Etching Solutions for Heat Exchanger Components

Advanced Chemical Etching Ltd.

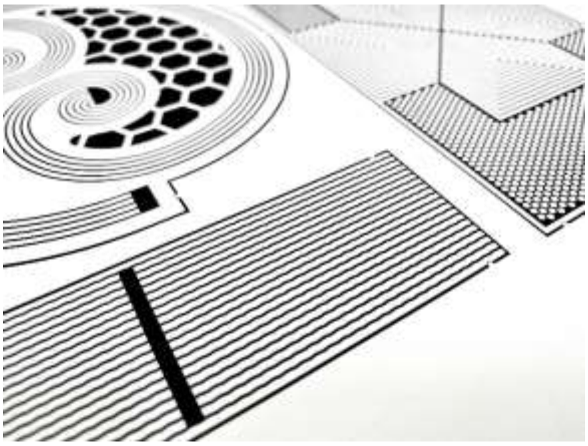
Contents

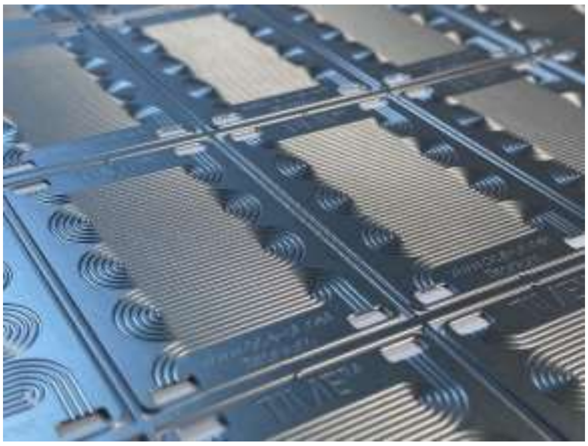
WHAT IS PHOTOCHEMICAL ETCHING?

Photochemical etching is a subtractive metal processing technique in which metal is removed selectively from a flat metal surface using a chemical reagent to create specific shapes or patterns.

The process uses CAD drawings transferred onto transparent photo-tools and used to create a negative image on a photosensitive polymeric film (photoresist) applied to the metal surface.

This process produces high resolution parts, often with complex geometries or with arrays of variable aperture profiles in relatively thin flat metal sheets from several tens of microns to ~2 mm in thickness. The process has a number of technical and economic advantages over other techniques such as traditional metal cutting and stamping.






WHAT ARE HEAT EXCHANGER PLATES?

Heat exchangers are designed to facilitate the transfer of thermal energy (heat) from one fluid to another. Heat exchangers are ubiquitously used in a wide range of applications from food sterilization to power generation. In recent years, there has been a drive to develop more compact and efficient heat exchangers for a wide range of applications where heat management is required. In many applications, it is desirable to reduce the volume of the heat exchanger without reducing the heat transfer surface area. Compact heat exchangers are characterized by a large heat transfer area to volume ratio starting around 700 m2/m3.

An important type of heat exchangers is the plate heat exchanger. Plate heat exchangers use metal plates with features or geometries that allow the flow of two fluids and the transfer of heat between these fluids. This type of heat exchanger was introduced in 1923 for milk pasteurization and is widely used in food and drink processing. A plate heat exchanger consists of one or multiple stacks of alternating layers (hot-cold, hot-cold, etc.) of corrugated metal plates in a bolted frame. The edges of the exchanger cores are sealed using gaskets or by brazing, laser welding or diffusion bonding. Plate heat exchangers can handle high pressures up to 600 bars or even higher, and temperatures from deep cryogenic to more than 800°C.

Fluid flow and heat transfer can be achieved using flow channels of different shapes. Heat transfer can be enhanced by providing a large surface area between the two fluids and by using a metal of high thermal conductivity in the construction of the exchanger plates. An example application of plate heat exchangers is in the cooling of lithium-ion batteries. Lithium-ion batteries are widely used to store energy in electric and hybrid electric vehicles. In order to maintain an optimum battery temperature, the battery is cooled using a plate-to-plate heat exchanger which transfers the heat from the battery coolant loop to the vehicle’s refrigerant loop. A number of potential applications of compact heat exchangers have also been reported, including applications in the nuclear industry and as a means of heat dissipation from NASA’s future spacecrafts.

This document aims to demonstrate how the photochemical etching technique can be employed in the manufacture of plate heat exchangers, and how it can be useful in the optimization of the design of such heat exchangers. But first, let us take a brief look at how heat is transferred between two fluids.

