Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

High temperature interaction between liquid Gd-containing alloys and selected oxides

N. Sobczak[1,2], P. Turalska[1], M. Homa[1], A. Siewiorek[1], G. Bruzda[1], R. Nowak[1], A. Kudyba[1], I. Kaban[3], N. Mattern[3], J. Eckert[4,5]

[1]Foundry Research Institute, 73 Zakopianska Str., 30-418 Krakow, Poland
[2]Motor Transport Institute, 80 Jagiellonska Str., Warsaw, Poland
[3]IFW Dresden, Institute for Complex Materials, P.O. Box 270116, 01171 Dresden, Germany
[4]Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, 8700 Leoben, Austria
[5]Department Materials Physics, Montanuniversitat Leoben, Jahnstrase 12, 8700 Leoben, Austria

The sessile drop method was applied for investigation of high temperature interaction of liquid Gd, Ti, binary Gd-Ti and ternary Gd-Ti-Zr alloys in contact with dense polycrystalline Y_2O_3 and ZrO_2+3%Y_2O_3 substrates. During high temperature tests performed under flowing Ar, the contact angles were determined from the images of drop/substrate couples recorded with CCD camera. The effect of metal chemistry on its melting, wetting behaviour and reactivity in contact with oxide substrates are analysed.

Keywords: *wettability, reactivity, Gd-alloys, oxides*

1. Introduction

Gadolinium (Gd) is widely used in advanced alloys to improve their functional and utility properties. However, high melting temperature, high oxygen affinity and chemical aggressiveness against most available refractory materials makes difficult melting, casting as well as high-temperature testing of Gd-containing alloys using container-assisted methods (e.g. calorimetric studies, measurements of surface tension of liquid alloys) [1,2].

The paper is focused on investigation of high temperature interaction between liquid Gd-containing alloys and selected oxides.

2. Experimental

The materials were pure Gd (99.95%), Ti (99.98%) and their binary and ternary alloys produced by arc melting (Table 1). Dense polycrystalline oxide substrates were made from Y_2O_3 and ZrO_2 powders by HT-HP synthesis and polished up to a roughness of about 120 nm.

Real-time melting, wetting, spreading and solidification behaviour of selected Gd/oxide systems were examined by the sessile drop method [3,4] using experimental facility described in [4,5].

During high temperature tests, the selected metal/substrate couples were contact-heated to the test temperature under protective atmosphere (flowing Ar) and their images were recorded with a high-speed high-resolution CCD camera. The test temperatures were about 50 to 100°C above the melting points of the metal samples.

The structure and chemistry of solidified couples were examined both on the top surfaces and on cross-sections using optical microscopy (OM) and scanning electron microscopy (SEM) coupled with energy dispersive X-ray analysis.

3. Results

Wetting phenomenon was observed between Y_2O_3 substrate and pure Gd immediately after its melting (1312°C) showing θ~65°. Upon 2 min heating to 1360°C, a contact angle degreased to a final value of 33°. Similar wetting behavior was observed for $Gd_{60}Ti_{40}$ alloy at 1473°C.

Table 1. Contact angles of selected Gd/oxide couples

Metal	Substrate	Temp. °C	θ,°
Gd	Y_2O_3	1360	33
$Gd_{60}Ti_{40}$	Y_2O_3	1473	33
$Gd_{30}Ti_{70}$	Y_2O_3	1500	157
Ti	Y_2O_3	1760	77
Gd	ZrO_2+3%Y_2O_3	1362/1412	68
Ti	ZrO_2+3%Y_2O_3	1720/1770	122
$Gd_{60}Ti_{40}$	ZrO_2+3%Y_2O_3	1697	92
$Gd_{40}Ti_{60}$	ZrO_2+3%Y_2O_3	1760	80
$Gd_{40}Ti_{30}Zr_{30}$	ZrO_2+3%Y_2O_3	1650	104
$Gd_{40}Ti_{30}Zr_{30}$	ZrO_2+3%Y_2O_3	1660	101
$Gd_{40}Ti_{40}Zr_{20}$	ZrO_2+3%Y_2O_3	1690	95
$Gd_{40}Ti_{20}Zr_{40}$	ZrO_2+3%Y_2O_3	1700	97
$Gd_{40}Ti_{20}Zr_{40}$	ZrO_2+3%Y_2O_3	1717	94

