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COMPANY VISIT: ATOMISING SYSTEMS

PM2014 WORLD CONGRESS
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Kanthal APMT™: Making high temperature sintering more cost competitive

Kanthal APMT, an advanced Powder Metallurgical FeCrAlMo alloy, has been introduced to the market in a wide range of product forms including hot rolled wide plate, bar, rod, wire and extruded tubes and is therefore a facilitator for furnace components for use at a temperature range where ceramics or cold wall chambers have previously been the only viable options. Bo Jönsson and Roger Berglund, of Sandvik Heating Technology, present the alloy’s basic properties and describe several applications within Powder Metallurgy where the alloy provides the potential to increase sintering temperatures and extend lifetime of critical components.

Kanthal® materials and systems from Sandvik have for decades been a standard solution when it comes to electrical resistance heating. The product range has expanded over the years from FeCrAl and NiCr metallic alloys to include a range of ceramic materials and heating elements, such as Kanthal Super [MoSi2] and Kanthal Globar® [SiC] heating elements, as well as seamless extruded tubes and also into components and systems for thermal processing and process heating.

This evolution is now taking another step through the introduction of a range of Kanthal high temperature materials and components. These are intended to withstand and protect from heat in components such as retorts and muffles for PM sintering, furnace rollers and furnace furniture and not to primarily generate heat in heating elements.

Traditionally, wrought or cast Ni-base alloys have been used for this type of high temperature construction, but their limited oxidation resistance above 1100°C and sensitivity to carburising may be a problem in many industrial high temperature processes. As an example, PM steel sintering is largely carried out at the (in this context) relatively low temper-
nature of around 1130°C, primarily due to the limits set by available construction materials and the high costs involved in going to conventional vacuum sintering.

Conventional wrought FeCrAl high temperature alloys are, on the other hand, well known for their superior oxidation resistance up to 1300°C or even 1400°C. This outstanding resistance to oxidation is based on their ability to form a very slow growing and protective alumina scale during service. However, the main drawback of these alloys is their relatively low mechanical strength at high temperatures that severely limits their application in mechanically stressed components, such as hot retorts containing a vacuum.

Sandvik researchers were able to enhance the relatively poor high temperature creep properties of FeCrAl alloys as long ago as the late 1980s by inventing a unique rapid solidification powder metallurgical process route (RSP). As a result, Kanthal APM was presented to the wider market in 1989. Since then Kanthal APM has become the preferred choice for high performance and mechanically stable electrical heating elements and radiant tubes within semiconductor and industrial high temperature processing.

This article will give a brief introduction to the further enhanced strength alloy Kanthal APMT, a FeCrAlMo alloy that bridges the gap between high temperature metallic alloys and ceramics, in terms of application temperature (see Fig. 1), and will also look at some application examples within Powder Metallurgy.

**Kanthal APMT properties**

Kanthal APMT is optimised for hot strength and retained alumina scale protection up to 1250°C or, for shorter periods, even up to 1300°C. This is a temperature range where Ni-base alloys degrade rapidly due to accelerated oxidation and grain boundary softening. Table 1 compares the chemical composition of Kanthal APMT with those of previously developed Kanthal alloys. Fig. 2 illustrates the prevailing strengthening mechanisms in Kanthal APMT.

By combining additions of Mo and trace elements with the unique process route, the result is an alloy that exhibits a unique combination of resistance to oxidation and corrosion and excellent form stability that exceeds that of Ni-base alloys at higher temperatures. An adherent alumina layer on the alloy surface forms spontaneously during service (Fig. 3). This thin oxide scale provides resistance to corrosion attack in most industrial atmospheres and gives great advantages compared with chromia-forming high temperature Ni-base alloys in terms of maximum operating temperature and life.

**Oxidation resistance**

Alumina formation provides several major advantages; slow oxidation rate, very high scale adherence, chemical stability towards water, carbon and sulphur. These advantages transform into a number of practical benefits in oxidising and carburising environments compared with the best Ni-based chromia-formers, in terms of longer lifetime (of the order of 10 times), 100 to 200°C higher possible operating temperature, as well as very minor particle emissions (spallation) and negligible amounts of gas phase emissions. There is no critical temperature range where oxidation rates are accelerated, although isothermal exposures have shown

![Fig. 2 Polished and etched micrograph from 8 mm hot rolled plate, b) TEM section showing the ferritic base metal, grain boundaries and refractory strengthening particle dispersion](image)

![Fig. 3 SEM example from fractured section of APMT exposed to 1300°C for 1100 hours using 20 hour thermal cycles. The dense and coherent oxide is evident even after this fairly tough exposure](image)

<table>
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<th>Mo</th>
<th>RE</th>
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**Table 1 Nominal compositions of Kanthal APMT and previously developed materials**

Fig. 2 Polished and etched micrograph from 8 mm hot rolled plate, b) TEM section showing the ferritic base metal, grain boundaries and refractory strengthening particle dispersion

Fig. 3 SEM example from fractured section of APMT exposed to 1300°C for 1100 hours using 20 hour thermal cycles. The dense and coherent oxide is evident even after this fairly tough exposure
that oxide growth rate, although very slow, is similar at 800 and 900°C due to a gradual change to the stable and more protective α-alumina phase at higher temperatures.