HEAT TRANSFER AND THERMAL CONDUCTIVITY

On a molecular level, heat is a measure of the average kinetic energy of the molecules that make up a material (that is, the energy due to the movement of the molecules). In fluids (i.e., liquids and gases), molecules are in constant motion, and the faster they move, the higher their kinetic energy and the higher the temperature. The molecules of a solid, in contrast, do not move from one point to another; instead, they vibrate. The higher the temperature of the solid, the faster its molecules or atoms vibrate and the bigger the amplitude of the vibrations.

To transfer heat from a hot fluid to a colder fluid, we need a method of transferring the kinetic energy of the fast-moving molecules of the hot fluid to the slower-moving molecules of the colder fluid. This can be achieved through the use of a medium that can absorb thermal energy from the hot fluid and deliver it to the colder fluid. The medium must be (i) in the solid state so that it forms a physical barrier between the two fluids, (ii) chemically passive towards the two fluids so that it does not react with them, and (iii) a good conductor of heat. A certain class of materials fits the bill perfectly, namely metals. Metals are solid and remain in the solid state at high temperatures; several metals have excellent chemical resistance thanks to their protective oxide layer; and finally, metals are excellent conductors of heat.

The high thermal conductivity of metals is a result of a special feature of their atomic structure. In the solid state, the atoms of a metal join together in a way that allows each atom to donate one, two, or three of its electrons to form a sea of electrons that are free to move within the metallic structure, while the atom itself turns into a positive ion. This sea of delocalized electrons is central to many of the useful properties of metals. It allows metals to conduct electricity and heat and it gives metals a strong metallic bond. When one end of a metallic bar is heated, the heat causes the free electrons in the heated part of the bar to move faster. These high-energy electrons then collide with slower electrons and also with the positive ions of the metal. With each collision, a fast-moving electron transfers part of its energy to a slower-moving electron or to a metal ion. As a result, the electrons move faster and the ions vibrate more. The vibrations spread throughout the metal, heating up the entire metal bar.

The same mechanism operates when one side of a metal sheet is in contact with a fluid at high temperature while the other side is in contact with a fluid at a lower temperature. Heat is transferred from the hot fluid to the metal, and then from the metal to the colder fluid. The larger the contact area between the fluids and the metal, the higher the rate of heat transfer. Heat exchangers utilize this mechanism to allow hot fluids to transfer their heat to colder fluids through a metal medium.

The rate at which heat is conducted through a metal varies from metal to metal. Silver, copper and gold, for example, have very high thermal conductivities at 420, 390 and 318 W/m°C, respectively. Aluminium – an attractive metal in many applications due to its light weight – is also an excellent thermal conductor at 220 W/m°C, while stainless steel has one of the lowest thermal conductivities among metals at 14 W/m°C, but this is still significantly higher than the conductivity of most non-metals. For comparison, the thermal conductivity of water is 0.6 W/m°C.

CHEMICAL ETCHING OF HEAT EXCHANGER PLATES

Photochemical etching is used to create flow channels that are typically between 0.2mm and 3mm in width on flat metal plates. The narrow channels allow a large heat exchange surface area within a relatively small volume. The etching technique is similar to the process used to manufacture electronic printed circuit boards, hence the name given to this type of heat exchangers. The flow channels produced by etching have a semi-circular cross section. The plates can be manufactured in a range of high-performance alloys such as austenitic stainless steels, nickel-based alloys, copper and titanium.

The etched plates are stacked and then joined together using diffusion bonding. This is a solid-state joining process that works by applying heat (at temperatures in excess of 60% of the melting point of the metal) and pressure in a controlled atmosphere to allow grain growth across the two metal surfaces being joined. The resulting joint exhibits the strength and ductility of the parent metal.

