TUESDAY, AUGUST 28, 2007, PM

COM 2007: International Symposium on **Light Metals** in Transport Applications
Session 37: Alloys Properties and Applications
Sponsors: Light Metals Section of MetSoc, TMS
Chair(s): M. Pekguleryuz, McGill University;
J.P. Martin, Aluminium Technology Center
Room Confederation 5—13:40

Paper #1160—13:40
The role of aluminium for energy and greenhouse gas savings in transport
P. Kistler, K. Buxmann, International Aluminium Institute

This paper will focus on the environmental aspects of the lightweighting of transport, which are related to the savings of fuel and electricity. While several materials can be used for lightweighting of transport, it is aluminium, which offers not only significant advantages during the use stage, but also in the end-of-life stage. Life cycle assessment is used to quantify the relative benefits of light-weighting specific components of cars, busses, ships and trains. A vehicle consists of many components, which are produced by different processes and undergo different types of end-of-life operations. This document does not intend to compare a generic aluminium vehicle with a generic "heavy materials" vehicle. It rather tries to use a pragmatic approach based on specific examples of components where both aluminium and steel (mild and high strength) have been considered as alternatives in the design of a new vehicle, which have to fulfil identical requirements on performance. For each component sensitivity analyses is applied to see the impact of each parameter such as the end-of-life recycling rate and the lifetime driving distance. Significant greenhouse gas savings by the use of aluminium are demonstrated for cars and even higher ones for trucks, busses, trains and ships. In addition, the total potential benefits of lightweighting with aluminium are shown on the global level.

Paper #1191—14:00
Effect of alloying additions on the development of texture and residual strain in plane-strain compression of magnesium alloys
D.G. Sediako, M.A. Gharghouri, R.B. Rogge, NRC

The chemistry of the alloys and the casting/rolling production routes determine the cost and properties of the wrought material. For example, the coarse-grained structure frequently associated with DC casting requires complex rolling schedules to refine the grain size. A problem exists in characterizing material properties from the viewpoint of material texture. This study will contribute to the general understanding of the development of residual strains and texture during rolling of binary Mg-Al alloys and several commercial Mg-based alloys. Alloy composition influences deformation behaviour. Aluminum is one of the most common alloying elements in Mg alloys, however, in coarse-grained Mg-Al

alloys, aluminum may contribute to shear band formation. The enhanced deformation in shear bands causes accelerated recrystallization, resulting in a finer grain structure. Strain accumulates in the shear band, and the resulting stress concentration may lead to an earlier failure in the rolling direction than in the transverse direction. The mechanical properties of Mg-Al alloys are also affected by heat treatment because of the precipitation of the b -$Mg_{17}Al_{12}$ phase, which increases with decreasing cooling rate and increasing aluminum content. The tensile and yield strengths increase steadily with increasing aluminum content, while the elongation can vary widely in the composition range 4-5wt.% Al. This may be attributed to the balance between solution hardening from dissolved aluminum and the morphology of the b-phase. Rolling results in a strong crystallographic texture, which is responsible for the tension-compression strength asymmetry exhibited by rolled magnesium alloys. Understanding the influence of alloy composition on texture evolution in plane-strain deformation will provide useful information to optimize industrial rolling technologies for higher-end magnesium alloys. Neutron diffraction is a powerful tool for understanding the effects of processing on micro-structure. The ability of neutrons to penetrate deeply into materials allows information to be retrieved from all regions of a bulk specimen without destructive and time-consuming sectioning operations. In-situ experiments will be performed to measure the evolution of texture and the development of residual strains as a function of applied strain.

Paper #1133—14:20

Mechanical properties of A356 thixoformed alloy produced by SIMA process

A.F. Boostani, B. Niroumand, F. Karimzadeh, M.A. Golozar, Isfahan University of Technology

There are various methods for production of thixoforming stock. One of these is called Strain Induced Melt Activation (SIMA). In this study the effect of thixoforming process on mechanical properties of A356 alloy has been investigated. At first in order to produce a nondendritic structure to be used in thixoforming process, samples were subjected to 20 % cold working and then reheated up to 590 and 600 degrees celsius for 10 minutes. A 30 and 50 % hot working on samples was then performed. Obtained results showed that thixoforming at 590 degrees celsius with 30% hot working could produce materials with high quality index (high ductility) which might be suitable for automobile industries applications. A new mechanism for morphology changes of silicon particles, which resulted in increasing of ductility of A356 thixoformed alloys, presented.

Paper #1165—14:40

Grain refinement of B206 aluminum – copper alloy

N. Dahata, C. Ravindran, Ryerson University,
F.H. Samuel, University of Quebec at Chicoutimi,
T.W. Gustafson, GM Powertrain Casting Development and Validation Centre

Earlier research has indicated that an addition of titanium master alloy to aluminum alloys, results in improved fillability, grain refinement and finer pores. B206 alloy differs from other alloys used in automotive industry with respect to titanium level. This paper examines the effect of alloy chemistry (copper and titanium levels) and grain refinement (Al -5wt% Ti-1wt%B grain refiner) on grain size, microstructure and microporosity in B206 aluminum alloy. In this study, characterization of grain size, microstructure and microporosity was carried out using light optical microscopy (LOM) and scanning electron microscopy (SEM). Results have shown that with the addition of 0.05 wt% titanium resulted in grain refinement of B206 alloy. With an increase in titanium to 0.25 wt%, further grain refinement, much reduced pore size and uniform distribution of pores resulted. These results suggest that B206 with proper addition of titanium has a promise as an alloy for automotive casting.

Paper #1167—15:00

Mechanical properties and corrosion resistance of some creep resistant magnesium alloys

S. Amira, N. Giguère, D. Dubé, R. Tremblay, E. Ghali, Université Laval

In the last two decades, many new creep-resistant magnesium alloys have been developed for high temperatures applications. Their mechanical performance and corrosion behaviour were reported for various experimental conditions. However, these conditions often led to uneven comparison basis. In the present study the microstructure, mechanical properties and corrosion performance of four of these newly developed creep-resistant magnesium alloys were systematically compared. Specimens were obtained from experimental box-like components that were die-cast and thixocast in comparable conditions. Their mechanical and corrosion properties were compared using similar testing conditions. Results show that the creep resistance, strength and impact resistance of specimens are comparable but systematically lower compared to specimens cast under optimized conditions. The reduced concentration of elements such as Al, Ca, Sr and Ce lead to a decrease of the corrosion resistance of the magnesium alloys in 3.5% NaCl solution.

Coffee Break—15:20 – 15:40

Paper #1136—15:40

Effect of T6 heat treatment on mechanical properties of AZ91+RE magnesium alloy

K. Meshinchi Asl, A. Tari, F. Khomamizadeh, Sharif University of Technology

In this study the effects of T4 and T6 heat treatments on microstructural characteristics of AZ91 alloy containing Rare Earth elements have been investigated. Formation of intermetallic $Al_{11}RE_3$ needle shape particles which have a good thermal stability reduces both formation of β($Mg_{17}Al_{12}$) and discontinues precipitation in AZ91 alloy which are dominated at the grain boundaries and are responsible for poor mechanical properties specially in elevated temperatures. For AZ91-RE samples both T4 and T6 heat treatments led to a continuous precipitation of β particles at the grain boundaries after aging. However, in AZ91 samples (with no Rare Earths) precipitation was discontinuous at grain boundary areas. This type of precipitation is one of the main reasons of poor mechanical properties of this alloy at elevated temperatures.

