Advanced aluminium extrusion technology

An extensive co-operative research programme with the School of Materials, University of Manchester and Innoval Technology has enabled Heat Trace to develop a range of new aluminium extrusion process techniques and a family of aluminium-based heating products. **By M. A. McCool[1], N. S. Malone[1], J. O'Connor[1], P. Howe[1], S. Mills[1], G. E. Thompson[2], Y. Liu[2], X. Zhou[2], M. Curioni[2], E. McAlpine[3], G. Scamans[3], C. Butler[3]**

Abstract

For the manufacture of these products, Heat Trace has installed a continuous metal extrusion development line. Aluminium can be fed in a number of forms, including rod and granules. Solid sections can be produced using the radial process, operating in the tangential mode, which enables articles to be sheathed with a patent-protected continuous coating.

Although the replacement of copper conductors and stainless steel jackets with aluminium has resulted in major cost savings, the major advantage is that aluminium enabled different design geometries and concepts to be used. This work has produced a range of novel aluminium-based heating products, which have major technical benefits and include the following applications:

1) Trace heating cables used for freeze protection and temperature control (oil refineries, chemical plants)
2) Automotive heated products for under-seat heating, heated fluid pipes (AdBlue, windscreen washer liquid), tank heaters and heated washer nozzles
3) Rail heated products for frost and snow protection of switch points, third rail, catenaries, pantographs, tunnels, roofs, platforms and walkways

Introduction

The work reported here is the result of a collaborative research project that was undertaken as part of a programme sponsored by the UK Technology Strategy Board (TSB). The objective of the project was to develop a new family of aluminium-based heating products for a range of applications. Traditionally, electrical trace heating products, discussed in detail elsewhere (1,2), employ copper conductors and polymeric or metallic cable jackets. A major consideration is the substitution of both of these elements with aluminium. Not only is there a potential for significant cost savings but, more importantly, product designs and service performance may be greatly enhanced as a result of this material substitution.

Trace heating cables are widely used for temperature maintenance of industrial processes and freeze protection. A typical cable comprises three fundamental building blocks, namely a heating zone surrounded by an electrically insulative layer, which itself is encapsulated with a protective stainless steel outer jacket.

For a self-regulating type heater, as shown in **Fig 1**, the heating zone typically comprises two copper conductors and a semi-conductive polymer exhibiting PTC properties (ie, a positive temperature coefficient of resistance). A unique property of such heaters is that they are inherently temperature safe and cannot burn out, unlike alternative heater designs (i.e. constant power cables).

Fig 2 displays the power output of a self-regulating heater, which decreases with increasing temperature until, at a certain temperature, the power output is zero.

The major safety feature of these heaters is that they are self-limiting and, therefore, cannot fail in a catastrophic manner. The self-regulating effect and its relevance to conductive polymer composites have been described elsewhere (3).

The use of aluminium in self-regulating heaters has enabled these products to be competitive in existing applications and, importantly, to be exploited in many more applications than conventional copper-based products.

Experimental

Historically, aluminium has not been used extensively in electrical heating products. Hence, a research programme was designed to generate the platform technology required. Three major areas of experimental activity were investigated, including production development, laboratory studies of the aluminium-polymer interface and testing of bench-top experimental units.

• ConformTM extrusion of aluminium-based heating products

In 2011, Heat Trace installed a Continuous Rotary Extrusion (CRE) (**Fig 3**) at their Bredbury Technology Centre, Stockport, UK.