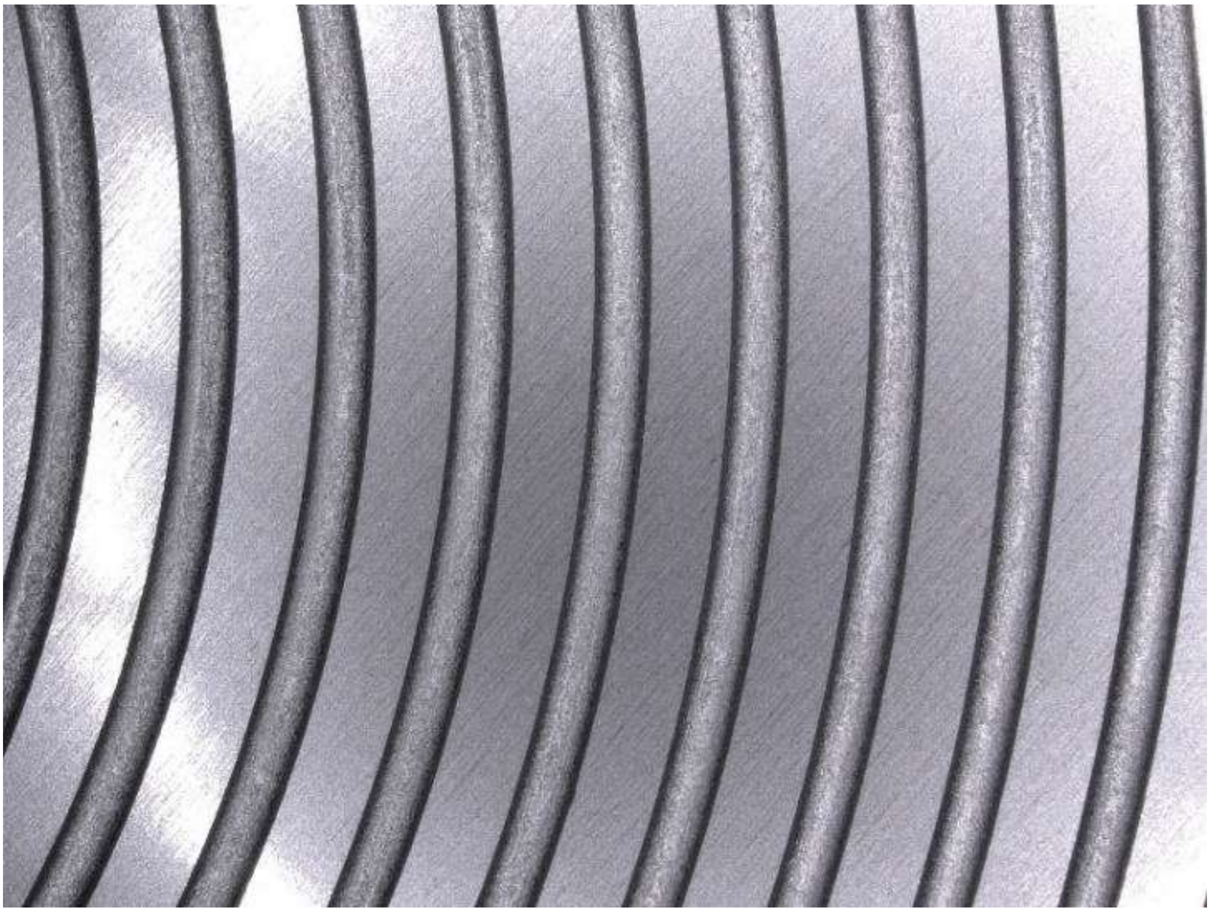
Printed circuit heat exchangers are used in applications such as natural gas processes, gas turbines, and hydrogen fuelling stations. Two major factors affecting the thermal performance of these heat exchangers are the geometry (e.g., wavy or zigzag shaped) and dimensions of the flow channels, and the type of flow employed (parallel, counter or cross flow). During the development stage of the heat exchanger for a particular application, the speed and low-cost tooling of the photochemical etching process allows different channel geometries and flow types to be tested. Experimentation with different designs can be achieved at a low cost.

The flow channels produced by photochemical etching usually have a semi-circular cross section, as shown below. The images show a cross section through an etched plate with multiple one- and two-sided offset flow channels.