Paper #1157—16:00

Evaluation of equi-axed grain structure in sima processed AS21 magnesium alloy

M.B. Karimi, M.H. Heidary, F. Khomamizadeh, Sharif University of Technology

In this study, the effect of strain level and holding time in semisolid temperature range via SIMA process on AS21 Mg alloy was investigated. Some cylindrical samples of this alloy with 1cm in height and 2.5cm in diameter (H/D=0.4) were compressed to 10%, 20%, 30% and 40% at 300˚C. Then, the samples were reheated in semisolid temperature range at 614˚C for various times. The results of optical microscopy and image analysis showed that with increasing of strain and holding time, dendritic structure changed to equi-axed structure, gradually. Also, the best conditions to obtain good globular structure were achieved. Furthermore, it was seen that after compression and reheating, Mg_2Si intermetallics with Chinese script morphology converted to dispersed-fine particles which were distributed into the α-Mg grains.

Paper # 1153—16:20

Hardening and Softening in MG-AL-CA and MG-AL-SR alloys at elevated temperatures

Z. Trojanová, P. Lukáč, Charles University

The deformation behaviour of ternary magnesium alloys AX (Mg-Al-Ca) and AJ (Mg-Al-Sr) were investigated in tension as well as compression tests. The samples were deformed at temperatures between 20 and 300 °C and at an initial strain rate of the order 10^{-4} s^{-1}. The flow stress decreases with increasing temperature. The macroscopic work hardening rate decreases with increasing flow stress and temperature. The stress and temperature dependence of the work hardening rate is a result of the hardening and softening processes. Stress

relaxation experiments have been performed in order to reveal features of the thermally activated dislocation motion. Internal and effective stress components of the applied stress were estimated. A decrease in the internal stress was observed at elevated temperatures, which indicates recovery process (-es). A more detailed analysis of the estimated values of the activation volume and activation energy helped to interpret the thermally activated processes during plastic deformation. It is concluded that the deformation behaviour of the alloys depends on the activity of non-basal slip, which is strongly influenced by temperature.

Paper #1140—16:40

The effect of T7351 heat treatment on the mechanical and SCC properties in aluminum AA7075 alloys

M. Esmailian, Iranian Research Organization for Science and Technology

All studies have been done on the effect of T7351 heat treatment on mechanical properties and resistance to Stress Corrosion Cracking (SCC) in Aluminum AA7075 alloys indicated that this treatment increases both SCC resistance and mechanical properties. In this study, mechanical properties and microstructural evaluation have been investigated for T73, T7351, full annealed and as received specimens. The specimen with T7351 heat treatment indicated the best mechanical properties in comparison with other samples and results showed theirs Ultimate Tensile Strength (UTS), Yield Strength (YS) and elongation (%e_1) were 463Mpa, 416Mpa and 12% correspondingly. Furthermore, the microstructural evaluation showed that by this treatment the precipitates can immigrate from grain boundary into the grains and average grain size can be decreases to 9.5 μm. The corrosion examination showed that the SCC resistance of T7351 specimens increases because of homogenous precipitates dispersion and reduction in Mg and Cu contents in grain boundary precipitates.

Paper #1127—17:00

Mechanical properties of semi-solid A356 alloy formed by thixoforming process

S. Tahamtan, M.A. Golozar, F. Karimzadeh, B. Niroumand, Isfahan University of Technology

Semi solid forming technology has advantages over other conventional forming processes such as Die cast and squeeze cast. Thixoforming technology can produce non-dendritic alloys for the semi-solid forming of complex-shaped parts in metal alloys. Mechanical and corrosion properties of the semi-solid components can be improved by processing parameters such as solid fraction of the material, heat treatment conditions and reduction of cross section (percentages of hot working). A356 aluminum alloy is the most widely used alloy for semisolid processing. In the research work presented here, mechanical properties of a thixoformed A356 alloy were measured and compared with the mechanical properties of rheocasted and gravity casted alloy with the same

composition. In the thixoforming process, a 60 percent solid fraction alloy was reheated to 600°C and 610°C, hold about 10 minute, and then 30% and 50% reduction of cross section was applied. Microstructural and mechanical properties of specimens produced were investigated. Results obtained show that tensile strength, yield strength and elongation –to-failure of thixoformed alloy at lower temperature (600°C) was more than at higher temperature (610°C). Tensile strength, yield strength and elongation –to-failure of thixoformed alloy were higher than rheocasted and gravity casted samples. It was shown that improvement in the mechanical properties due to thixoforming process is attributed to morphological aspects of silicon phase, as well as non-dendritic structure produced.

Cu2007: International Symposium on **Economics and Markets**
Session 38: Economics and Markets III
Sponsors: The Management and Economics Society of CIM, MMIJ, GDMB, IIMCh
Chair(s): J. Makkonen, Bolden Harjavalta Oy;
J. Postle, Roscoe Postle Associates
Room Sasketchewan—13:40

Paper #1089—13:40
The copper miracle: fundamentals and non-fundamentals analysis for 2003-2006
J.I. Guzmán, University of Chile

Since 2003 the world commodities prices have reached unthinkable records, mainly due to the recovery in demand, lead by China. In the case of copper, the price rose almost to 4 dollars per pound in 2006, which was never predicted and not even understandable using the conventional supply and demand analysis. This article investigates the fundamentals, that is, the supply and demand analysis, versus the non-fundamentals, specially referred to as a blooming of copper as a financial asset, for the copper market in the 2003-2006 period. The results indicate that, while in a first stage (2003-2004) the gap between demand and supply could have explained reasonably well the price, in the second stage (2005-2006) it would have responded more to speculation than fundamentals. All of this shows us that we would expect the future of the copper price possibly to depend not only on the traditional fundamentals' study but also on non-fundamental's analysis.

Paper #1083—14:05
After reaching the peak how far and how fast is the descent?
D. Davidson, Paradigm Capital Inc.

Most hard commodities prices are well past the highs set in the inflationary period of the late 1980's, at least in US dollar terms. Copper has been the star

performer of this class during this bull market, up approximately 500% trough to peak. This paper addresses some of the main drivers for copper supply and demand as well as the most pressing issues facing the industry during this extended period of unprecedented prices. China's voracious appetite for the world's raw materials has coincided with supply constraints, providing a most welcomed tonic for the resource industry. Conditions within China and its economic outlook will continue to have profound effects on both supply and demand for copper. The impact on world copper supply and demand from other economies, including India and Russia, will also be addressed. The influence of investment funds and other participants in the copper market will be assessed.

Paper #1087—14:30

Macro trends in copper consumption

G.A. Campbell, Michigan Technological University

This paper looks at how changes in the economies and demographics of the eight largest copper-consuming countries have been affecting their consumption of copper. The period of 1976 to the present is considered. Annual changes in measures like intensity-of-use of copper, per capita consumption of copper, copper consumption based on per capita income, and copper consumption from industrial production for each country and in aggregate are calculated. Other factors like the change of industrial production relative to total GDP and population/age trends are also established for the individual countries. Non-parametric and parametric statistical tests are used to determine the significance of observed trends and relationships for individual countries and in aggregate. The results give insights into how copper consumption is changing for the countries and what economic/demographic factors are driving these changes. These insights provide some guidance about where copper consumption trends are headed in the future.

Paper #1082—14:55

Competitive strategies of primary copper producers, 1999 - 2005

C.A. Moscoso, University of Chile,
A. Ebensperger, Atacama Resource Capital Project, InverChile S.A.

