

WEDNESDAY, AUGUST 25, 2004, A.M.

**SESSION 40: FOURTH INTERNATIONAL SYMPOSIUM ON ADVANCES IN
REFRACTORIES FOR THE METALLURGICAL INDUSTRIES**

BASIC SCIENCE (II)

Sponsors: Materials Science and Engineering, The Metallurgical Society of CIM, The Refractory Ceramics Division of the American Ceramic Society and The Canadian Ceramic Society.

Room: Webster C

Chairmen: P. BOCH, Université Pierre et Marie Curie, Paris, France, and
N.S. ZHOU, Henan University of Science and Technology, Luoyang, Henan, China

PAPER 40.1 — 8:05

PREDICTION OF THE THERMAL SHOCK RESISTANCE OF REFRACTORY MATERIALS USING R -
VALUES.

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M. FOOLADI MAHANI, University of Kerman, Kerman, Iran

The knowledge of the thermal shock resistance of refractory materials is of utmost importance due to their wide range of applications in various industries, namely; ceramics, oil refinery, thermal insulation, nuclear power, chemical and petrochemical industries. Thermal shock resistance is measured in terms of the number of cycles that a refractory material can withstand when subjected to sudden temperature changes. This property is measured experimentally by heating a sample of the material and cooling it in a known environment then the number of cycles it withstands this treatment without spalling is a measure of its thermal shock resistance. Although this method of experimentation has long been the practice, but it is both expensive and time consuming. Various studies have been carried out to predict this vital property, however, the range of applications are limited. The present study employs a test rig by which temperature distributions in magnesite samples are accurately measured. This information plus other results obtained from relevant tests on related properties are used to develop a model which predicts the number of quench cycles withstand by different materials when subjected to sudden temperature changes. The comparison of the theoretical values using the solution of the presented model with experimental data for different materials having different thermal resistance shows a closed agreement.

PAPER 40.2 — 8:30

THERMOMECHANICAL BEHAVIOUR: FROM CERAMICS TO REFRACTORIES.

M. BOUSSUGE, École des Mines de Paris, Evry, France

Ceramics and refractories have many common constituents and consecutively exhibit several analogous properties. For example, concerning the thermomechanical properties this paper will focus on, the type of creep that can be observed in both materials is often the same (kinematic hardening). Changes in microstructure (phase transformation, dehydration, sintering, crystallisation...), induced by heating and/or cooling, can also drastically modify the mechanical behaviour of ceramics and refractories.

But the coarse granulates, the porosity and the impurities contained in industrial refractories may lead to specific responses of this material to thermal and/or mechanical loadings. In particular, some differences can be observed with technical ceramics in the main type of damage observed in service : diffuse damage in refractories (microcracking) and localised damage in ceramics (macrocracking). In this paper, the possibilities of transferring a part of knowledge from ceramics to refractories will be discussed, in the field of thermomechanical properties : experimental characterization techniques, mechanical behaviour models,... Finally, some problems caused by scale effects and by the integration of thermomechanical properties of refractories in the numerical simulation of industrial structures will be evoked.

PAPER 40.3 — 8:55

BRITTLE-DUCTILE TRANSITION OF AN Al_2O_3 - SiO_2 REFRACTORY MATERIAL

J.A. RODRIGUES, S.F. SANTOS and V.C. PANDOLFELLI, Federal University of São Carlos, São Carlos, Brazil

Under conditions of stable crack propagation at room temperature, the elastic energy stored in ceramic materials is converted mainly to surface energy. However, at high temperatures, creep may also occur in such materials, in which case it will present a ductile behavior. This paper discusses the brittle-ductile transition of a refractory material. Stable crack propagation and creep tests were carried out under a three-point bending device. A commercial ceramic

containing 63 wt-% of SiO₂ and 31 wt-% of Al₂O₃ was used as testing material. The results revealed that the change in behavior from brittle to ductile was caused by softening of a vitreous phase present in the material's microstructure.

PAPER 40.4 — 9:20

HIGH TEMPERATURE MECHANICAL BEHAVIOUR OF FUSED-CAST REFRACTORIES.

L. MASSARD, M. BOUSSUGE, École des Mines de Paris, Evry, France,
E. YEUGO FOGAING, M. HUGER and C. GAULT, École Nationale Supérieure de
Céramique Industrielle, Limoges, France

This study has been carried out owing to the French research program PROMETHEREF, which aims to improve the knowledge of thermal and mechanical properties of industrial refractories at high temperature. In this frame, this paper relates a collaborative study between Saint-Gobain CREE, R&D Centre for Saint-Gobain Ceramics & Plastics in Europe (Cavaillon), the Materials Center P.M. Fourt of Ecole des Mines de Paris (Evry) and the Research Group on Heterogeneous Materials (GEMH) of ENSCI (Limoges). Data collected at high temperatures by using different means (bending tests, ultrasonic measurements,...) allows the identification of the high temperature behavior of two fused cast materials, produced by Saint-Gobain group for the glass manufacturing industry. The results emphasize the importance of the transformation of zirconia and of the viscosity of the glassy intergranular phase on the mechanical behavior. Damage under the form of microcracking caused by thermal expansion mismatch between the phases is also observed during cooling down at low temperature, when the material is elastic.

