New fused coatings for combined wear and corrosion resistance

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ABSTRACT

Fused coatings produced by thermal spraying and subsequent fusion have been used in industry for more than 50 years. In the field of thermal spraying fused coatings have the advantage that they exhibit a metallurgical bond to the substrate and a very low level of porosity (no through porosity) as a result of the fusion step. Over the last years new alloys have been developed which extended the range of applications towards more corrosive conditions. However, even these alloys were not adequate when used in waste-fired boilers (mainly due to the presence of chlorine) or in highly aggressive aqueous media, as are found, for instance, under conditions of dew point corrosion.

For this reason, a development programme was undertaken to create a new family of fusible alloy powders for thermal spraying. Coated plate samples were finally prepared of the most promising alloys by combustion spray and fuse and HVOF spraying and by plasma transferred arc (PTA) deposition. The samples were evaluated with respect to their wear and corrosion performance as well as hardness in the temperature range up to 500 °C. The results for the spray and fused coatings presented here show that the new alloys have an excellent combination of high corrosion resistance in different corrosive environments and very good wear characteristics.

1 INTRODUCTION

"Self-fluxing" alloys can basically be characterised as a group of Ni(Cr)BSi-alloys with high temperature brazing characteristics. Ni may in some cases be substituted by Co and in rare cases by Fe. Additions of B and Si lower the fusion temperature to typically 1030 to 1130°C and render the alloy easily fusible due to an inherent self fluxing ability. Examples for early standardisation of some original key alloys are traceable for surfacing as rods and electrodes /1/, as powders for brazing purposes /2/ and for thermal spray applications /3/.

For large area and automated applications, fused coatings are often applied with the "(first) ***Spray and Fuse*** (then)" /4,5/ process. Carbides are blended into the powder if high abrasion resistance is required. Spray and fuse coatings, applied in a thickness of typically 0.5 to 2 mm, exhibit a high bond strength (metallurgical bond with the substrate) and very low porosity level (they are gas tight).

Characteristics and recommended use of the basic range of self fluxing alloys are well investigated and documented in literature /6,7,8,9/. This type of coatings is widely used in many industries for wear and corrosion protection and/or to minimise friction. Plungers, sleeves, tubes, rolls, guides, tools, extruders and glass moulds are some of the typical applications.

For combined wear and corrosion protection, the 60 HRC alloy (Ni 15Cr 4Fe 4Si 3B 0.7C) can be looked at as starting point for further developments for improving the alloy's corrosion resistance. The high amount of boron needed for the "self fluxing effect " and the carbon bind appreciable amounts of Cr as borides and carbides, thereby lowering its matrix content of Cr and the corrosion resistance. Lowering B and/or C appreciably improves corrosion resistance but will also reduce wear resistance and hardness.

Additional alloying has lead to three powder types which have improved corrosion resistance:

- Increased Cr content, up to 26% (alloy NiHCr; see section 2)
- Added Cr, ***Mo*** and Cu (<5% of each) (alloy NiCrLMo; ")
- Substitution of Ni with Co and Mo addition (<8%) (alloy CoNiCrMo; ")

These alloys have been taken as a reference for the current alloy development. The need to further improve gas tight, wear- and corrosion-resistant coatings for hot corrosion applications (for instance boiler tubes in waste incinerators) or acid-resistant coatings for the chemical and petro-chemical industry, was the driving force to assess new alloying possibilities. To match those requirements, a range of Ni- base self-fluxing powders with high Cr and ***high Mo*** content was developed. Mo was considered in earlier work to be detrimental for the self fluxing characteristics if added in very high amounts. To overcome these problems was one of the targets of the alloy development.