This article applies the market driven management approach to analyze the competitive strategies followed by leading copper producers in the period 1999 – 2005. Within the framework of Natural Resource Economics and the specific characteristics of copper, resource and factors markets, we examine the competitive position of CODELCO, Rio Tinto, BHP Billiton, and Phelps Dodge. In order to achieve an above-average profit performance in the different business units in its portfolio, a mining firm should consider the strength of its competitive position, relative to direct competition. While the reference market's attractiveness is mostly determined by forces outside the firm's control, the business unit's competitiveness and the development of corporate opportunities leading to a stronger strategic positioning, can be largely shaped by the firm's

choices. This means analyzing the different variables that determined competitiveness in the copper industry in this period. The analysis considers the static or structural form of competition, as well as the growing importance of the dynamic dimensions, related with the building of strategic capabilities and talents of the firm.

Coffee Break—15:20 – 15:40

Paper #1093—15:40

Copper prices, currencies and global growth – Outloook 2007-2008

P. Mohr, The Scotiabank Group

LME copper prices have remained at exceptionally profitable levels in 2007 – underpinned by ongoing strength in emerging markets – including significant re-stocking by China's fabricators early in the year --only a slow start to new mine expansion and, more recently, by labour disruptions in Latin America and Canada. Global demand for refined copper is expected to grow by more than 4% in 2007—a faster pace than the 3.3% of 2006. Demand in the emerging world will climb by 7%, more than offsetting a slight decline in G7 consumption (linked partly to the correction in U.S. housing and motor vehicle production). World demand should still be advancing at an above-average pace in 2008-09. While copper prices are expected to gradually unwind in the next several years, as new mine production comes on stream, prices should remain quite elevated compared with the 1990s. Higher trend growth rates for consumption – linked partly to strong global business investment -- and escalating capital costs will underpin prices.

Paper #1097B—16:05

The impact of emerging markets on copper supply and demand - the case of India and China

M. Ruhrberg, International Copper Study Group

In recent years, China and India have emerged as major players in the copper sector. Over the last decade, around 50% of additional global refined copper usage growth can be attributed to them. The paper provides an overview of the current and future copper supply and demand situation in both countries. Results from two market studies commissioned by the International Copper Study Group (ICSG) are complemented with recent copper statistics on North-East and South-East Asia, as well as further sectoral analysis. Developments and trends in copper mining and metal production, semis production, and major end use areas are highlighted. While providing insights into sectoral patterns and growth trends, the paper provides the basis for comparing structure and output of the copper sectors in some of the major copper-using countries in Asia. Afterwards, the current copper reservoir in use associated with infrastructure, buildings, industrial equipment, transportation systems and households is assessed using

the ICSG Copper Flow Model. Finally, the identified copper flows are analyzed regarding the potential impact on the future world supply and demand situation.

Cu2007: The John Dutrizac International Symposium on Copper
Hydrometallurgy, Incorporating the 37th Annual Hydrometallurgy Meeting
Session 39: Impurity Control and Recovery
Sponsors: Hydrometallurgy Section of MetSoc, IIMCh, MMIJ, GDMB, EPD of TMS
Chair(s): L. Treadgold, Nikanor PLC Douglas;
M. Stelter, Tu Bergakademie Freiberg
Room Alberta—13:40

Paper #0976—13:40
Hydrometallurgical processing of gold bearing copper enargite concentrates
C.G. Anderson, L.G. Twidwell, Montana Tech

With demand and prices for copper and gold at near record high levels, coupled with a lack of readily treated orebodies, the emergence of environmentally sound hydrometallurgical treatment of enargite concentrates has become a priority. This paper will outline the application the industrially proven technologies of low pressure and temperature NSC (Nitrogen Species Catalyzed) pressure leaching and ASL (Alkaline Sulfide Leaching) for the recovery of copper and gold from enargite. Copper can be recovered as cathode metal or as a clean concentrate suitable for smelting. Gold is recovered by smelting, conventional cyanidation or alkaline sulfide hydrometallurgy. Coupled with this is the effective precipitation and stabilization of arsenic as scorodite and ferrihydrite.

Paper #1005 – 14:05
Rate of gold dissolution in concentrated cupric chloride solutions
R. Von Bonsdorff, J. Aromaa, O. Forsén, Helsinki University of Technology,
M.H. Barker, Outokumpu Technology

Electrochemical and quartz crystal microbalance (QCM) methods were used to investigate the dissolution rate of gold in a solution similar to those utilized by the Outokumpu HydroCopper® process. The measurements were conducted in an electrolyte solution where [NaCl] = 2.8-280 g/L, pH = 1-2.5, $[Cu^{2+}]$ = 0-30 g/L and T = 70-95°C. According to these measurements, the solution flow has the greatest impact on the dissolution rate of gold in the HydroCopper® process. Under adequately acidic conditions (pH < 3), the dissolution rate of gold increases with increasing cupric concentration, increasing chloride concentration and increasing temperature. The results and trends observed compared well with the literature.

Paper #1188—14:30

The treatment of arsenical materials in pressure leaching of copper concentrates at Dynatec

R.M. Kalanchey, R.M. Berezowsky, M.J. Collins, Dynatec Corporation

The application of pressure oxidation processes to copper feed materials has gained increased exposure in recent years and some of these processes have made commercial inroads, although rather limited to date. Among the hydrometallurgical processes with significant commercial potential, Dynatec's copper pressure leaching process has been applied to arsenic-bearing copper materials and has shown, through a number of batch and continuous test programs, that pressure oxidation is a technically feasible option for the recovery of copper with coincident sequestration of arsenic in an environmentally benign residue.

Paper #1020 – 14:55

Differences in the removal of antimony (III) and antimony (V) from copper electrolyes using ion exchange

P.A. Riveros, J.E. Dutrizac, R. Lastra, CANMET-MMSL

Antimony is commonly found in copper electrolytes and can contaminate the cathode deposit. Several methods, such as ion exchange, solvent extraction and precipitation, have been developed to remove antimony from copper electrolytes. However, past research has been carried out almost exclusively with Sb(III), whereas the presence and behavior of Sb(V) in the electrorefining circuit have been largely ignored. In this study, the behavior of Sb(V) species was monitored and compared to that of Sb(III) species, using specially developed analytical and SEM-EDS techniques. Significant differences in the behavior of the two species were noted. Although the solubility of Sb(III) increases with temperature in synthetic copper electrolytes, the solubility of Sb(V) appears to be constant over the range from 30 to 80°C. Whereas Sb(III) forms several crystalline oxy-sulphate compounds, Sb(V) appears to remain as an amorphous oxide. Both Sb(III) and Sb(V) are extracted by aminophosphonic resins, and Sb(III) is readily eluted by HCl or complexing agents. By contrast, concentrated HCl elutes Sb(V) inefficiently and complexing agents, such as EDTA and tartaric acid, do not elute Sb(V) to any significant extent. This observation implies that in industrial practice, unless special measures are taken, Sb(V) will accumulate on the resin, eventually impeding the ion exchange process.

Coffee Break—15:20 – 15:40

Paper #1007—15:40

Recovery of bismuth from the precious metal discharge solution process development at Kennecott Utah Copper refinery

D. Kim, S. Wang, Kennecott Utah Copper Corporation

Kennecott operates one of the largest and most modern copper refineries in the world at Magna, Utah, USA. The inputs to the refinery are anodes produced at Kennecott Smelter, which has extremely high contents of lead and bismuth. In order to minimize undesired effects in the electrolytic refining process, unwanted impurities, especially bismuth, must be controlled. This paper describes the process development of practicing state-of-the-art quality control and presents the pilot test results of using the MRT Technology for Bi production.