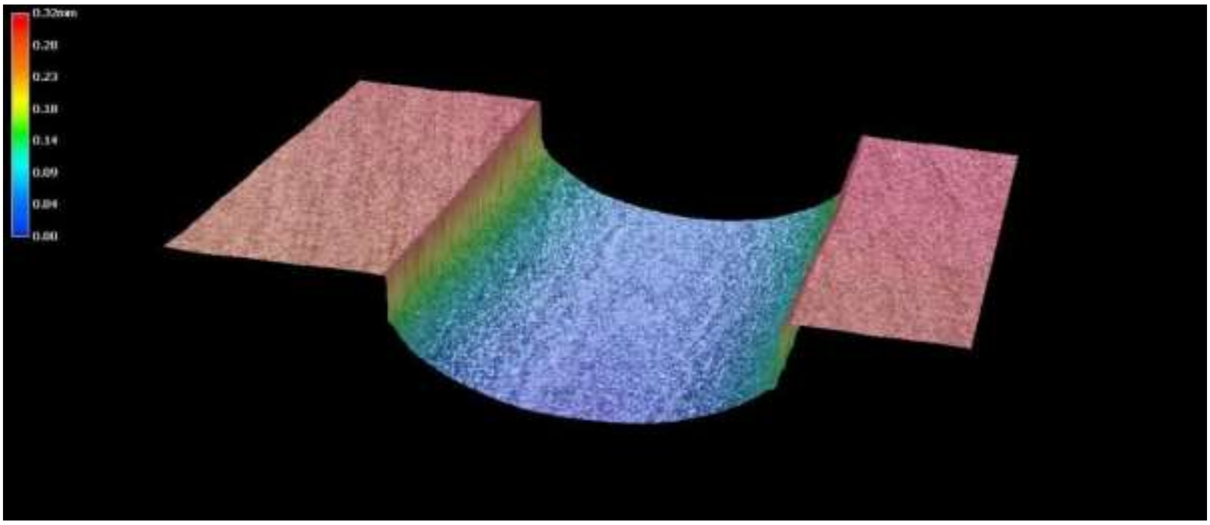
Flow channels on a heat exchanger plate produced by photochemical etching

Advanced Chemical Etching Ltd. manufactures heat exchanger plates in different sizes, metals and geometries. In particular, ACE can produce high quality heat exchanger plates in four classes of materials: stainless steel, aluminium, copper and titanium alloys. Flow channels are created by selectively dissolving the metal in a controlled way during the photochemical etching process. First, a photosensitive polymeric film, known as the photoresist, is applied to the metal surface. The required plate design is then printed on a transparent polymeric film called the photo tool. The photo tool is used to transfer the image onto the photoresist-coated metal sheet using UV light. The photoresist is then selectively removed from the areas that require etching, thus exposing the bare metal in these areas. In the etching step, the bare metal is dissolved using a chemical reagent until the required dimensions are achieved. Finally, the photoresist layer is removed using a special chemical reagent.

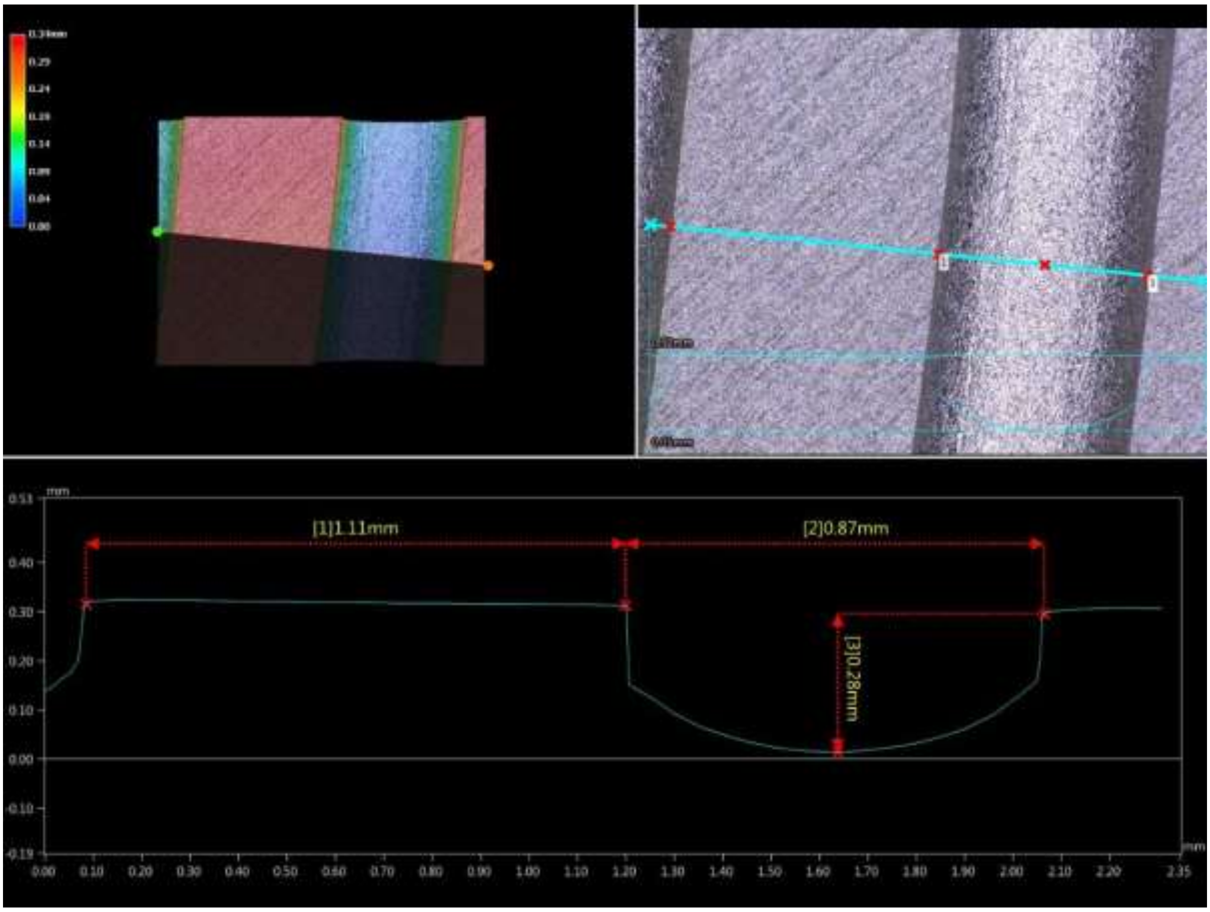
The below photos show a section of a stainless steel plate with semi-circular channels with 20x magnification and 3D microscopic images of ridge and channel details.