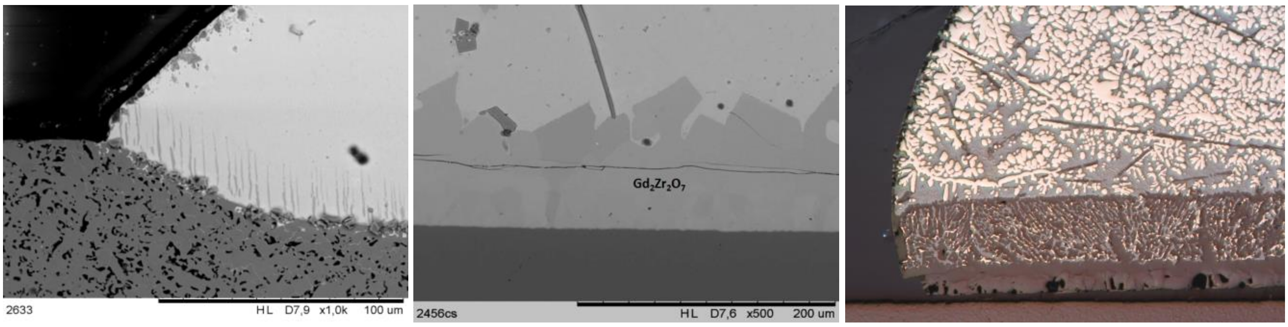

Fig. 1 Microstructures of cross-sectioned sessile drop couples:
a) Gd/Y_2O_3; b) Gd/ZrO_2+3% Y_2O_3; c) $Gd_{40}Ti_{40}Zr_{20}$/ZrO_2+3% Y_2O_3; a,b - SEM; c - OM

Y_2O_3 was also wetted by pure Ti, contrary to the high Ti-containing alloy $Gd_{30}Ti_{70}$ showing non-wetting behavior and a very high contact angle.

The ZrO_2 substrates containing 3%Y_2O_3 exhibited much worse wettability with both pure metals and their alloys. These substrates were not wettable by pure Ti at the experimental temperatures of 1720°C and 1770°C, contrary to pure Gd showing a good wetting at 1362°C and 1412°C. Alloying Gd with 40% Ti caused significant increase in the contact angle and non-wetting behavior at 1697°C. Further increase of the Ti content to 60% made ZrO_2+3%Y_2O_3 substrate wettable at 1760°C. For Gd-Ti-Zr alloys with 40% Gd, when Ti was partially replaced by Zr, no wetting was observed at selected temperatures.

Structural characterization of solidified couples revealed significant difference in the mechanisms of high temperature interaction in the studied systems. In the Gd/Y_2O_3 couples, the interaction is dominated by a strong dissolution of the substrate in the liquid metal resulting in the formation of a deep crater in the substrate, alloying Gd drop with Y and the growth of directionally solidified interfacial region during cooling (Fig. 1a). On the contrary, the interaction of both pure Gd and selected Gd-containing alloys with ZrO_2-3%Y_2O_3 substrates is controlled by the formation of continuous interfacial reaction product $Gd_2Zr_2O_7$ (Fig. 1b).

Additionally in the Gd-Ti-Zr/ZrO_2-3%Y_2O_3 couples, a Gd-rich layer is evidenced in the Gd-Ti-Zr drop near the reactively formed interfacial layer while the other part of the drop is almost free of Gd (Fig. 1c). This effect is related to the liquid metal de-mixing since the Gd-Ti-Zr alloys exhibit miscibility gap in the temperature rage studied in this work.

4. Summary

Dissolutive wetting mechanism is responsible for a good wetting of liquid Gd and Gd-rich alloys on Y_2O_3 substrates.

Wetting phenomenon in the Gd/ZrO_2+3%Y_2O_3 couple is dominated by the formation of continuous and wettable layer of a new phase $Gd_2Zr_2O_7$ at the interface.

Alloying Gd with Ti or Ti+Zr reduces reactivity of liquid metal with both Y_2O_3 and ZrO_2+3%Y_2O_3 substrates thus resulting in higher contact angles.

Acknowledgements

This study was done in the frame of collaboration program between the German Academic Exchange Service DAAD and the Ministry of Science and Higher Education of Poland. Financial support from the National Science Centre of Poland (program HARMONIA, project No. 193624) and the German Academic Exchange Service DAAD (Project No. DAAD-56269397) is acknowledged.

.

References

[1] I. Kaban, R. Nowak, O. Shuleshova, B. Korpala, G. Bruzda, A. Siewiorek, J.H. Han, N. Sobczak, N. Mattern, J. Eckert: J. Mater. Sci. 47/24 (2012) 8381-8386

[2] N. Sobczak, R. Nowak, A. Siewiorek, B. Korpala, G. Bruzda, I. Kaban, O. Shuleshova, J.H. Han, N. Mattern, J. Eckert: Proc. 71st World Foundry Congress, Bilbao, Spain (2014).

[3] N. Sobczak, M. Singh, R. Asthana: Curr. Opin. Solid State Mater. Sci., 9/4 (2005) 241-253

[4] N. Sobczak, J. Sobczak, R. Asthana, R. Purgert: China Foundry 7/4 (2010) 425-437

[5] N. Sobczak, R. Nowak, W. Radziwill, J. Budzioch, A. Glenz: Mater. Sci. Eng. A495 (2008) 43-49