Paper #0953—16:05

Characterization of flue dusts from a copper smelter furnace, copper recovery and arsenic inertization

A. Morales, Universidad Católica del Norte,
M. Cruells, A. Roca, R. Bergó, Universitat de Barcelona

Flue dusts from a copper smelting furnace (continuous furnace), have been extensively characterized. The main phases detected have been cuprospinel, anhydrous copper sulfate (chalcocyanite), lead sulfate (anglesite) and arsenic oxides (claudetite and arsenolite). As minor phases, zinc sulfate (zincosite) and several copper or copper/iron sulfides were detected (digenite, anilite, bornite, cubanite), and also a copper oxide (tenorite). The suspension of this material in water leads to the partial dissolution of copper and zinc (chalcocyanite and zincosite) and arsenic oxides. The hydrocyclone classification of the residue makes it possible to obtain two fractions: a copper-rich coarse fraction and an arsenic-rich fine fraction. The coarse fraction can be recycled to the smelting furnace and the fine fraction can be mixed with wastewater sludge from a paper factory, to make both residues inert before disposing them to landfill.

Paper #0945—16:30

Arsenic immobilization and metal recovery from El Teniente smelter dust

R. Ichimura, Japan Oil, Gas and Metals National Corporation,
H. Tateiwa, Mitsui Mining and Smelting Co. Ltd.,
C. Almendares, Centro de Investigación Minera y Metalurgica,
G. Sanchez, CODELCO Las Ventanas Division

This paper summarizes the results of a five-year project, which aimed at improving the current method to process the arsenic-bearing smelter dust of El Teniente. This project, which was started in 2001, was carried out jointly by JOGMEC (Japan Oil, Gas and Metals National Corporation) and CIMM (Centro de Investigación Minera y Metalurgica, Chile), and was financially supported by the Japanese and the Chilean governments. In the new process, the smelter dust is leached with sulfuric acid to dissolve arsenic, which is subsequently precipitated as crystalline ferric arsenate (scorodite) at ambient pressure by controlling the crystallization and crystal growing stage. As a result, a stable form of ferric arsenate is obtained, which passes the U.S. E.P.A. TCLP limit of 5 mg/L As. Copper and zinc are subsequently recovered from the arsenic-free solution. The copper product can be fed into the main copper production circuit

at the Las Ventanas Smelter and Refinery, whereas zinc is recovered as a marketable product. A demonstration plant was installed and operated at CODELCO's Las Ventanas Smelter and Refinery. The basic and detailed engineering design was prepared by Mitsui Mining and Smelting Co. Ltd (MMS) on the basis of a joint study done by JOGMEC, CIMM and CODELCO's Las Ventanas Division.

Paper #1003—16:55

Osmium and rhenium in copper ores of Kazakhstan

Z.S. Abisheva, A.N. Zagorodnyaya, N.S. Bekturganov, Centre of Earth Sciences, Metallurgy and Ore Beneficiation

The Zhezkazgan copper sulfide ore deposit in Kazakhstan contains both rhenium and the rare osmium isotope "osmium-187" (^{187}Os) in the high isotopic purity of 99.4 ± 0.2%. This isotope is believed to have originated as a result of the disintegration of one of the rhenium isotopes, according to the reaction: $^{187}Re_{75} \rightarrow {}^{187}Os_{76} + \beta^- + \nu\sim$ (where β^- is a β-particle, ν~ is a β-disintegration antineutrino). The distribution of osmium and rhenium in metallurgical byproducts produced during the recovery of copper from these ores has been studied and process flowsheets for the processing of rhenium and osmium-containing byproducts have been developed.

Cu2007: The John Dutrizac International Symposium on Copper
Hydrometallurgy, Incorporating the 37th Annual Hydrometallurgy Meeting
Session 40: Leaching III
Sponsors: Hydrometallurgy Section of MetSoc, IIMCh, MMIJ, GDMB, EPD of TMS
Chair(s): P. Schwartz, CSIRO Minerals;
M. Dry, Consultant
Room Manitoba—13:40

Paper #0940—13:40

Acid generation by in-situ sulfur biooxidation for copper heap leaching

P.G. West-Sells, Western Copper Corporation,
S.C. Bouffard, Barrick Technology Centre,
A.F. Tshilombo, Dynatec Corporation,
A. Bruynesteyn, Westcoast Biotech Ltd.

At Barrick's Zaldívar Copper Mine in Chile, the addition of sulfuric acid to the ore going to heap leaching is a major expense. A process in which a portion of this acid is replaced by elemental sulfur added to the heap has been developed by Barrick and Westcoast Biotech that has the potential for significant cost savings. Initial shake flask tests with plant raffinate solution indicated that oxidation of elemental sulfur by a culture of sulfur-oxidizing bacteria, some indigenous to the Zaldívar heap, showed a significant lag period. This lag period could be reduced by dilution of the raffinate, but dilution would not be economical to implement at

Zaldívar. Short (0.75 m) column tests indicated that after the initial lag period, sulfur biooxidation occurred steadily and the acid requirement for obtaining the same copper recovery as the control without sulfur was reduced by as much as 13 kg/t. These tests were followed by taller (5.1 m) column tests that confirmed the reduction in acid consumption, with no negative effect on copper extraction.

Paper #0947—14:05

Bioleaching of chalcopyrite by the thermophilic archaean acidianus brierleyi in batch and continuous-flow stirred tank reactors

Y. Konishi, N. Saitoh, T. Nomura, Osaka Prefecture University

This paper reviews the mechanism and kinetics of bioleaching of chalcopyrite by the thermophilic archae Acidianus brierleyi in batch and continuous-flow reactors. Rate data for the batch bioleaching of chalcopyrite concentrate were collected to clarify mechanism of the chalcopyrite bioleaching with A. brierleyi. The chalcopyrite leaching was markedly accelerated in the presence of A. brierleyi, and greater than 90% copper leaching was achieved within 10 days. Chalcopyrite leaching took place predominantly as a result of direct attack by adsorbed bacteria on the sulfide surface, the chemical leaching with ferric iron being insignificant. Batch rate data collected under a variety of operating variables were analyzed with our batch bioleaching model, in order to estimate microbial kinetic and stoichiometric parameters for the microbial growth on chalcopyrite. The batch model and the estimated parameter values were used to find optimum operating conditions. Moreover, the batch model was extended to describe the bioleaching in continuous-flow stirred tank reactors. Simulations based on the continuous reactor model and the estimated parameter values were used to predict the leaching fraction as a function of the number of reactors connected in series.

Paper #1181—14:30

Applications for biogenic sulphide reagent for copper recovery in copper and gold hydrometallurgical operations

R.W. Lawrence, P.B. Marchant, M. Bratty, D. Kratochvil, BioteQ Environmental Technologies Inc.

Sulphide is an effective reagent in the precipitation of base metals for both metal winning and environmental control. BioteQ Environmental Technologies Inc. has successfully demonstrated in industrial plants that biogenic sulphide reagent can be generated cost effectively and used to win metals such as copper, zinc and nickel from low-grade leach solutions and wastewater. Commercial plants in which sulphide reagent is used to produce high quality treated effluents for discharge directly to the environment are also in operation. Operations utilizing biogenic sulphide reagent for copper recovery from acid drainage and low grade leach solutions are discussed, including those at Bisbee, Arizona, commissioned in 2004 and at the Dexing mine in China, scheduled for commissioning in 2007. In addition, a new application of BioteQ's technology for the recovery of copper from gold-cyanide solutions, and the regeneration of cyanide, utilizing biogenic

sulphide in place of chemical sulphide reagents in the SART process is described.

