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# Selection of High Temperature Resistant Alloys for a New Monitoring Technology Sensor

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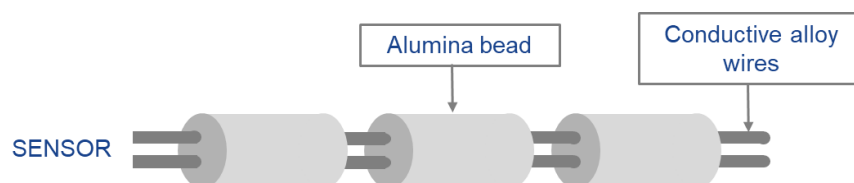
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## Context

High temperature monitoring remains a challenge for many industries. Punctual measurements can be achieved using thermocouples. However, they only provide occasional and isolated measurements, rather than continuous and comprehensive data. Recent advances in Optical Time Domain Reflectometry (OTDR) succeeded in distributed measurements, but optical fibers do not withstand temperature above 600°C over times compatible with industrial needs (several years). In this context, sensors based on Electrical Time Domain Reflectometry (ETDR) are promising solutions. It consists in sending a high frequency electro-magnetic signal within a transmission line (Fig.1) made of materials compatible with high temperature and durability requirements. The signal processing of backscattered waves allows distributed temperature measurements all along the sensor. The aim of this study is to select the most promising materials that can undergo the target temperature through several years while allowing temperature monitoring.



**Fig. 1** Sensor based on ETDR: 2 metallic wires threaded in alumina beads

Various candidate alloys for the manufacturing of ETDR sensor systems were studied: alumina as a dielectric and Pt, Fine Grain Stabilized Pt, W, Ni-based alloys and FeCrAl alloys as conductor lines. These sets of materials were defined following a material selection study based on their electromagnetic transmission properties, and their theoretical resistance to corrosion according to supplier datasheets. In order to assess the ageing of the selected materials, oxidations in laboratory atmosphere were performed at 1000°C for durations ranging between 24 and 264 hours.

## Materials and methods

Wires of 500 µm diameter of three Fe-based or Ni-based alloys were studied. Their chemical compositions and maximum operating temperature, provided by the supplier, are reported in Table 1. Fe-20Cr-5.3Al (Kanthal® AF) is an alumina forming ferritic stainless steel which contains yttrium to promote the formation of protective and adherent  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> scale [1]. Ni-10Cr and Ni-5AlMnSi are respectively chromia and alumina forming Ni based alloys.

**Table 1.**

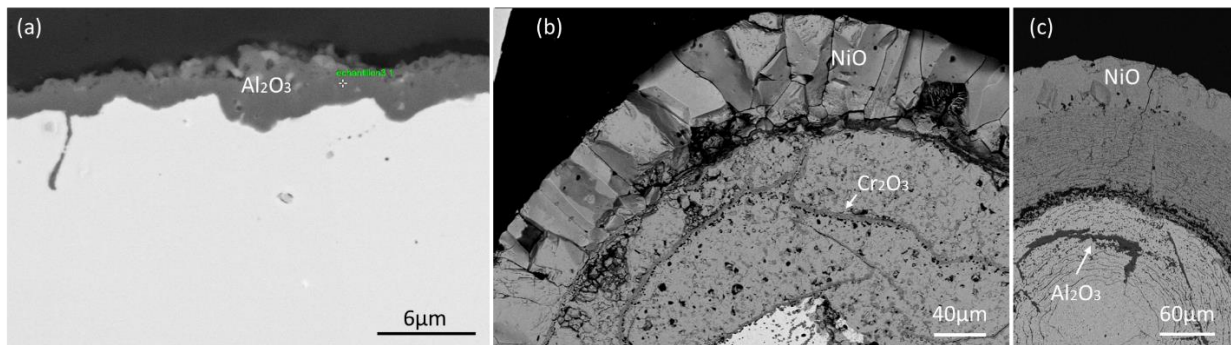
Chemical compositions of the studied alloys

Composition wt.%	Ni	Cr	Fe	Al	Mn	Si	T°C Max
<b>Fe-20Cr-5.3Al</b>	-	20 - 23.5	Bal.	5.3	<0.4	<0.7	1300°C [2]
<b>Ni-10Cr</b>	Bal.	10	-	-	-	-	1100°C [3]
<b>Ni-5Al</b>	Bal.	-	-	-	5	-	1100°C [4]

The different wires presented were aged threaded into alumina beads (according to sensor configuration, see Fig.1) in laboratory atmosphere for 24, 48, 96 and 264 hours at 1000°C. After ageing, SEM observations coupled with EDS analysis (ZEISS Ultra 55) were performed on wire cross section.

## Results and Conclusion

SEM cross section of Fe-20Cr-5.3Al (a), Ni-10Cr (b) and Ni-5AlMnSi (c) aged for 264 hours at 1000°C in laboratory atmosphere are shown in Figure 2. A 3µm layer of protective Al<sub>2</sub>O<sub>3</sub> was formed on Fe-20Cr-5.3Al (Fig. 2a) whereas both Ni-10Cr and Ni-5AlMnSi suffer from breakaway oxidation (Fig. 2b-c). In both cases, the oxide scale is composed of an outer layer of NiO. The inner oxide scale and the deep internal oxidation zone reveal complex chemistry and microstructure. Concerning Ni-10Cr (Fig. 2b), the inner oxide layer is composed of small precipitates of Cr<sub>2</sub>O<sub>3</sub> embedded in NiO. A continuous Cr-rich oxide layer probably linked to the grain boundaries of the former bulk alloys can also be observed. The interface between NiO and (NiO+Cr<sub>2</sub>O<sub>3</sub>) sublayers appears to be the former surface of the bare alloy which provide information on sublayers growth directions. Regarding Ni-5AlMnSi (Fig. 2c), both inner oxide scale and internal oxidation zone have concentric structure of alternating protective Al<sub>2</sub>O<sub>3</sub> and NiO (oxide) and Al<sub>2</sub>O<sub>3</sub> and Ni (internal oxidation zone). These structures suggest the local chemical failure of the protective oxide [5] linked to the thin wire thickness [6]. The oxidation kinetics of these metal wires affect drastically their effective conduction since the electrical signal is essentially carried at the conductor extreme surface (skin effect in the sensor frequency range).



**Fig. 2** SEM cross section of Fe-20Cr-5.3Al (a), Ni-10Cr (b) and Ni-5AlMnSi (c) wires threaded into alumina beads oxidized for 24 h at 1000°C in laboratory atmosphere

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