**Lifetime assessment**

The lifetime of components is typically limited by creep deformation and/or by oxidation and hot corrosion. Design of components for service at very high temperatures also makes it necessary to understand and control the combined action of simultaneous oxidation and mechanical stresses that may occur from external loads or from thermal gradients. At high temperature and below a certain critical load, the failures are typically determined by the oxidation process. On the other hand, at higher loads and lower temperature, failure is often controlled by the mechanical properties.

During exposure, thermal cycling and also mechanical damage often cause micro-cracks or even macro-defects in the oxide scale. Aluminium then diffuses from the interior of the alloy to the scale interface to repair the scale. The oxidation-limited lifetime is reached when the aluminium level beneath the oxide layer is too low to support the continued alumina formation in those defects. It is found that the critical aluminium level is in the range from one to three wt. % Al remaining in the alloy. Comparative life testing may be assessed by using electric current to heat the samples to a specified temperature as shown in Fig. 4. Based on oxidation tests such as these and theoretical models, it is actually possible to estimate oxidation life of real components fairly accurately.

**Corrosion resistance in controlled atmospheres**

Kanthal APMT forms a protective scale in most commonly-used controlled atmospheres such as endo-, exo-gas and H₂. The only condition in terms of corrosion and where some caution is needed and where Ni-base alloys may be a better choice, due to risk for nitriding, is very dry N₂ or N₂/H₂ mixtures.

Furthermore, due to the extremely dense alumina scale formed and its low permeability of carbon-containing species, the carburisation resistance of Kanthal APMT is excellent in comparison with chromia-forming materials. Kanthal APMT is almost entirely insensitive to metal dusting and its alumina surface is also non-catalysing, which reduces the amount of graphite and coke deposition.

**High temperature creep resistance**

In general, the creep rupture strength for APMT alloys is comparable to high temperature Ni-base alloys above 900°C, but the advan-
Kanthal APMT

<table>
<thead>
<tr>
<th>Form</th>
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<tr>
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<tr>
<td></td>
<td>Length</td>
<td>≤ 4500</td>
<td>≤ 177.17</td>
</tr>
</tbody>
</table>

*Cold rolled strip can be delivered as cut to length products

**Length depending on cross section

Table 2 Forms of supply. Other sizes and forms can be discussed on request.

Welding and joining

The APMT alloy is normally welded using TIG/GTAW. Preheating to approximately 250°C and post-weld annealing at 850°C is however necessary. Some creep strength is lost in the weld and this is normally handled by design so that welds are placed at positions where the stress level is somewhat lower or cross sections are larger. As a rule of thumb, loss of creep strength in an APMT/APMT alloy TIG butt-weld corresponds to a 100°C temperature rise of the base alloy.

Kanthal APMT has slightly lower thermal expansion coefficient compared with common austenitic FeNiCr and NiCr alloys. Although generally an advantage, in dissimilar welds, this will impose stresses during thermal cycling. Welds in general, but dissimilar welds in particular, should therefore preferably be positioned where stress levels or temperatures are below their maximum levels.

In addition to TIG welding there are several other welding techniques that can be used, such as laser or MIG welding. Also brazing has been shown to give good results when it is possible to prepare the gap to adequate tolerance and to perform a heat cycle in vacuum.

Forming and cutting

Kanthal APMT is ductile at room temperature with elongation to rupture between 10 and 25% depending on product form. Since room temperature impact strength is relatively low, it is recommended that plastic deformations are performed using a preheating to ≥250°C when possible, and especially so for heavy dimensions.

Bending over an edge with controlled radius gives less localized stress compared to V bending with a press and is preferred when possible. Using V bending, preheating is generally needed. For preheated plate and strip, the minimum bending radius is R\text{min} = 2t using edge and R\text{min} = 3t using V bending. Tough forming operations, such as press forming, are readily carried out at red hot temperature where the ductility is extremely high.

Cutting may be performed with different conventional methods, including laser cutting using Ar shield gas, but water-jet cutting has the advantage of not creating mechanical stress and also not affecting the surface conditions negatively.

Application examples

Hot wall vacuum and inert atmosphere bell furnace designs

Most batch processes using vacuum or low pressure at high temperature use cold wall equipment with a graphite or Mo-heated process chamber inside a water-cooled pressure bearing vacuum chamber. The unique combination of properties of Kanthal APMT will provide a number of important opportunities. Due to its combination of adequate oxidation resistance and sufficient mechanical strength, it greatly expands the upper temperature limit for hot wall furnace design, in which the chamber (retort) wall combines the function of keeping a low pressure or vacuum and also constituting the hot wall that transfers heat to the parts inside. This double function obviously puts high demands on the wall material, but, on the other hand, it offers great advantages for batch as well as continuous processes.