Paper #0949—14:55

Bioleaching of fine low grade copper ores

M. Oliazadeh, G. Jozani, University of Tehran,
Z. Manafi, S.A. Seyed Bagheri, National Iranian Copper Industries Company,
A.R. Shahverdi, University of Medical Sciences,
A. Oliazadeh, University of Toronto

The bioleaching of fine low grade copper sulfide ore is described. A sample of ground (>1 mm) copper ore from Sarcheshmeh, Iran, was subjected to a series of agglomeration procedures and subsequently leached. The best agglomerate was obtained by using lime and sulfuric acid as binders. A column bioleaching test of agglomerated ore was then run for 105 days along with a non-inoculated control column having thymol as bactericide. The results show that about 77.5% of copper was extracted in the bioleaching, whereas the control column achieved only 57% copper leaching.

Coffee Break—15:20 – 15:40

Paper #0973—15:40

Hydrocopper for treating variable copper concentrates

K. Hietala, L. Haavanlammi, Outokumpu Technology Oy,
J. Karonen, Outokumpu Research Oy

The Outokumpu HydroCopper® process is a chloride based atmospheric leaching process alternative that can treat a variety of different concentrates. Chalcopyrite and other copper sulfides can effectively be leached under atmospheric pressure in strong, aggressive chloride solution using copper (II) ions as oxidant. Impurities are removed from the solution as carbonates and ion exchange. Copper is precipitated from the purified pregnant leach solution as copper (I) oxide, which is filtered and reduced by hydrogen gas to metallic copper powder, which is melted and cast into copper product. Sodium chloride solution from copper (I) oxide precipitation is decomposed in a chlor-alkali electrolyser, to products of which are circulated back to the process. The process has been designed for copper concentrates and is a fast and economical way to produce copper wire rod directly from concentrate. The process can efficiently handle impurities like arsenic and mercury, which can be harmful in the pyrometallurgical processes. The process has been tested in the laboratory and 1 ton/day demonstration plant scale and it has been proven to be commercially viable. The process has been designed to meet the strictest directives for emissions. Other environmental factors are carefully considered to obtain the highest possible eco-efficiency.

Paper #0956—16:05

Copper leaching from IOCG ore and concentrates

M. Xioa Bo, H. Wantanabe, Y. Takasaki, T. Okura, Akita University,
M. Tamura, J. Seong-Jin, H. Nakamura, Y. Kida, Japan Oil, Gas and Metals National Corporation

In recent years, there has been a heightened interest in the hydrometallurgical processing of sulfide ores and concentrates (especially copper sulfide ores and concentrates) mostly in the USA and Chile. Currently, hydrometallurgical operations account for about 30% of the primary copper production. In the present research, the leaching phenomena of IOCG (iron-oxide hosted copper-gold) ores and concentrates were studied. The IOCG ore, which is characterized as having a predominant amount of magnetite with fine chalcopyrite, is currently the center of attention for new copper resources. Heap leaching of IOCG ore is desirable because of its low cost. However, the leaching characteristics of the ores and concentrates and the mechanisms of copper leaching require investigation. This study defines the factors, which affect the leaching operation, such as the ORP, pH and oxidizing agents. Based on these results, the optimal leaching conditions are provided for pilot column leaching test and ultimately, commercial operations.

Paper #0984—16:30

The oxidative leaching of a copper sulphide intermediate product

Y.M. Shneerson, A.Y, Lapin, T.Y. Kositskaya, Gipronickel Institute

The copper concentrate was extracted from copper and nickel matte after its hydrometallurgical treatment and nickel removal. The concentrate containing 60-74% of copper was represented by two principal copper minerals, digenite and covellite. The oxidising leaching of this kind of concentrate was studied at the Gipronickel Institute. The effect of key parameters, such as temperature, oxygen partial pressure and initial solution compound, on the rate of copper dissolution and transfer of sulphur from sulphide to elemental form was investigated. It was shown that at temperatures about 90°C, the sulphur content of covellite converts to elemental form. Under autoclave conditions at 110°C, the elemental sulphur dissolves as a sulphate-ion. At the temperature range from 50 to 90°C, the copper dissolution rate is in direct relation with temperature. By increasing the temperature to 130°C, this effect is reversed. Based on the research work, a technological flowsheet for the leaching of the copper concentrate was developed.

Paper #1182—16:55

Modern stainless steel for leaching plants

S. Ekman, J. Olsson, A. Bergquist, Outokumpu Stainless, Avesta Research Centre

The paper describes and discusses the use of stainless steels for leaching plants emphasising the duplex family, i.e., austenitic-ferritic stainless steels. This group has generally twice the proof strength of the more common 300-series austenitic

grades, which implies possibilities to reduce the gauge at construction of pressure vessels and atmospheric tanks and vessels and thereby possibilities to reduce the weight. The duplex grades have also higher surface hardness resulting in better resistance to mechanical wear, i.e., abrasion and erosion corrosion. The lower contents of nickel and molybdenum imply lower cost and a more stable price considering the present market situation for these alloying elements. Corrosion data from laboratory and pilot plant tests, as well as examples of applications of duplex and highly alloyed austenitic grades, are presented.

Cu2007: International Symposium on **Electrowinning and Electrorefining**, Incorporating the 37th Annual Hydrometallurgy Meeting
Session 41: Electrorefining Plant Practices and Design II
Sponsors: Hydrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
D.J. Robinson, Dremco Inc.;
G.E. Houlachi, LTE- Hydro-Québec
Room British Columbia—13:40

Paper #0773—13:40
Expansion projects at Tamano refinery
T. Maruyama, M. Furuta, M. Oida, K. Shimokawa, M. Narita, Hibi Kyodo Smelting Co. Ltd.

Tamano Refinery started its operation in 1972 with the cathode production capacity of 84,000 tons per year. After several expansions, the production capacity increased to 228,000 tons per year in 2001. In this paper, we are introducing our next expansion projects starting October 2006. The project expands the production capacity of cathode from 228,000 tons to 260,000 tons per year. The main modification of this project is the conversion to the ISA process and the installation of additional seventy-two cells in the No.2 Tankhouse. The No.1 Tankhouse remains the same, using the conventional process. Half of our starting sheet cells are converted to commercial cells. The other expansions are to enlarge our purification plant. And the incidental facilities are enlarged, for example, circulation tanks, heat exchangers, filtration system, etc. Finally, this paper describes those improvements to our refinery performance and preparing for future expansions.

Paper #0777—14:05
Modernization of tankhouse technology in Boliden Harjavalta Oy Copper refinery in Pori
K. Pienimäki, Boliden,
H. Virtanen, Outokumpu Research

Boliden Harjavalta Oy has produced copper since 1945. The essential idea has always been continuous development of process efficiency and environmental

friendliness by using the Best Available Techniques (BAT). The ongoing development step is to increase the production capacity up to 210 000 tpy of anode copper and 155 000 tpy of copper cathode. One of the focal issues in this action is modernization of the copper refinery to utilize permanent cathode technology. This paper describes the refinery project and the technology used in it.

Paper #0779—14:30

Ventanas refinery: continuous improvement using conventional technology

R. Abel, N. Cornejo, CODELCO-Chile

During the last eight years, the Ventanas electrolytic refinery has been improving its results by applying a series of new operational practices, such as the reduction of electrode spacing from 115 mm to 105 mm., raising the current density to 305 A/m^2, modification in the operators shifts to about 70% of the workers, reducing the pulling cycles by two hours, and the erection of a new anode preparation machine. These improvements allowed an increase in the refinery capacity from 323,000 to 382,000 metric tons of electrolytic copper per year. In the same period it has obtained certification under the ISO 9001:2000 and ISO 14001:2004 standards. All of these developments have been achieved using conventional technology with copper starting sheets.

