Advanced Aluminium Extrusion Technology Produces a Novel Family of Aluminium-based Heating Products for Automotive and Other Markets

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Abstract: An extensive cooperative 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. 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 granular, and the extruded product can be produced either by radial or tangential extrusion and in either profile or 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

Keywords: Aluminium heating products, automotive, rail

1. Introduction

The work reported in this paper is the result of an ongoing collaborative research project carried out as part of a programme sponsored by the UK Technology Strategy Board (TSB). The objective of the project is 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 are 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.

Fig 1 - Electrical trace heating cable

For a self-regulating type heater, as shown in Figure 1, the heating zone comprises two copper conductors and a semi-conductive polymer exhibiting a PTC (positive temperature coefficient of resistance) effect. 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).
Figure 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 more competitive in existing applications and, more importantly, to be used in many more applications than the copper-based self-regulating products.

2. Experimental:

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 carried out: production development, laboratory studies of aluminium-polymer interface, and testing of bench-top experimental units.

a) Conform™ extrusion of aluminium-based heating products

In 2011, Heat Trace Ltd installed a Conform™ Continuous Rotary Extrusion (CRE) development line (Figure 3) at their technology centre in Bredbury, Stockport, UK.

The CRE process was originally developed by the UK Atomic Energy Authority (UKAEA) and first patented in 1972 (4). Following its inception, it has become an established method for continuous manufacture of extruded non-ferrous profiles, using rod and particulate feedstock by the radial extrusion process (5, 6).

The Conform™ can also be used for tangential extrusion as shown Figure 4.

Feedstock enters a grooved, rotating extrusion wheel and 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, 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 a CRE development line, the facility has been used to develop 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.
Samples of extruded aluminium conductors are shown in Figure 5.

b) 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 the tin/copper-polymer and nickel/copper contacts that are relevant to the current copper-based heating cables. Various samples of aluminium-polymer plaques were made with a laboratory melt press plus as 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). Images of selected samples are shown in Figure 6.

This work characterised the similarities and differences in the three metal/polymer systems, namely that 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 heating products.

c) 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 sandwich heater is shown in Figure 7.

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 (Figure 7) 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, with a summary list given in Table 1.

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<th>Market</th>
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<td>Platforms, walkways</td>
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<td>Access ramps</td>
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Table 1 - Applications of aluminium-based heating products

These products will be customized for each application. There are four major design platforms: trace heating cable, heated tube, sandwich heater and ladder mat heater and examples of these are discussed below.

**a) 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, the viscosity increases and wax deposits build up on the inner wall of the tube reducing the production rates. In the past, the only solution was to shut down production and to remove the deposits by mechanical means (7).

A 3-phase trace heating cable (Figure 8) with aluminium conductors and an aluminium jacket is used for the down-hole heating of the oil production tube. The major advantage of 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 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, maintaining 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 will be attached at the top of the well head. Typical circuit lengths of self-regulating cables for this application are about 750 m.
**b) Heated subsea pipelines**

Subsea pipeline (8) is a submarine pipeline carrying oil or gas products either
1) from a well head to a production platform or a FPSO (Production, Storage, and Offloading vessel) or
2) from shore storage to a tanker.

![Image of subsea pipeline configuration](image)

Fig 9 - Subsea pipeline configuration reproduced by kind permission of Technip UK

Figure 9 shows 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, the latter a major subsea services company. This joint development produced the world’s first electric traced heated reeled pipe-in-pipe system. This is capable of multi-directional flexing and 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.

**c) Rail heaters**

In the Rail industry, electrical heating 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.

![Image of rail heaters](image)

Fig 10 - Heating of switch points with aluminium jacketed heating cables

Aluminium jacketed rail heaters, (Figure 10), have been installed by Network Rail.

**d) 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 added to diesel fuel. However, AdBlue needs to be kept above a certain temperature and the conventional way of doing this is to attach a trace heating cable to the pipe.

However, aluminium enables a novel design to be used: 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:

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.

Figure 11 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 Figure 11, which estimate 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 applications of pipe trace heating.

4. 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 the polymers, which indicate 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 copper based heaters.

5. Acknowledgements

We would like to gratefully acknowledge that this work was partly financially supported by the UK Technology Strategy Board (Project number 100745). The three technical partners of this project were:
i) The School of Materials, The University of Manchester, UK.
ii) Innoval Technology Limited, of Banbury, Oxon, independent aluminium materials and engineering technology consultancy.
iii) Heat Trace of Helsby, UK, manufacturer of electrical heating products.

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