Here the alloy is a facilitator, since hot wall retorts using Kanthal APMT can be applied up to at least 1250°C, which is between 100 and
200°C more than is possible with Ni-base alloys. The heat is then provided externally by a conventional electric or gas fired furnace or even induction.

The advantages with hot wall designs are great in terms of increased productivity and lower cost due to:

- Lower investment
- Faster cycle time
- Effective and easy access loading
- Multiple process chambers may be served by one heating system
- Reduced energy consumption due to reduced or eliminated need for water cooling.

The advantages in using a metallic alloy as compared to possible ceramic solutions include weldability, freedom of design, ruggedness and gas tightness. However, depending on temperature and material thickness there is a limitation in size if the wall will have to carry the atmospheric pressure at the full operating temperature. Some application examples are given below.

**Retorts**

PM vacuum/inert gas sintering of magnetic and medical implant materials such as SmCo and CoCr alloys is carried out at high temperature close to 1250°C in order to achieve almost 100% density and to fulfil high demands on surface quality and mechanical and magnetic properties. To realise the advantages with hot wall technology, the sintering step has been carried out very successfully by using Kanthal APMT retorts made from plate and tube in combination with Kanthal external electric resistance heating systems.

Alumina formation provides additional advantages. This comes from the extremely high affinity to oxygen of the alumina-former Kanthal APMT. While the protective alumina scale forms on its surface, it also acts as a getter for residual oxygen and adsorbed water and thereby further reduces the level of oxygen in the chamber and improves sintering of easily oxidised Cr containing alloys. At very low oxygen levels and dew points in inert or H₂ atmosphere, the thin alumina scale therefore still forms, although very slowly, which prevents metal-metal sticking. In the case of carburising gases, the alumina forms a very protective barrier towards carburisation and also prevents build-up of coke deposits.

**Muffles, load support, baskets, trays and belts for continuous processing**

Sintering of conventional press and sinter steels is performed using NiCrFe alloy muffle continuous furnaces operating at ~1120°C. This temperature is chosen primarily for reasons of high temperature performance of the available NiCrFe-based furnace construction materials and, therefore, steel powders are mostly optimised to give acceptable properties at this temperature. Increased sintering temperature gives substantial improvement potential for part mechanical properties through a greater freedom of alloy design and there are important threshold levels at which PM parts could qualify into even higher loaded components and gain substantial new market share. Even more interesting is the prospect of increasing the sintering temperature to levels that give closed porosity, thereby making it possible to apply a HIP (Hot Isostatic Press) cycle directly on the sintered parts to reach 100% density. This could potentially be applicable to pressed, MIM (Metal Injection Moulded) or Additively Manufactured parts.

Kanthal APMT therefore offers a possibility for greatly improved properties in PM through the use of relatively conventional all metallic furnace designs, for components such as muffles, load supports, trays and baskets. In these components, the alumina formation on Kanthal APMT also provides an inert and non-sticking surface towards the sintered products. The designs will be fairly conventional, although built using a quite unconventional alloy and operating at > 1200°C.
Kanthal APMT trays have also been successfully applied to replace ceramic trays in batch, belt and pusher type furnaces, withstanding thermal shock in mesh belt sinter quench furnaces to enable automated handling.

Other applications
A wide range of tube, bar, wire and plate dimensions is available for high temperature components including radiant tubes. Kanthal APMT can offer great advantages, especially in high temperature operation or in carburising atmospheres due to the clean and inert alumina surface.

Thermocouple protection tubes and thermo-wells see all environments and temperatures possible. At temperatures above 1100°C in oxidising environments, Kanthal APMT replaces brittle ceramic protection tubes and in, for instance, petrochemical processes its outstanding resistance to carburising and sulphidation solve severe corrosion problems experienced with Ni-base alloys.

Furnace rollers made from conventional NiCr(Fe) wrought or cast alloys suffer from severe oxidation and often also carburisation, when applied in oxidising conditions at the high temperature needed for the treatment of certain stainless steel grades, for example. Lifetime in this application has been improved from six to twelve months to at least four years when changing to Kanthal APMT rollers. By eliminating the need for cooling in many cases, Kanthal APMT also helps reduce energy consumption.

Conclusion
Kanthal APMT is an advanced powder metallurgical dispersion strengthened FeCrAlMo alloy, optimised for continuous service as a construction material in the temperature range up to 1250°C in oxidising and corrosive environments. It has now been introduced in a wide range of product forms, including wide format hot rolled plate, bar, wire and extruded tubes.

With its unique combination of alumina-based oxidation resistance and high form stability, Kanthal APMT opens up new possibilities for design of improved thermal processes within Powder Metallurgy. This will offer the potential for improved product properties, higher productivity, lower costs and large energy savings.

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References
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