PAPER 40.5 — 9:45

HIGH TEMPERATURE MECHANICAL BEHAVIOR OF TWO REFRACTORY CASTABLES: EXPERIMENTS AND SIMULATIONS.

H. MARZAGUI, T. CUTARD, École des Mines d'Albi, Albi, France,
M. ROSEFID and E. OUEDRAOGO, Institut National Polytechnique de Grenoble –
ENSHMG, Grenoble, France

The present work is achieved in the framework of a French national program on modeling and experimental characterization of the thermo-mechanical properties of refractory materials (PROMETHEREF). This research program is aimed to establish fair models and experimental database and to make it available to industrial partners for numerical simulation of industrial structures made of these materials. The present paper focuses on two silico-alumina refractory castables, an andalusite based one and a bauxite based one. We will present the first rheological characterization results achieved at room on normal and preheated samples of these two refractory castables. Refractory castables are characterized with the help of four points bending tests, compression tests and tensile tests.

COFFEE BREAK — 10:10 – 10:40

PAPER 40.6 — 10:40

EAF SLAG DESIGN FOR MAXIMIZING REFRACTORY SERVICE LIFE.

K.S. KWONG, J.P. BENNETT, USDOE, Albany, Oregon, U.S.A.
W.E. LEE and S. ZHANG, University of Sheffield, Sheffield, United Kingdom

An EAF slag properly saturated in MgO results in increased refractory service life and steelmaking efficiency. A computer model was developed using phase equilibrium data from the MgO-CaO-SiO₂-FeO, MgO-CaO-Al₂O₃-SiO₂ and SiO₂-CaO-Al₂O₃-FeO systems to predict MgO saturated slag chemistry. This model has been successfully applied to a commercial EAF, although disciplined plant practices are required to achieve benefits from slag chemistry control.

PAPER 40.7 — 11:05

THE EFFECT OF AN APPLIED ELECTRICAL POTENTIAL ON REFRACTORY CORROSION BY SLAG.

B.J. MONAGHAN, S.A. NIGHTINGALE and M. FUNCIK, University of Wollongong,
Wollongong, Australia

An investigation has been carried out to assess the effects of an applied voltage on the dissolution rate of MgO refractory in a steelmaking like slag. In this study corrosion results obtained from dip tests using a dense direct bonded MgO refractory in a CaO-SiO₂-Fe₂O₃-FeO-MgO slag are presented. These results demonstrate that the application of a voltage across a dense MgO refractory-slag interface can change the rate of refractory dissolution. For the slag composition used and the voltage range tested, it was found that a maximum corrosion rate was obtained at a voltage setting of -0.45V. The results of this investigation have been explained in terms of voltage affects on Marangoni

(interfacial tension induced) stirring and its effect on the MgO dissolution reaction that is at least partly controlled by mass transfer in the slag.

PAPER 40.8 — 11:30

LABORATORY STUDIES ON CORROSION BEHAVIORS OF MGO-C REFRACTORIES IN VOD PROCESS CONDITIONS SIMULATED BY BALZERS VACUUM INDUCTION FURNACE.

M. GUO, S. PARADA, S. SMETS, P. JONES and B. BLANPAIN, Catholic University of Leuven, Heverlee, Belgium

The corrosion behaviour of a pitch-bonded MgO-C refractory in contact with a vacuum oxygen decarburisation slag with high Al_2O_3 content (12-17 wt%) is investigated under VOD process conditions by rotating finger tests in a vacuum induction furnace. The refractory degradation mechanisms are studied by the characterisation of the corroded microstructures using scanning electron microscopy, equipped with energy dispersive spectroscopy. The influence on the refractory wear of the process temperature, corrosion time and the Al_2O_3 content in the slag is discussed. The degradation mechanisms include slag infiltration, direct MgO dissolution from the refractories into the penetrated slag, erosion of magnesia grains at elevated temperatures, removal of carbon through the MgO-C reaction, and finally, oxidation of refractory carbon by reducible slag components. Both a porous MgO layer and a dense $(Mg)(Al,Cr)_2O_4$ spinel at the slag/brick interface were observed. Their formation mechanisms and industrial relevance are discussed.