Paper #0745—14:55

Copper refining electrolysis at high current densities with conventional technology

A. Castillo Atenas, P.A. Muñoz, CODELCO-Chile

The majority of refineries that operate with traditional starting sheet technology use a relatively low current density of 250 A/m^2. Industrial tests at high current density with conventional technology were carried out in Refinery of Potrerillos, getting satisfactory results that are similar the results obtained with permanent cathode technology. The series of copper refining electrolysis trials were carried out between 300 to 325 A/m^2. Electrolysis conditions, in accordance with industrial practice, were kept constant in all sets of experiments as follows; 45 g/L Cu^{2+}, 210 g/L H_2SO_4, 62 ºC, electrolyte circulation of 14-18 L/min. The same dosing of additives used in permanent cathode technology was required in these tests. In general, only minor operational modifications were necessary in comparison to normal practice in the Refinery to assure the good results. Different quality of starting sheet and anodes were examined. The test included starting sheets from smelter and laminated process. Results indicate that the physical quality of the electrodes and the control of the process during the two first days of operation are the keys to get the best results.

Coffee Break—15:20 – 15:40

Paper #1171—15:40

Development of electrorefining processes in the polish copper smelters

W. Baranek, A. Chimielarz, Z. Smieszek, Instytut Metali Nieżelaznych

The paper describes activities undertaken for intensification of copper cathodes production in electro-refining plants of the Polish copper smelters: 'Legnica', 'Głogów I' and 'Głogów II'. In the 'Legnica' smelter, Outokumpu–Wenmec machine was used for preparation of copper anodes. Intensive studies were conducted in order to optimise copper electro-refining conditions. As the result of them, spacing between the electrodes was reduced to 99 mm, which enabled placing forty-one cathodes in each tank and increasing amperage from 10.8 to 13.0 kA. This modification resulted in the increase of electro-refining capacity to 103,000 tons/y. Intensification of the copper production at 'Głogów II' by 18,000 tons/y became possible after development of new electro-refining procedures, including application of a regime of changes in electrolyte level during the cathode cycle, implementation of the changes in location of starting sheets relative to anodes, and in dimensions of the sheets, and modification in the shape of the anodes. Similar works have been performed at 'Głogów I', which were concentrated mainly on defining of a new method of anodes preparation, modification of their geometry, determination of optimum current density, composition of a set of inhibitors and of a method of their introducing. The implemented solutions resulted in the increase in electro-refining capacity at 'Głogów I' from 207,000 to 240,000 tons/y.

Paper #1177—16:05

Control of copper electrolyte impurities – overview of the short bed ion exchange technique and Phelps Dodge El Paso case study

M. Sheedy, P. Pajunen, Eco-Tec,
B. Wesstrom, Freeport-McMoRan Copper & Gold

This paper discusses the short bed ion exchange technique for the removal of metal contaminants from copper electrolyte bleed streams. Processes for the selective removal of sulfuric acid, arsenic, antimony, bismuth, and iron will be discussed. A case study outlining the performance history of a short bed system for sulfuric acid removal followed by a two stage selective precipitation system producing a nickel carbonate by-product at the Phelps Dodge Mining Company El Paso operation will be presented.

Paper #1185—16:30

Process improvements at Kennecott Utah Copper refinery

T. Maio, S. Bird, D. Kim, F. Rundloff, P. Penunuri, S. Wang, Kennecott Utah Copper Corporation

Twelve years ago, Kennecott Utah Copper modernized its Refinery in conjunction with the modernization of the Kennecott Smelter with the latest flash smelting and flash converting technologies. The Refinery modernization

consisted of installation of new polymer concrete cells, installation of KIDD TPS (total production stripping) system, installation of automated materials handling system, and the construction of a new hydrometallurgical slimes treatment process and precious metals plant. This paper outlines the Refinery operations and process improvements. Also presented are the newly implemented technologies and operating results of one of the world's largest and most modern electrolytic copper refineries.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 42: PS Converting II
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): T. Warner, WorleyParsons HGE;
I. Kojo, Outokumpu Technology
Room Territories—13:40

Paper #0875—13:40
Review of high pressure tuyere injection
I.E. Hills, C. Harris, A.E.M Warner, WorleyParsons HGE

Since the late Dr. Keith Brimacombe, et al, performed tests at the now-closed Asarco Tacoma smelter and the Inco Copper Cliff Smelter on Peirce-Smith copper converters almost thirty years ago, many Pyro-metallurgists have investigated using the technology. To the best of the authors knowledge, except for shrouded tuyere technologies using substantial oxygen enrichments, the core idea of using high pressure air injection has not been implemented anywhere in the world. This paper reviews the fundamentals of this technology and summarizes the basic economic considerations. It also presents the circumstances of where and when high-pressure injection might be justified.

Paper #0842—14:05
Implementation of Air Liquide Shrouded Injector (ALSI) Technology at the Thai copper industries smelter
J. Kapusta, Air Liquide Canada Inc.,
N. Wachgama, R. Pagador, Thai Copper Industries Public Co. Ltd.

The Thai Copper Industries smelter (Thai Copper) is located some 200 km southeast of Bangkok near the MapTaPhut deep sea port in one of the industrial centres of Thailand. Although construction of the complex started in the mid 1990s, the smelter, acid plant and refinery were completed in 2004. Thai Copper is a state-of-the-art copper smelter processing imported concentrates with a total yearly capacity of 165,000 tonnes of cathodes. It employs the El Teniente Technology where concentrates are blended and smelted continuously in a primary smelting reactor to produce high grade matte or white metal. The white metal is converted in batches to blister copper in Hoboken siphon converters equipped with Air Liquide Shrouded Injector (ALSI) Technology for sonic injection

of oxygen enriched air. Final refining is carried out in two anode furnaces prior to anode casting and electrorefining. Thai Copper and Air Liquide Canada executed a technical assistance agreement in late 2005. Pre-commissioning of the shrouded injectors took place in July and November 2006 while hot commissioning occurred in December 2006. This paper presents the major technical aspects of the joint commissioning, including the establishment of operating practices specific to shrouded injection converting. Preliminary results of this first commercial implementation of ALSI Technology in copper converting are also provided.

Paper #0857—14:30

Technology and operational improvements in tuyere punching, silencing, pyrometry and refractory drilling equipment

M.J. Marinigh, Heath & Sherwood (1964) Limited

Increased safety requirements, higher operational costs, greater environmental restrictions, and new competitive processing techniques are the challenges smelter operators must confront in order to remain economically viable. In converting furnaces which have tuyères such as the Noranda Reactor and the Teniente, Peirce Smith and Hoboken converters, efficient tuyère line management is critical to optimizing blowing rates, increasing refractory life, and improving safety. This paper will describe recent improvements made to equipment used for tuyère punching, tuyère silencing, tuyère pyrometry and refractory drilling of tuyères and how the proper application of the equipment can lead to operational and safety improvements.

