniques were used for the construction of micro heat pipes. Special emphasis was dedicated to the diffusion welding wire micro heat pipes. The thermal performance of these heat pipes were compared with that for a working fluid

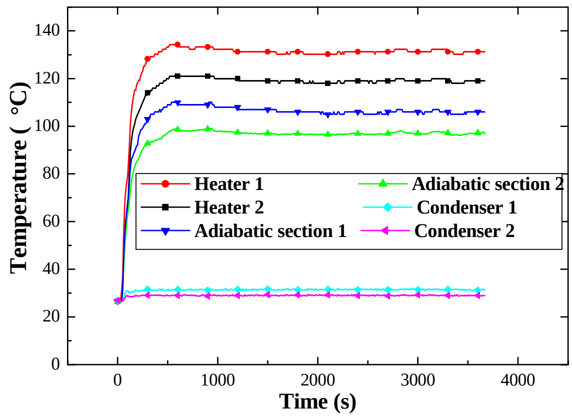

Figure 13- Micro heat pipe without working fluid, for 10 W of heat dissipation.

The results of this work indicated that the maximum heat transfer occurred for the micro heat pipe with machined grooves, due to the large number of grooves available (*53*), against only *12* grooves for welding process. Actually, the geometry of the heat pipe fabricated was not favorable for the employment of the diffusion welding technology, because only a few grooves were possible to be obtained. This study indicates, however, that this new technology is promising, due to the quality of the corners obtained and due to the easy and inexpensive fabrication process.

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