Advanced Characterisation of Oxide Scales Formed on Chromium-based High Temperature Alloys

EUROCORR 2019 Young Scientist Grant – Brief Summary

The purpose of this research cooperation was to start a long-term cooperation between Anke Silvia Ulrich from DECHEMA-Forschungsinstitut (main applicant), Germany, and Dr. Alexander Knowles from University of Birmingham (co-applicant), United Kingdom. The cooperative project is assigned to research in high temperature material development focussing in the development of Cr-based alloys. The stay of Anke Silvia Ulrich in Birmingham was originally planned from 1st of March 2020 to 31st of May 2020 but had to be shortened unexpectedly due to the C-19 worldwide pandemic from 1st of March 2020 – 13th of March 2020. However, since then the applicants have been pursuing a close cooperation focussing on the development of Cr-based alloys for high temperature applications, such as concentrated solar power plants or gas turbines.

Cr-based alloys offer significant potential as new high-temperature materials for working temperatures beyond those of Ni-based superalloys. The advantages of using Cr as the base element at high temperatures are (i) its lower density, (ii) its oxidation performance up to 1000°C in dry air, and (iii) its low costs, and (iv) high melting point. However, some drawbacks still exist, counteracting the application of Cr-based alloys in several fields: (i) a ductile to brittle temperature > room temperature, (ii) nitridation and (iii) the formation of volatile oxide species and scale spallation at T > 1000°C. Recently it was found that alloying with Si and other ternary alloying elements such as Ge, Mo, and Pt can highly improve the oxidation resistance [1-4]. However, still the formation of the Cr_2O_3-SiO_2 duplex scale has to be investigated in more detail [5]. Especially when it comes to the effect of ternary alloying elements on SiO_2 scale formation, further advanced characterisation techniques such as transmission electron microscopy (TEM) are required to understand the differences in performance.

Previous experiments with Pt addition to Cr-Cr_3Si-alloys have revealed some interesting effects. The cooperative TEM investigations were therefore started with analyzing the microstructure of selected Cr-Si- and Cr-Si-Pt-alloy compositions [6]. From the experimental point of view, the investigation of alloy microstructures is considered as a first step in gathering experience with TEM measurements as the sample preparation is slightly easier in comparison to investigations on oxide scales. Due to the unexpected interruption of the stay in Birmingham and the lockdown of the university, the planned joint TEM investigations could not be fully conducted on the oxide scale. However, since then the research dealing with the development of Cr-based alloys for high temperature applications has continued in both institutions with a strong focus on the use in renewable energy systems such as concentrated solar power plants (CSP). Several samples were sent back and forth between Anke Silvia Ulrich (Germany) and Dr. Alexander Knowles (United Kingdom) and accompanying e-meetings for further experimental tests and analytic investigations which will result in joint scientific publications.

[1] A. Soleimani-Dorcheh, W. Donner, M. C. Galetz (2014). On ultra-high temperature oxidation of Cr–Cr_3Si alloys: Effect of germanium. Materials and Corrosion, 65(12), 1143-1150.

[2] A. Soleimani-Dorcheh, M. C. Galetz (2015). Oxidation and nitridation behavior of Cr–Si alloys in air at 1473 K. Oxidation of Metals, 84(1), 73-90.

[3] A. S. Dorcheh, M. C. Galetz (2017). Oxidation–nitridation mechanism in eutectic Cr-silicide alloy and its mitigation by germanium alloying. Oxidation of Metals, 88(5), 549-564.

[4] A. S. Ulrich, P. Pfizenmaier, A. Solimani, U. Glatzel, M. C. Galetz (2020). Improving the oxidation resistance of Cr-Si-based alloys by ternary alloying. *Corrosion Science*, *165*, 108376.

[5] A. Solimani, T. Nguyen, J. Zhang, D. J. Young, M. Schütze, M. C. Galetz (2020). Morphology of oxide scales formed on chromium-silicon alloys at high temperatures. Corrosion Science, 176, 109023.

[6] A. S. Ulrich, A. J. Knowles, V. Cantatore, A. Bhowmik, M.T. Wharmby, C. Geers, I. Panas, M. C. Galetz. Pt Accelerated Coarsening of A15 Precipitates in Cr-Si Alloys. Submitted to Acta Materialia (2020).