2 EXPERIMENTAL

The new Ni-based coating (NiCrHMo) has been comparatively evaluated with respect to the Ni-based coatings NiCrLMo and NiHCr and the Co-based alloy CoNiCrMo. The alloy types of the four self-fluxing coatings used in the tests are as follows:

NiCrHMo :	Ni 18Cr 13Mo Fe Cu B Si	**NiCrLMo** :	Ni 18Cr 4Mo Fe Cu B Si
NiHCr :	Ni 26Cr B Si	**CoNiCrMo** :	Co 27Ni 19Cr 5Mo B Si

The coatings have been produced with the spray & fuse technique. This is a two-step procedure involving the deposition of the alloy powder by thermal spraying, in this case flame spraying with the ROTOTEC® 80 equipment, followed by a fusion step. The fusion for the test samples was done with a oxyacetylene torch. The substrate material was a common carbon steel. The coating characterisation included:

- Hot hardness testing in the temperature range up to 500 °C (NIKON QM)
- Abrasive wear testing using a dry sand rubber wheel apparatus according to ASTM G65-91, Procedure A
- Corrosion testing (in agreement with DIN 50905), using a tube-shaped glass cell with polymer seals to run immersion tests, while exposing only a defined area of the coating to the test solution. The test solution was prepared with p.a. grade chemicals and deionised water and was agitated during the test period of 168 hrs in all cases.

3 RESULTS AND DISCUSSION

3.1 Hot hardness

The hot hardness values for the four coatings in the temperature range 30-500 °C are given in Fig. 1. The new alloy NiCrHMo has a room temperature hardness of about 750 HV0.3, falling between the values of the other coatings. With increasing temperature its hardness drops slower than that of the other Ni-based alloys, retaining a value of 400 HV0.3 at 500 °C, thus behaving more like the Co-based alloy CoNiCrMo. This feature is also important for good high temperature erosion resistance. High temperature erosion can be a problem in coal fired boilers (especially in Fluidised Bed Combusters).

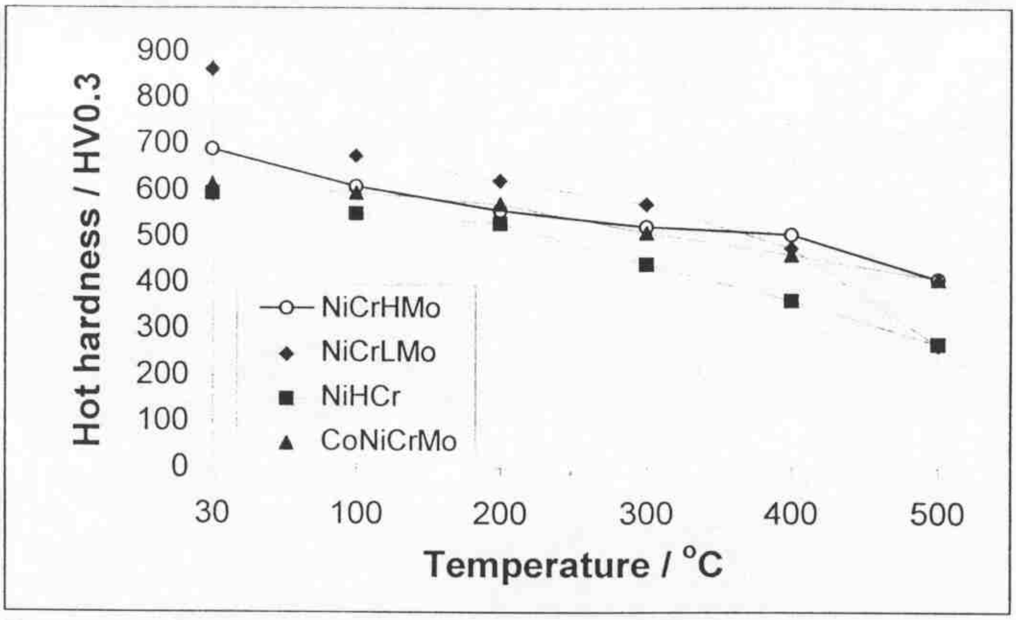

Fig. 1: Hot hardness of the coatings as a function of temperature

3.2 Resistance to abrasive wear

Resistance to abrasive wear at room temperature was tested with a dry sand rubber wheel apparatus (ASTM G65). Results for the four coatings are shown in Fig. 2. The wear behaviour roughly corresponds to the hardness level of the coatings. The two "softest" coatings, NiHCr and CoNiCrMo, show the highest wear values, the hardest coating performs best. Coating NiCrHMo, although having a significantly lower hardness than coating NiCrLMo, exhibits a comparably good wear resistance.