Flow channels on a heat exchanger plate produced by photochemical etching (20x magnification)



Cross-section of an etched flow channel at 200× magnification



Measurements of channel and ridge dimensions taken with a digital 3D microscope

The channel and ridge dimensions are shown in above image in addition to the typical cross section of the channels that can be produced by photochemical etching. In this case, the channel depth is 0.28mm, the channel width is 0.87mm and the ridge width between two adjacent channels is 1.11mm.

The channel and ridge dimensions have a big influence on the overall performance of the heat exchanger. The dimensions of the channels affect the heat transfer characteristics between the two fluids. The surface between adjacent channels – the ridge surface – can affect the bonding characteristics, as well as the flow and heat transfer characteristics. A smaller ridge width allows for a larger overall flow and heat transfer area on the plate, but reduces the available metal-to-metal contact area between the bonded plates. Optimization of this dimension should yield the minimum acceptable ridge width that allows a sufficient bonding surface area without compromising the flow and heat transfer characteristics of the heat exchanger. Trials conducted at ACE show that a ridge width as narrow as 250μm can be produced consistently by photochemical etching.

The speed and low cost of the etching process mean that several design iterations can be produced and tested within a short period of time in order to arrive at the optimal plate design. Advanced measuring equipment such as CMM (co-ordinate measuring machine) and 3D microscopy can be used to measure the etched features accurately and within minutes.

Moreover, advanced etching techniques developed at Advanced Chemical Etching now allow heat exchanger plates to be manufactured to a high level of quality in titanium and aluminium, two metals that are difficult to etch using conventional etching methods. The innovative etching processes use advanced analytical techniques such as x-ray fluorescence to monitor and control the etching chemistry, resulting in consistent etching and improved quality conformance.

SUMMARY

Plate-to-plate heat exchangers are made from metal plates that contain flow channels on their surface. The geometry and dimensions of the channels have a direct influence on the heat transfer characteristics of the heat exchanger. It is therefore important to optimize the design of the heat exchanger plates to obtain the best possible heat transfer surface area while allowing a sufficient metal-to-metal contact area for joining the plates.

Photochemical etching can be used to create flow channels of different shapes and dimensions and on different types of metal alloys. The flexibility, low cost and fast turnaround times of the etching process make this the ideal manufacturing process for producing heat exchanger plates. Various designs can be produced and tested quickly. The process is capable of etching stainless steel, nickel-based alloys, copper, aluminium, titanium and other alloys. Advanced chemical analysis techniques can be used to monitor and control the etching chemistry, making it possible to etch large production volumes with consistent quality. Through R&D, ACE will continue to push the boundaries of the photochemical etching technology in order to meet the evolving demands of the heat exchanger sector.

WHO IS ADVANCED CHEMICAL ETCHING LTD?

Founded in 2000, Advanced Chemical Etching Ltd. are a specialist manufacturer of photochemically etched precision metal components. We are a dynamic team of experts with longstanding experience, who take pride in producing outstanding quality with our customers' requirements at the heart of every step of the way.

We are specialised in prototyping, pre-production and mid-size production runs. Providing solutions to our customers who seek to overcome challenges in their product development projects is at the core of our business.

Let's talk about your next project!

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