The CRE process was originally developed by the UK Atomic Energy Authority (UKAEA) and was first patented in 1972 (4). Following its inception, it has become an established method for continuous

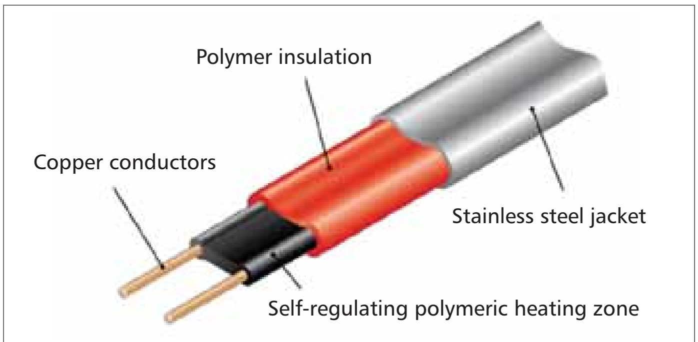

Fig 1 Electrical trace heating cable

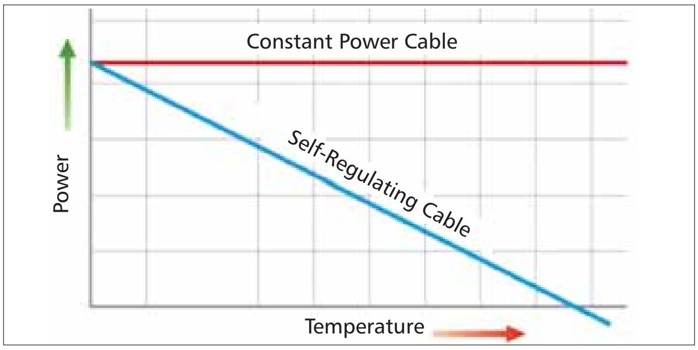

Fig 2 Comparison of power outputs of self-regulating and constant power heaters

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Fig 3 Continuous Rotary Extruder (CRE)

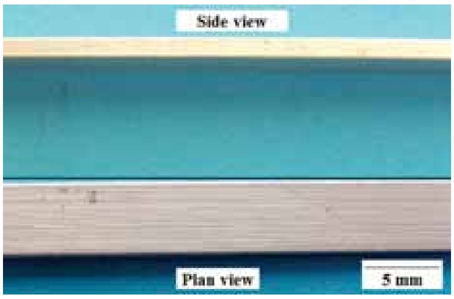

Fig 4 Sample of extruded aluminium conductor

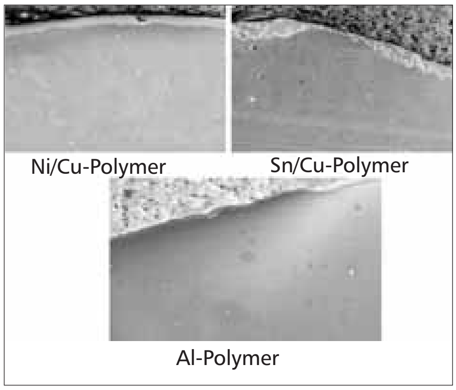

Fig 5 Scanning electron micrographs of metal-polymer interfaces

manufacture of extruded non-ferrous profiles, using rod and particulate feedstock by the radial extrusion process [5, 6].

The CRE can be used for both radial and tangential processes. For the former, rod feedstock enters a grooved, rotating extrusion wheel; it is prevented from continuing its route around the wheel by means of an abutment. As a result, the previously solid feedstock becomes plastic due to the high pressures and temperatures developed in the material, thereby enabling it to be formed to an appropriate shape on exiting the extrusion die.

A process variation also allows the continuous metal sheathing of cables by the tangential method. A tube is formed through which the cable to be sheathed is passed. The sheathed product is subsequently cooled and travels through a series of drawdown dies, where the sheath is compressed onto the cable.

Since the introduction of the CRE development line, the facility has been used to provide manufacturing processes for the following:

1) Tangential processing for the aluminium sheathing of continuous lengths of series resistance heating cable.

2) Radial extrusion of aluminium conductors for series resistance heating cables.

3) Radial extrusion of aluminium conductors for subsequent use as electrodes in a self-regulating laminate heater prototype.

4) Development of customised aluminium-based products for non-heating applications and customers.

A sample of an extruded aluminium conductor is shown in **Fig 4**.