Paper #0853—14:55

Melting behavior of solid feed charged onto bottom stirred matte bath

M. Barati, University of Toronto,
C. Harris, WorleyParsons HGE,
S. Clarke, Xstrata Nickel

Different gas purging methods to metallurgical baths have been applied to date, among which are top lancing and bottom blowing through tuyeres or porous plugs. Among these, the porous plug bottom blowing technique has shown higher efficiency in gas utilization than tuyeres and top blowing, due to smaller bubble size and lower liquid velocity. However, the studies related to bottom stirring of metallurgical baths are limited to slag-less or thin slag-covered melts. In particular, there is no examination of stirring ability in conditions similar to Falconbridge's Slag Make Converter, where the bath is covered with a thick slag layer and a stream of solids is charged on the bath from top. This study was undertaken to investigate the application of gas purging through a porous plug in stirring in and melting of the solid feeds. The spreading behaviour and melting time of a solid layer forming on a plume created by stirring were calculated using the existing models. The results show that formation of a thick solid layer, specifically in areas beyond the plume region is very likely. Nevertheless, the

thickness of the layer and melting time do not appear unreasonably high. It is predicted that by proper controlling of gas flowrate and plug configurations, successful solid charging through the mouth can be practiced.

Coffee Break—15:20 – 15:40

Paper #0884—15:40

Changes in the slag converters chemistry due to the Southern Peru Ilo smelter modernization

J. Suárez Condezo, E. Herrera Alarcón, Southern Peru Ilo Smelter

The Ilo Smelter Modernization Project will require treating the slag from the Peirce Smith converters in Slag Cleaning Furnaces using pig iron technology. Currently the slags from the converters show variable magnetite contents. The copper contained in this slag is recovered in Reverberatory Furnaces, where the smelting rate was improved due to the high silica content of the converter slag. Preliminary industrial tests where developed to clean the slag from converters using pig iron. The results showed that the magnetite content has a significant influence in this process. This work describes the actions that are being implemented in the converter operation to control the magnetite content in the slag in order to maintain the high copper recovery of the smelter when the new facilities are commissioned. This task will demand a strong control of both the slag chemistry and converter practices in order to get the copper recovery considered as the design criteria (~97.4%).

Paper #0823—16:05

METTOP process control and regulation system

I. Filzwieser, METTOP - Metallurgische Optimierungs GmbH

The Peirce Smith converter is the key metallurgical vessel in the majority of copper smelters. During the two step process, oxygen enriched air is injected through a row of tuyeres into the matte received from a primary smelting unit. Additionally, in the first step the iron content is oxidized into a fayalite slag by the addition of silica. During the second step, the remaining copper sulphide is converted into blister copper with a final sulphur content of approximately 200 ppm. The overall efficiency of this process is determined by the total reaction time, the slag quality and quantity, and the chemistry of the final blister copper. To increase the reaction kinetics during both stages, the METTOP Process Control and Regulation (MPCR) system was developed, which consists of four elements:

1. OPC – Optical product control
2. ACR – Automatic computer regulation
3. GCU – Gas control unit
4. GIS – Gas injection system

The OPC system from SEMTECH records the optical spectrum emitted by the off gas flame providing immediate, detailed process information. Using this online

data, additional gas can be automatically injected into the converter through a gas injection system opposite the tuyere zone. An improved oxygen distribution in the melt and the accurate determination of the process end point results in a significant reduction in the process cycle time. Furthermore, by maintaining the reaction closer to the equilibrium the final sulphur and oxygen content can be reduced compared to the conventional process. In particular, the final sulphur content can be lower than 70 ppm, eliminating the need for an oxidation step in the anode furnace.

Paper #0797—16:30

A thermochemical model of the Pierce – Smith copper converter: part I. slag making stage

N. Aminizadeh, S.H. Mansouri, Shahid Bahonar University of Kerman

A thermo-chemical model of the Peirce-Smith copper converter has been developed to predict the molten temperature. The primary assumption of the model was that all matte, slag and gaseous phases in the converter were in thermal and chemical equilibrium. In this model, the matte components were considered only as copper, iron and sulfur elements. In the slag making stage, all the reacted iron was converted to fayalite. The reaction rate of iron and oxygen in this stage was considered to be constant. The converter temperature was calculated by heat balance over time. The model was validated by a detailed comparison with measured industrial data. A good agreement was obtained. The converter temperature depends on process parameters such as oxygen efficiency and molten emissivity.

Paper #0798—16:55

A thermochemical model of the Pierce – Smith copper converter: part II. blowing copper stage

N. Aminizadeh, S.H. Mansouri, Shahid Bahonar University of Kerman

A thermo-chemical model of the Peirce-Smith copper converter in blowing the copper stage has been developed to predict the molten temperature. The key assumption of the model was that white metal and gas phases in the converter were in thermal and chemical equilibrium. In this model, the chemical reaction of white metal and oxygen was accomplished completely. So long as sulfur existed in the bath, the generation of Cu_2O was frozen. The reaction rate was considered to be constant and controlled by the reacted sulfur. The converter temperature was calculated by heat balances over time. The model was validated by a detailed comparison with measured industrial data. A good agreement was obtained. The converter temperature depended on process parameters such as oxygen efficiency, molten emissivity and oxygen enrichment.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 43: Alternative / Other Technologies II
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): C. Newman, Hatch;
M. Syamujulu, KCM
Room Algonquin—13:40

Paper #0822—13:40
Outokumpu blister smelting processes – clean technology standards
I.V. Kojo, M. Lahtinen, Outokumpu Technology Oyj

Continuous development of technologies has been self-explanatory for Outokumpu Technology's engineers for decades. The aim in the development has always been the improvement of profitability of the copper production but also the sustainability of the processing i.e. high copper recovery, low external fossil based energy utilization, high emission captures and of course low operation and investment costs. Outokumpu Technology's long-term view of the development is a change towards continuous processes and elimination of number of unit operations in smelting i.e. elimination of possible sources of emissions. Outokumpu blister smelting processes i.e. Outokumpu Direct-to-Blister Flash Smelting and Kennecott-Outokumpu Flash Converting have shown excellent operational results during the years of operation and it is expected that soon more than 10 % of the world primary copper is produced by these technologies. The paper will give some background of this development trend.

Paper #0817—14:05
Study into feasibility of basic modernization of a copper smelter using the roasting-smelting flow diagram for treatment of sulphide feed materials
A.V. Tarasov, V.M. Paretsky, Federal State Unitary Enterprise

There are still a number of copper smelters in the world using the roasting and smelting process flow diagram for treating sulphide raw materials. The technical, economic and environmental performance indicators of such operations are inferior to the respective indicators of advanced processes. First of all with respect to copper and sulphur recovery: 95% and 75% as compared with 98% and over 90%, respectively. Based on the studies of the single-stage smelting process to produce white metal and blister copper conducted during recent years an analysis of the feasibility of roasting-smelting technology improvement was carried out in the Gintsvetmet Institute to substantially increase the copper and sulphur recoveries. On the basis of this analysis, it was proposed to modernize the technology and equipment within the framework of the existing process flow-sheet. The proposed modernization implies an increase in the roasting temperature; higher desulphurization degree in the process of roasting; a number of modifications in the roaster design depending on the particular conditions of a given operation; addition of lime flux to the feed charge to roasting; and transition

to combined calcium-silicate smelting slags. The metallurgical and energy computations made have indicated that the proposed modifications of the technology will improve the copper and sulphur recovery up to 98% and 90%, respectively. The required capital investments have been estimated using as an example a particular copper smelter, the payback period determined taking into consideration additional output, fuel saving and a reduction in fines for sulphur emissions. For comparison, the capital cost of a smelter modernization is given for change-over to basically new autogenous Ausmelt, Outokumpu and Vanyukov smelting technologies.

