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Fabrication of Large Three-Dimensional Flow Path Structure Using SS Flexible Tube

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Abstract. Aluminum is a commonly used material when cooling channels are required due to its high thermal conductivity and light weight. However, aluminum has a low corrosion resistance which is a key factor to be aware of when a cooling system utilizing water is required. Metal Technology Co. Ltd. (MTC) currently manufactures a variety of aluminum products in which stainless steel (SS) tubes are embedded and bonded with HIP to improve corrosion resistance while maintaining a light weight. As the demand for complex three-dimensional (3D) cooling channels increases, the complexity creates limitations on creating the cooling channels using the current methods and processes. 3D flow paths can be fabricated if SS tubes are bent and then welded together, but the assembly process for HIP is complex. Complex, thin-walled SS flexible tubes are not able to withstand the pressures applied during diffusion bonding. MTC, has successfully developed an alternative for making internal 3D cooling channels with SS flexible tubes.

Introduction

As the demand for smaller more powerful chips in the semiconductor market grows, so does the need for more complex cooling systems for the equipment that makes these chips. Some of the requirements for these new systems are low weight, high thermal conductivity and efficiency, and high corrosion resistance. With that in mind, flow path design in recent years is changing from a simple structure to a 3D structure. This requires more sophisticated manufacturing techniques and technology that can deliver the desired results.

Aluminum is often used as the material of choice for temperature control parts because of its excellent thermal conductivity and light weight. However, corrosion resistance is an obstacle when aluminum is used. Therefore, SS tubing is embedded in the aluminum and integrated with HIP to produce a temperature control component that is light weight and has excellent thermal conductivity while improving corrosion resistance.

However, there are some problems in fabricating parts with 3D flow paths. First, the more complicated the SS tube becomes, the more difficult it becomes to bend. Further, SS tube must have a wall thickness that can withstand bending without failure. As SS is inferior to aluminum in heat transfer, the performance of the cooling component decreases as the thickness of the tube becomes thicker. With that in mind, we propose manufacturing a large 3D flow channel structure using SS flexible tubes to solve these problems.

Challenge

Deformation of SS flexible tube

When manufacturing a 3D flow channel structure using SS flexible tubes, it is necessary for thin-walled SS flexible tubes to withstand the high temperature and pressure environment found during HIP treatment. We carried out various tests to determine the diameter and wall-thickness of the SS flexible tube to determine the parameters for temperature and pressure during HIP.

Heat exchange efficiency of SS flexible tubes and SS tubes
Temperature control parts are required to have high performance regarding heat exchange. It is anticipated that a cooling water channel with a SS flexible tubes wider surface area, in comparison with a standard SS tube, will provide better cooling performance. To confirm this, samples were produced to confirm the cooling performance and flow when using SS flexible tubes.

Experiment
Deformation of SS flexible tube
The HIP conditions were as follows: temperature at 600°C (1112°F) and pressure at 30Mpa. The aluminum "flowed" into the gaps in the SS flexible tube at all diameters. Figure 1 shows the HIP processing results.

Outline of test
- Flexible tube shape: Diameter of 16mm (0.63"), 29.5mm (1.16"), 54mm (2.13").
- Base metal: A1050 stress-relieving material is used.
- HIP-condition: Main thermal temperature 600°C (1112°F), pressure 30MPa

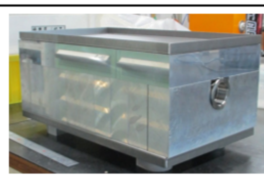
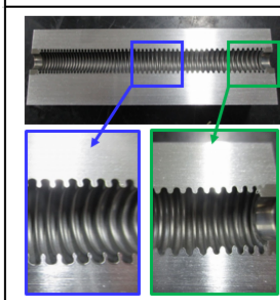
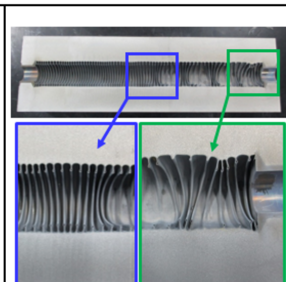
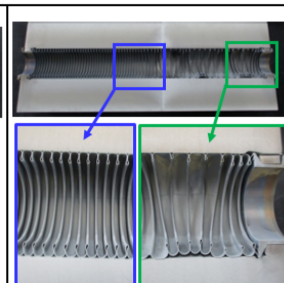
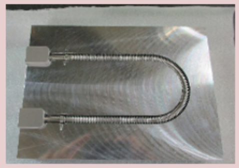
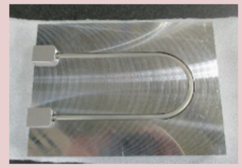
Tube Ø16mm (0.63")	Tube Ø 29.5mm (1.16")	Tube Ø 54mm (2.13")
Assembly		
		