• Laboratory studies of the aluminium-polymer interface

The quality of the metal conductor-polymer interface in a self-regulating type heater is critical for both heater performance and longevity. Good contact is essential. A study has been undertaken to compare the aluminium-polymer contact with that of tin/copper-polymer

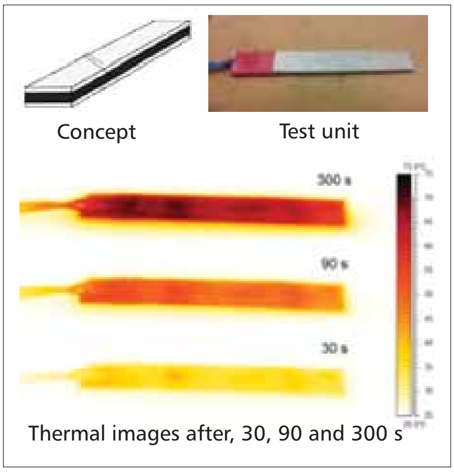

Fig 6 Aluminium laminate heater

and nickel/copper contacts that are relevant to current copper-based heating cables. Various samples of aluminium-polymer plaques were made with a laboratory melt press together with plaques fabricated on a production line.

Evaluation of these samples was carried out using impedance spectroscopy, Fourier transform infra-red (FTIR) spectroscopy, scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDX). SEM images of selected samples are shown in **Fig 5**.

This work characterised the similarities and differences in the three metal/polymer systems, revealing there was no significant difference between the contact of the aluminium-polymer and that of the tin/copper-polymer or nickel/copper-polymer. The outcome of this work suggested that aluminium-based heating products would have the same performance and longevity as copper-based types.

• Bench-top experimental units

For many of the products developed in the project, bench top experimental units were made and tested.

One of the benefits of using aluminium as a conductor is that it enables novel designs to be used. A radical new design of heater, referred to as a laminate heater, is shown in **Fig 6**.

On the outside, thin aluminium foils act as the conductors and the self-regulating heated zone is in the middle.

A thermal infra-red image (**Fig 6**) shows the effect of continuously energising the device after 30, 90 and 300 seconds. These images demonstrate the proof of concept of this design. The major advantage of this design is that the aluminium foils are flexible so that the heater can be customised to fit around the object to be heated.

3. Applications of aluminium-based heating products

There are a wide range of potential applications of aluminium-based heating products, which are summarised in **Table 1**.

The individual products are customized for each application. There are four major design platforms, namely trace heating cable, heated tube, laminate heater and ladder mat heater. Examples are now considered below.

• Oil wells

One of the major applications of trace heating cables is the oil industry. An application where aluminium offers major advantages is the down-hole heating of crude oil. Oil wells often have production problems as heavy crude oil flows from the reservoir bed up the production tube to the well head at the surface. The hot oil cools as it rises; consequently, the viscosity increases and wax deposits build up on the inner wall of the tube reducing production rates. In the past, the only solution was to shut down production and to remove the deposits by mechanical means [7].

Fig 7 shows a 3-phase trace heating cable with aluminium conductors and an aluminium jacket that is used for the down-hole heating of the oil production tube. The major advantage of the self-regulating heating cable is that the heat is applied where it is required. At the bottom of the well, the temperature of the oil is