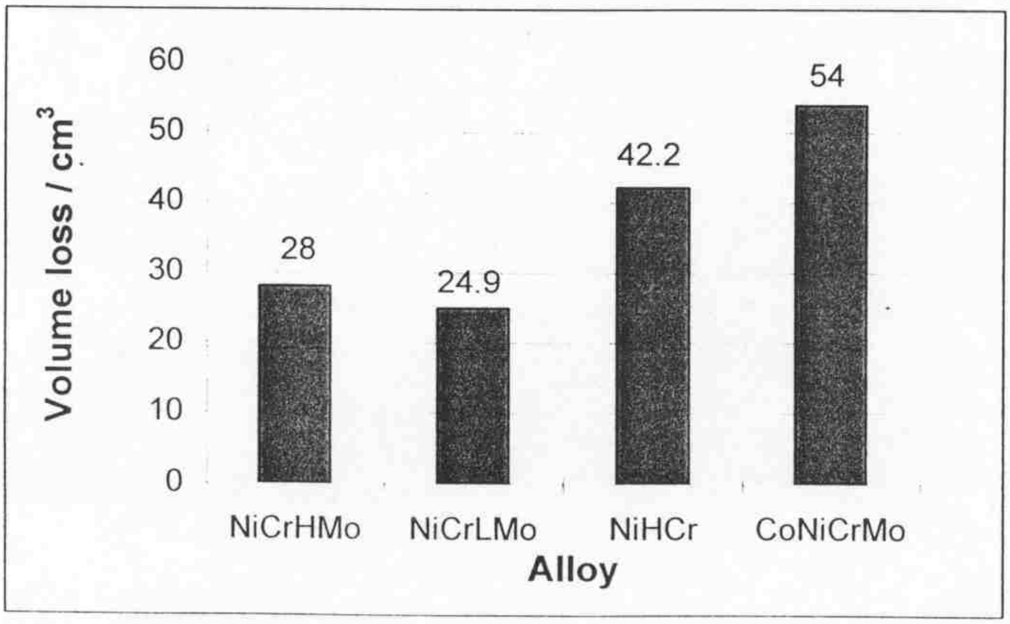

Fig. 2: Abrasive wear behaviour tested according to ASTM G65-91 Procedure A

The good wear behaviour is attributed to the specific microstructure of coating NiCrHMo, shown in Fig. 3, which is characterised by a small amount of primary Mo-rich hard particles in a eutectic matrix of different eutectic hard phases in a Ni solid solution.

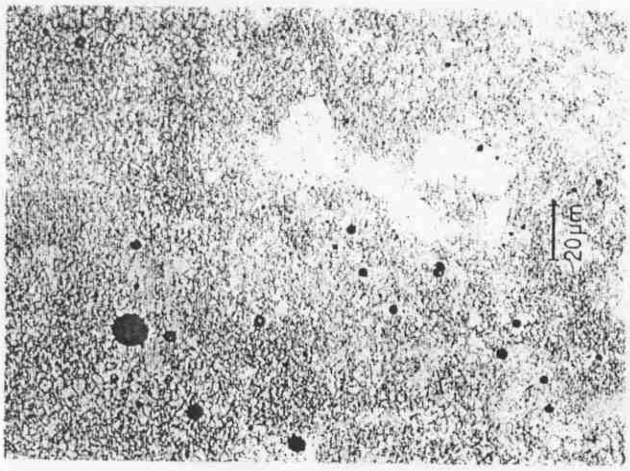

Fig. 3: Microstructure of coating NiCrHMo with primary Mo-borides in a eutectic matrix formed of eutectic hard phases and a solid solution of the alloying elements in Ni

3.3 Corrosion behaviour

Corrosion data are presented for acidic environments, such as are found in the chemical and petro-chemical industries as well as conditions encountered in acid dew point corrosion. Fig. 4 gives the average corrosion rates of coated plate samples exposed to hydrochloric, sulphuric and nitric acid of 10 % concentration (by weight) for a test duration of 168 hrs at 22±2 °C. Data for higher temperature aqueous corrosion, simulating dew point corrosion conditions with a mixture of 0.2 M HCl and 0.1 M H_2SO_4 at 70 °C are also included in Fig. 4.