After HIP		
		

Figure 1. SS Flexible Tube Diameter Difference HIP Test

As shown in Fig. 1 the 54mm (2.13") tube after HIP shows significant deformation and was unable to obtain the desired HIP results. The 29.5mm (1.16") tube did obtain the desired HIP results, but also showed some deformation. The small diameter tested at 16mm (0.63") was able to obtain the desired HIP results while maintaining the original shape of the flexible tube.

Heat exchange efficiency of SS flexible tube and SS pipe
(1) Confirmation of cooling performance using a small sample
Considering the above-mentioned diameter differences during HIP testing, a small sample was manufactured using a flexible tube with an outer diameter of 8.5mm. The SS tube is a thin

thickness tube that can be bent and has a shape similar to a flexible tube with an outer diameter of 8.5mm. Figure 2 shows the shape of each small sample.

	SS flexible tube	SS tube
Sample: Before HIP		
Sample: After HIP		

Pipe details

SS flexible tube: Diameter of 5.5mm (0.22") × 8.5mm (0.33") thickness : 0.15mm (0.006")

SS tube: Diameter or 5.35mm (0.21") × 6.35mm (0.25") thickness : 0.50mm (0.02")

Block outline

External dimensions: 200mm (7.87") × 150mm (5.91") × 65mm (2.56")

Figure 2. Small Sample Geometry

To confirm the state of heat exchange efficiency, the samples were heated to measure the temperature change while cooling water flowed through the tubes. Heated by a hot plate, the cooling water flowed at 4L/min after the small sample reached 100°C (212°F). The temperature was measured with a thermocouple. Figure 3 shows the measurement positions for the temperature check and the schematic diagram of the test. Figure 4 shows the temperature measurement results.