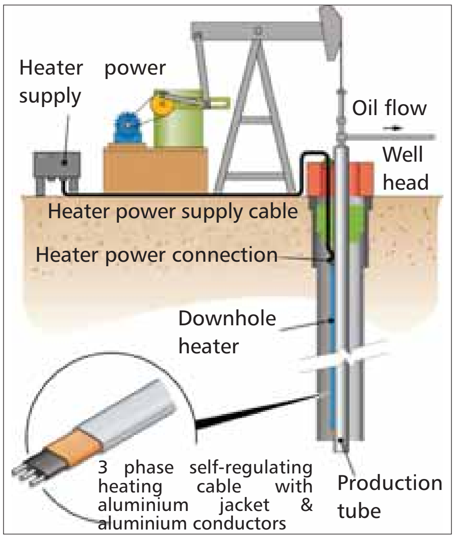

Fig 7 Aluminium 3-phase trace self-regulating

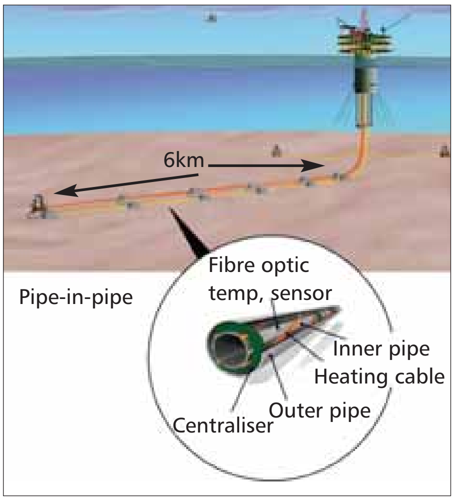

Fig 8 Subsea pipeline configuration reproduced with permission of Technip UK

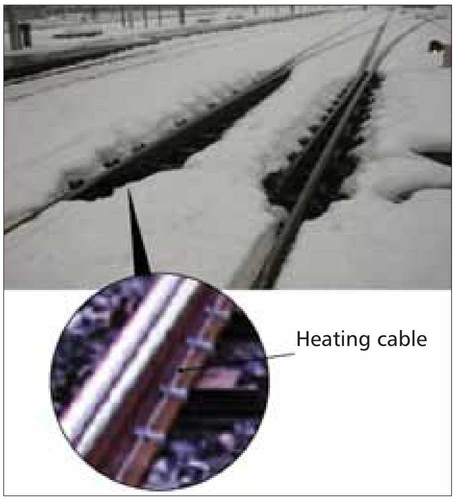

Fig 9 Heating of switch points with aluminium

the highest and the heat applied by the self-regulating cable is the lowest. As the oil flows up the tube, the temperature decreases and the heat applied by the self-regulating heater increases to maintain the oil at a viscosity that allows easy flow and prevents wax deposits.

One of the major advantages of aluminium in this application is reduced weight. The density of aluminium (2560-2640 kg/m^3) is only about 33% that of stainless steel (7480-8000 kg/m^3). Hence, for the same weight, an aluminium jacketed cable can be about three times the length of that of a stainless steel jacketed cable. This is important since the down-hole heater cable is attached at the top of the well head. Typical circuit lengths of self-regulating cables for this application are about 750 m.

- **Heated subsea pipelines**

A subsea pipeline[(8)] is a submarine pipeline carrying oil or gas products either (i) from a well head to a production platform or a FPSO (Production, Storage, and Offloading vessel), or (ii) from shore storage to a tanker.

Fig 8 displays a subsea pipeline configuration that has been installed in the North Sea at a depth of 120 m and has a length of 6000 m. Heat Trace worked closely with Total and Technip UK (a major subsea services company). This joint development produced the world's first electric traced heated reeled pipe-in-pipe system. This cable gives greatly improved heat transfer and, hence, major reductions in energy requirements. Phase 2 of the project will evaluate the benefits of replacing copper with aluminium. In this application, the design benefits of aluminium are far more important than cost benefits

- **Rail heaters**

In the rail industry, electrical heating

Market	Applications
General	High temperature
	High power
Residential &	Frost and snow protection
Commercial	Water pipes
Buildings	Gutters
	Paths
	Underfloor heating
	Heated hot water pipes
	Heated waste pipes
Industrial	
Oil	Refineries
	Oil wells - down hole heaters
	Long pipe runs - kms
Chemical	Chemical plants
Transport	
Automotive	Heated seats
	Heated tubes - AdBlue
	Heated windscreen washer tubes
	Heated windscreen washer tank
	Heated washer nozzles
Aerospace	Heated fuel lines
	Heated waste lines-sanitary
Rail	Frost and snow protection
	Heaters for:
	Third rail systems
	Switch points systems
	Catenaries & pantographs
	Pipes - rolling stock
	Tunnels, roofs & canopies
	Platforms, walkways
	Access ramps

Table 1 Applications of aluminium-based heating products

products are used for frost prevention and snow melting of a number of applications including third rail systems, switch point systems, catenaries, pantographs, tunnels, roofs, canopies, pipes, platforms, walkways and access ramps.