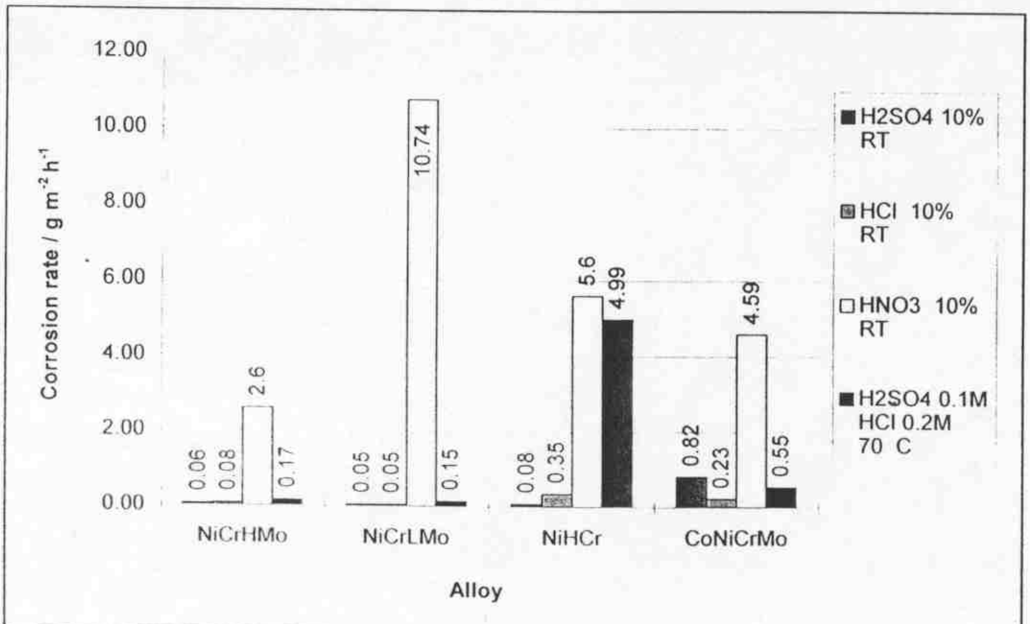

Fig. 4: Average corrosion rate of the coatings tested in different acid solutions for 168 hrs

The results shown in Fig. 4 indicate that coating NiCrHMo has an improved resistance to oxidising acidic environments and a comparable to better resistance in HCl and H_2SO_4. The improved performance mainly in HNO_3 is explained by the high Mo content. Mo is a strong carbide and boride former, thus binding a large amount of these elements. This leaves more of the alloy's chromium in the dissolved state, where it can provide protection against corrosion. In the alloys with lower Mo or without Mo addition, a significant amount of the Cr is precipitated as chromium carbides and borides. Besides this Mo in higher levels has shown to give improved resistance to "reducing" acids as HCl and H_2SO_4 as well as to chloride induced corrosion types as pitting and crevice corrosion. This positive effect is exploited in a large number of wrought NiMo and NiCrMo alloys.

4 CONCLUSIONS

- ◊ The new type of self-fluxing alloys has proven to have superior corrosion resistance in strong mineral acid solutions, including oxidising acids.
- ◊ Improved corrosion resistance could be realised without significantly impairing the good wear behaviour known for different self-fluxing alloys.
- ◊ Hot hardness of the new coatings shows a different temperature dependence than that of other self-fluxing Ni-base alloys, retaining a higher hardness level at elevated temperatures. This makes the new alloys a low-cost alternative to cobalt-based alloys for applications requiring good hot hardness characteristics.
- ◊ Deposition of the new alloy powder with PTA or HVOF will extend their application to other geometries and to components susceptible to high heat input. Initial corrosion tests with HVOF sprayed coatings show very promising results.

5 LITERATURE

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