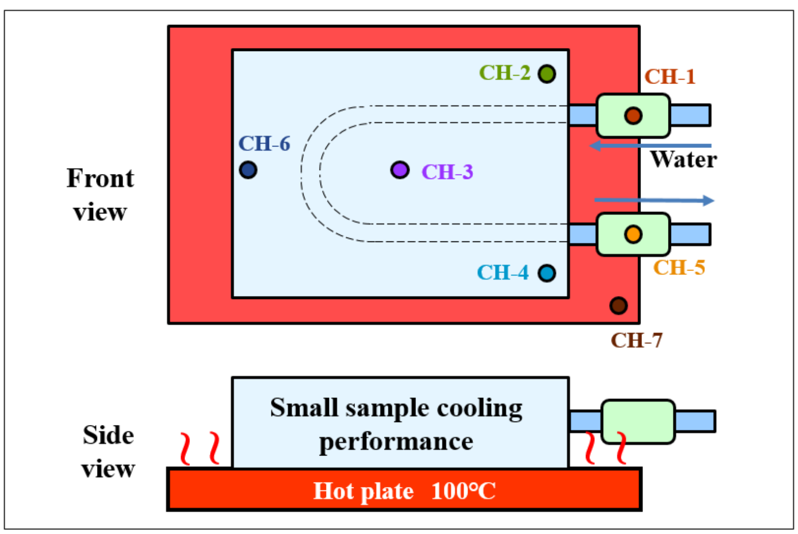


Figure 3. Test Overview

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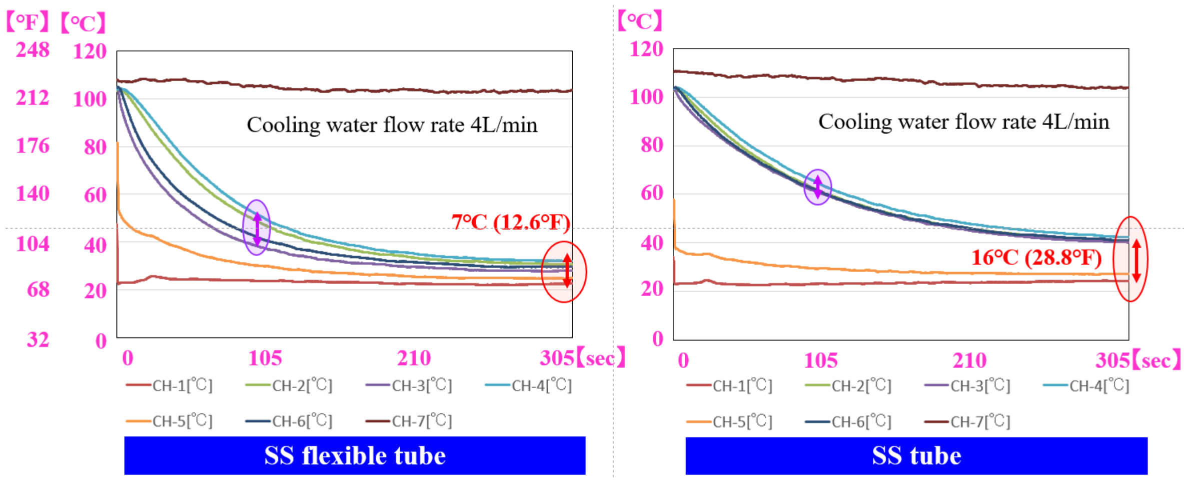


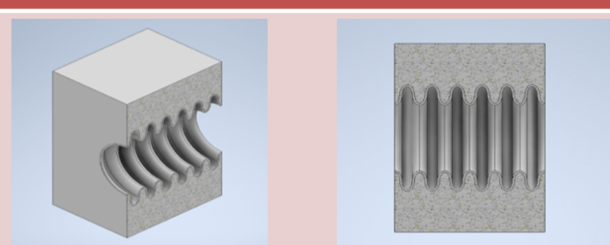
Figure 4. Actual Temperature Results of SS Flexible Tube and SS Tube

As cooling water flowed through the samples, a comparison of temperature at 105 seconds was done. While the standard SS tube temperature was between 60℃~65℃ (140~149°F), the SS flexible tube was between 38~48℃ (100.4~118.4°F). Although some variation was evident, this data shows that the SS flexible tube was more than 10℃ (18°F) cooler at this point.

When a temperature comparison of the samples was done at 305 seconds, the temperature variation in the standard SS tube was about 16℃ (28.8°F), while that of SS flexible tube was about 7℃ (12.6°F). The results show a difference of 9℃ (16.2°F) in the cooling capacity difference at the measured interval.

(2) Water flow vector analysis of SS flexible tube

Analysis was used to investigate the effects of unevenness on the surface of the flexible tube on the water flow. The analysis model was the SS flexible tube used in (1) "Confirmation of cooling performance using a small sample". Figure 5 shows the analysis model and analysis conditions. Analysis results are shown in Fig. 6.

	SS flexible tube
Analysis model structure	

Pipe details

SS flexible tube: Diameter of 5.5mm (0.22") × 8.5mm (0.33") thickness : 0.15mm (0.006")

Cooling water

4L/min(66.7g/sec)