Aluminium jacketed heaters have been used in applications on rail networks and an example is illustrated in **Fig 9**.

- **Automotive heaters**

Electric heating products have been used for some time in the automotive market for under-seat heating. The use of aluminium has generated new automotive applications such as heated fluid pipes (AdBlue, windscreen washer liquid), tank heaters and heated washer nozzles.

The heated pipe is an interesting application. AdBlue is an environmental control chemical that is injected into the exhaust system. Adblue tanks and fluid delivery hoses must be heated to maintain the material in the liquid state at low temperatures in order that it is available for injection as and when required. The use of aluminium enables an alternative design to be considered: a heated pipe. The novel feature is that the pipe, the electrical trace heating and the insulation are integrated into one unit. This design has three concentric elements, as follows:

i) The inner annulus is a conventional plastic pipe.
ii) The middle annulus is a sandwich heating zone, with two aluminium conductors and a semi-conductive polymer.
iii) The outer annulus is a thermal insulating jacket.

The major benefits of this design are:
i) Reduced energy requirements.
ii) Reduced manufacturing costs.
iii) Reduced material costs.
iv) Reduced installation costs.
v) Reduced size.

Fig 10 compares the design of a conventional trace heating system and heated pipe system with comparative thermal images.

As the heat is now applied equally at all points around the pipe rather than at a single point, the heat transfer is greatly improved. This is illustrated in proof of concept thermal imaging studies in **Fig 10**, which suggests that the improved heat transfer will reduce the energy required by about 60%.

Because of the reductions in capital costs, installation costs, energy costs and size, the heated pipe will be a major advancement in trace heating technology. In nearly all applications, the heated pipe will be technically superior and have lower capital and operating costs than conventional trace heating. However, more importantly, the heated pipe will enable trace heating to be used in new applications and in applications where trace heating has only made modest inroads.

In the long term, we believe that 'heater-in-pipe' (HIP) will become the market leader in virtually all existing plastic pipe trace heating applications.

Conclusions

This work has shown that aluminium can be successfully used in electrical heating products both as an outer protection sheath and as inner conductors. Very significant cost savings are achieved when the aluminium replaces both stainless steel and copper. The project has shown that excellent bonding can be achieved between aluminium and polymers, indicative of very good product performance and product life. The use of aluminium has enabled the design of novel electric heaters, which have major benefits compared to conventional copper based heaters. ■

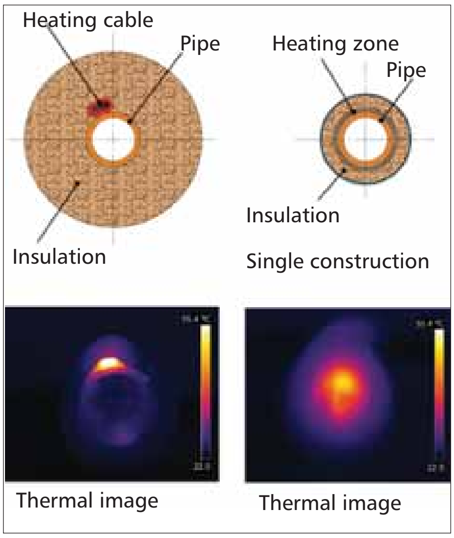

Fig 10 Comparison of trace heating (TH) and aluminium based heated pipe (ABHP)

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ii) Innoval Technology Limited, an aluminium materials and engineering technology consultancy which is part of the Danieli group of companies.

iii) Heat Trace, manufacturer of electrical heating products.

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