Laser welding for small copper tubes

The International Copper Association and Nexans have joined forces to develop a laser-based technology that could disrupt the conventional route for producing small-diameter copper tubes used in heat exchangers, writes Richard Barrett

Heat exchanger designs are rapidly evolving for applications requiring ever greater compactness and efficiency, and the use of new refrigerants places greater demand on the materials they are made of.

The high thermal conductivity needed for heat exchanger materials commonly calls for the use of two metals in particular – copper and aluminium. While the two base metals are sometimes used in combination – for example copper tubing joined to closely spaced aluminium fins – there is healthy competition between the two metals for applications in the multi-billion dollar market for heating, ventilation, air-conditioning and refrigeration (HVAC&R) units.

International Copper Association technology director Hal Stillman, based in the United States, noted that 1.6 million tonnes of copper are used in heat-exchange systems annually in industrial, commercial and residential air conditioning, heat pumps and refrigeration systems. He also said that 1 billion room-air-conditioning units have been installed globally, each of which uses two heat exchangers.

While he added that concerns about climate change will drive better designs of building envelopes to control their internal environment, the ICA estimates that as many as 3 billion room installations will be needed by 2050 as more people need the comfort and convenience of air-conditioning and refrigeration. According to the International Energy Agency's report *The Future of Cooling*, the global stock of air conditioners in buildings will grow to 5.6 billion by 2050, up from about 1.6 billion now.

There is a trend for tube diameters to become smaller

"The world is moving towards the decarbonization of home heating," Stillman added, "which means that heat pumps are also a growing market. As of now, room-air-conditioning system production alone sees a heat exchanger roll off global production lines every six seconds."

Regulatory demands to reduce or eliminate refrigerants that are particularly damaging to the Earth's ozone layer if released to the atmosphere – so-called greenhouse gases – have seen the introduction of other refrigerants, including propane and carbon dioxide. The flammability of the former needs careful management while the latter demands heat-exchange systems to operate at higher pressures. In addition, regulations now include the requirement for a minimum energy efficiency, which in turn requires improving the efficiency of the heat exchangers

Smaller tubes needed

All those factors, including the desire to make air-conditioning units more compact for city environments, have created a demand for smaller diameter copper tubes.

The ICA notes that there is already an established trend for copper tube diameters to become smaller – 9.5mm (3/8") outside diameter copper tube used to be the standard, before dropping to 7 mm to reduce costs and increase efficiency. Over the last 10 years, the ICA supported projects to reduce the tube diameter further to 5 mm, which is now becoming the new standard. Stillman noted that 4 mm diameter tubing is already in use in Japan and that 3 mm, or even 2 mm, diameter tubing is under development, having thinner wall, which could be used for high-pressure heat-exchange units.

Downsizing has reduced the amount of copper used in heat-exchange tubing by about 40%. Projects are under way in Europe, the US, Japan and China to advance the use of such small-diameter tube further. For example, the US Department of Energy Office of Building Technology is supporting a program to reduce the volume of heat exchangers by 20-30%.

"Small-diameter copper tubes of 3 and 2mm take many steps to produce," said Stillman. The conventional route for making copper tubes consists of billet-piercing to create a mother tube through extrusion, drawing down through dies to achieve smaller diameters, and annealing. This process is not well suited to making thin-walled, small-diameter copper tubes that will be needed in the future. Stillman explained that although traditional copper tube manufacturing can produce small-diameter products (2-3mm outside diameter), it is not cost-effective given the number of process steps required to achieve small diameters.

Tube from strip

Inspired by the consistency with which flat-rolled copper strip is already produced for applications such as microelectronics, the ICA looked at the possibility of making small-diameter tube by longitudinally welding a folded strip. Coils of thin gauge, precision-rolled copper strip are regularly produced in volume.

Such material can be slit into the widths needed to produce longitudinally welded tubes. The ICA witnessed the production of welded metal tubing by international cable and cable systems manufacturer Nexans, and partnered with it to test the possibilities of producing small copper tubes for heat exchangers using Nexan's technology and experience. Stillman initiated the project in the first half of 2018 with Ralf Egerer, director, machines & automation, Nexans, who is based in Hannover, Germany.

Both men saw the similarities between the tubular products already made for medical applications by using Nexans NanoWEMA™ forming and welding machines for thin-walled, small-diameter stainless steel and alloy tubes and the current need for copper tubes of similar dimensions for heat exchangers.

NEXANS

Nexans NanoWEMA™ technology

Stillman highlighted an added advantage that surface features can be created to increase the internal surface area of the tubes produced for heat exchangers by embossing the strip before forming and welding it to form a tube. Internal surface textures are added to larger diameter copper tubes produced conventionally for heat exchangers, but that feature is more difficult to achieve for very small diameters via that production route.

Nexans' existing NanoWEMA technology produces tubes with an outside diameter range from 2-7 mm and a wall thickness of 0.05-0.17 mm, used for cannulas and injection needles. Nexans says that the longitudinal welding of strip with an infrared laser to create tube offers a significant saving compared with TIG or plasma welding machines producing tubes with a 4-6 mm outside diameter, wall thickness of 0.15-0.22 mm and a line speed of 5-10 meters per minute.

In addition to being a manufacturer itself, Nexans has its own technology division designing production equipment. That division already supplies welding machines such as its NanoWEMA range for other metals, which use near-infrared (NIR) lasers to weld, but that wavelength is unsuitable for copper because the absorption of the energy needed to achieve the weld is poor due to reflection from the metal surface. Research demonstrated that the absorption of blue (450 nm wavelength) or green (532 nm) laser light was much better with about 75% absorption for liquid for copper with blue laser and over 65% absorption with green laser.

Demonstrating potential

In a recent pilot demonstration, Nexans showed the capabilities of one of its existing NIR machines that was modified to run with a laser emitting blue or green laser light.

Egerer stressed the importance of delivering a stable process to form tubing. That is achieved by using a closing die for final forming and guiding the open seam consistently under the welding laser. He stressed that a simple system that needs no electronic tracking or guidance system achieves very consistent presentation of the strip edges to the laser for welding: "We have 100% the same conditions under the laser," he stressed. Consistent and careful preparation of the surface of the copper strip is needed to ensure a constant weld quality.

He noted that the laser-welded copper-tube project draws on Nexans' 25 years of experience of using lasers for forming and welding, and the experience of building its existing equipment for producing other metal tubing, which can deliver "100 km in one shot" on equipment capable of running 60-70 hours without stopping. These machines use NIR lasers in a range of 2kW to 12kW.

It is particularly important for medical applications that the interior of tubes are free from contamination – something of similar importance for the easy flow of refrigerant inside copper heat exchanger tubing.

Why now?

So what is new and what has changed in technology for the production of laser-welded, small-diameter heat-exchanger tube? "It is the continuous production of copper tube using laser sources with minimum ▶