Figure 5. Analysis Model and Conditions

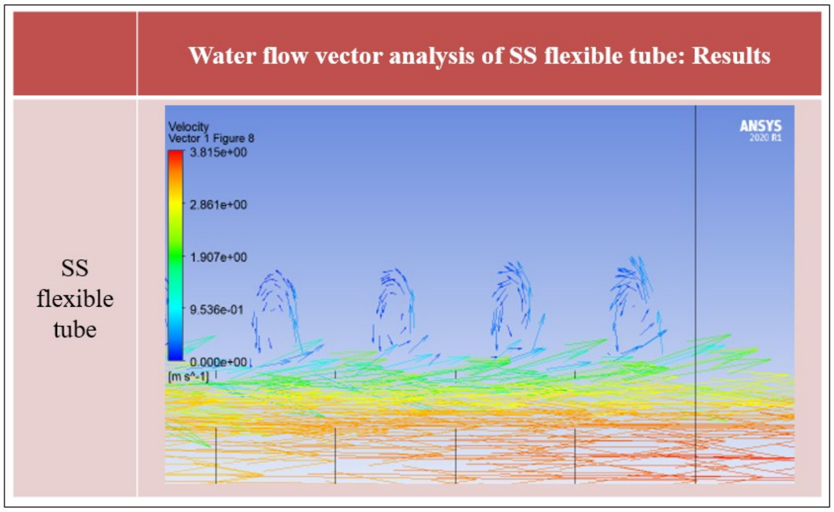


Figure 6. Water Flow Vector Analysis

Figure 6 shows that the water flow near the surface of the tube forms a vortex in the opposite direction to the flow due to the uneven design of the flexible SS tube. In addition, the flow velocity slows where the vortices are generated.
It was found that the flexible SS tube has higher cooling performance than the standard SS tube in the test results of the small samples described above, but it is believed that better cooling performance may be further improved by adjusting the water flow.

Adaptation to Large Parts Using SS Flexible Tube
Larger sample parts were tested using the processing conditions and test results described above.

Figure 7. Photographs are shown on the product.

- External dimensions: 400mm (15.75")×220mm (8.66")×30mm (1.18")
  Total length after assembly: 1200mm (47.2")
  Cooling tubes were placed on the curved surface of R2000 (78.7").
- Manufacturing process: Pre-processing → Assembly → HIP → De-capsulation →Machining → Wire cutting.

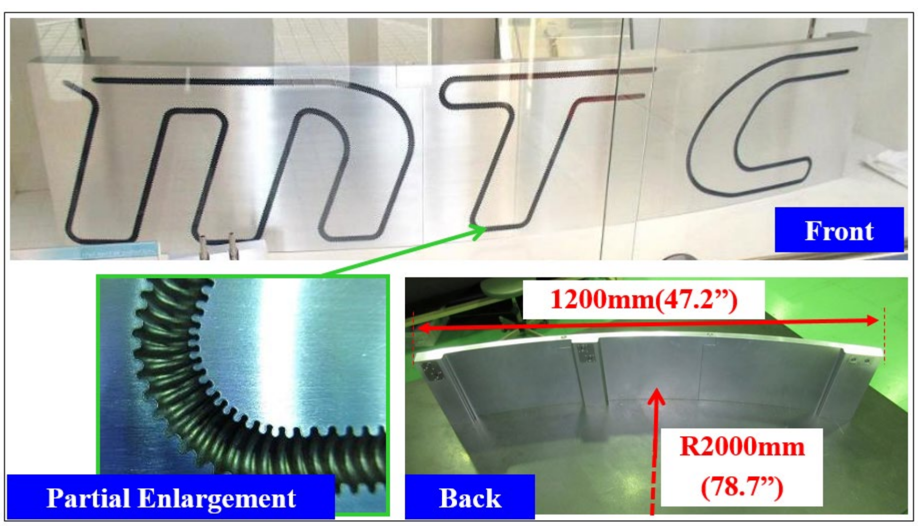


Figure 7. Large Part Sample Using SS Flexible Tube

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It was determined that the aluminum flowed into the gaps of the SS flexible tube without crushing the tube and the desired HIP effect was obtained in spite of the large parts. Samples were designed so that the letters "M T C" were exposed on the curved surface during cutting. It has been determined that manufacturing large 3D flow channel structures with complicated shapes is possible by using SS flexible tubes.

Conclusion

It was proven that the flow of aluminum, without crushing the uneven portion of the SS flexible tube is viable when diameters of 16mm (0.63") or less are used. Regarding heat exchange efficiency, SS flexible tubes were superior to standard SS tubes from the test results obtained from the small samples and a cooling capacity difference of 9℃ (16.2℉) was observed under the same conditions. Finally, it was determined that the manufacture of large 3D flow channel structures using SS flexible tube is possible.

Moving forward, the challenges of increasing the diameter and flow characteristics will be investigated. Once these challenges have been met, the range of products benefitting from this technology will expand and many more benefits will be achieved.

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