Paper #0803—14:30

Roasting kinetics of industrial molybdenite concentrates

T. Marin, G. Riveros, A. Warczok, Universidad de Chile,
T. Utigard, University of Toronto,
S. Jara, Xstrata Copper

Roasting of molybdenite concentrate is an important stage in the production of commercial molybdenum trioxide. The oxidation kinetic and mechanism of molybdenum sulfide concentrates from two plants were investigated at temperatures from 444 ºC to 640ºC. The rate of reaction was determined for thin layer samples in a muffle furnace at controlled temperatures, oxygen excess and removal of sulfur dioxide. For both concentrates the rate of reaction is fairly slow at temperatures below 500ºC and remains fairly constant from 540 to 600 ºC. It was observed that the concentrate from the first plant presents a tendency for sintering or glazing at temperatures above 620ºC, whereas the same phenomena was observed at 20 or 30 ºC higher temperature for the second concentrate. A kinetic model of two reactions, involving the formation of MoO_2 as intermediate oxide for the production of MoO_3 is proposed and activation energies of 23.0 and 20.8 kJ/mol for the first and second reaction were calculated for temperatures between 520 ºC to 600 ºC. These low values of activation energies indicate that the overall rate of oxidation is controlled by mass transfer, particularly in a porous layer of oxides. Therefore, the renewal of the surface by mixing and motion of the concentrate layer is of great importance. Sublimation of MoO_3 becomes significant for temperatures above 650 ºC.

Paper #0794—14:55

Copper roast segregation process: a promise to be fulfilled and a challenge for material handling technology

A. del Campo A., F. Cabrejos M., Jenike and Johanson Chile S.A.

The roast segregation process, which was patented in 1974, makes use of a set of chemical reactions that are different from the traditional sequential oxidation of iron and copper sulfides used by all modern pyrometallurgical processes to treat copper concentrates. It allows metallic copper to be obtained via sublimation of copper chloride at temperatures in the range of 700-800 ^{0}C. In addition it avoids melting the concentrate, doesn't require transferring molten materials, doesn't

need flux addition and allows nearly all of the sulphur to be removed in one stage as a high-SO_2 gas stream. Most importantly, it allows a decrease in the use of energy to approximately 6 million BTU/ton of anodes. This represents a saving of approximately 40%, compared to the potential of the most advanced processes presently used. Such a promising process has been waiting for its first industrial application for more than 30 years. This article examines the technical difficulties that have delayed application of the roast segregation process to beneficiate copper concentrates. Special emphasis is made on material handling aspects, discussing the possibility of using a well designed mass flow silo as the main processing vessel to carry out the segregation stage.

Coffee Break—15:20 – 15:40

Paper #0888—15:40

Flash smelting furnace of the KGHM Głogów copper plant - technological and process challenges as a driving force of its continuous modernization

Z. Gostyński, D. Haze, KGHM Polska Miedź S.A.

The paper is a historical cross-section through a 28-year period of operation of the direct-to-blister Flash Smelting Furnace in the KGHM Głogów Copper Plant. It presents the origin of the furnace as well as the path of numerous changes and modifications both in technology and process introduced in the furnace in response to the production and cost-reduction challenges. The authors provide justification of the statement that continuous improvement of the “Polish” Flash Smelting Furnace has ranked it among the most modern smelting units in the world.

Paper #0872—16:05

Alternative to improve the traditional chinese copper smelter

S. Demetrio, Smeltec S.A.,
J. He, NorthEastern University-Shenyang

China has a traditional segment of Copper Smelters with its own Chinese technology, typically small in size from 20.000 to 50.000 tCu/a, and they are responsible for the processing and production of more than 600,000 tonnes of blister copper per year. For occidental experts, like one of the authors, it is not so easy to believe that they are profitable, because the size and the use of old Blast Furnaces, but they are with simple and effective production lines. The authors are convinced that China has a good alternative to improve theses old copper production lines with small innovative changes in its process arrangement, jumping to higher level technology, more efficient in production, productivity and cost, assuring copper as a raw material for the country and its high speed development. The key to improve that the traditional Chinese Copper Smelter is white metal as an extra raw material as a first step doubling the copper production from raw materials and the complete replacement of concentrates by white metal (WM) in a second step increasing it four times or more as the final

goal. It is not so difficult nor expensive to make it happen, but there are a couple of questions for implementing this innovation in the copper smelter industry: 1 - Will the old fashioned mentality be open to this new direction for China being the biggest copper consumer on one side, and the biggest copper Primary Producers on the other hand? and 2 - Will they be open to follow this "win-win" strategic way for both ends of the copper market? We don't know if anybody will take up the challenge to improve it but our responsibility as a consulting expert and a university professor is to put the alternative on table for others to decide whether to implement it.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 44: Slag Cleaning
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): C. Nexhip, Rio Tinto;
A. Vahed, CVRD Inco
Room Quebec—13:40

Paper #0808—13:40
Evolution furnace rotatory slag cleaning. Caletones smelter - El Teniente division – CODELCO Chile
C. Carrasco, G. Duarte, J. Araneda, CODELCO-CHILE

Since November 2000, Caletones Smelter, Division El Teniente of CODELCO Chile, has been using only Teniente Converter (TC) as smelting units. The project to shutdown the last Reverberatory Furnace considered the installation of a fourth Slag Cleaning Furnace, modifications to the systems of concentrate injection into TC and a new Fluid Bed Dryer. These investments persecuted to maintain the base annual smelting capacity, about 1 million 250 thousand tonnes of concentrate.In 2004, Caletones incorporated several new equipment with the object to increase its smelting capacity to 1 million 440 thousand tonnes of concentrate. The principal units were:-New Oxygen Plant, with a capacity of 800 tpd of oxygen.- New Fluid Bed Plant, with a capacity of 120 tph.-New bins storage of concentrate, with a capacity of 500 tonnes.-New injection systems for Teniente Converters, with a capacity of 150 tph each. The present smelting capacity is about 1 million 350 thousand tonnes of concentrate. This work describes the evolution of the Caletones Smelter between the years 2000 and 2006, with respect to -Evolution Capacity Smelting Teniente Converter-Evolution Productivity Teniente Converter-Campaign Teniente Converter-Metallurgical Recovery (Slag Cleaning Furnace)-Evolution of Reverts (Secondary Stock)-Advanced Control Model in Teniente Converter-Human development.

Paper #0845—14:05
Slag cleaning of Outokumpu direct-to-blister flash smelting slags
J. Tuominen, Y. Anjala, P. Björklund, Outokumpu Technology Oyj

Outokumpu Direct-to-Blister Flash Smelting is currently in operation in two smelters, a third one is under construction and a fourth one is in the design phase. The two smelters in operation are the Głogow 2 smelter of KGHM Polska Miedz S.A. in Poland and the Olympic Dam smelter of BHP Billiton in Australia. The Outokumpu Direct-to-Blister smelter of Konkola Copper Mines Plc. in Zambia is under construction and the new smelter of Głogow 1 is under design and waiting for final go-ahead decision. Additionally, the Garfield smelter of Kennecott Utah Copper Corp. makes blister copper out of matte in a Flash Converting furnace. A similar operation is under construction for Yanggu Xiangguang Copper Co. in China. The slag cleaning process, which is needed to clean the slag of the Direct-to-Blister Flash Smelting Furnace, has different requirements depending on the feed to the flash furnace. These differences are discussed in the paper. The differences between the processes and slag produced are discussed as well as the metallurgical requirements for slag cleaning. The Direct-to-Blister process, where the blister copper is produced directly from concentrate in one step, requires at least a partial treatment of the slag in an electric slag cleaning furnace. The existing impurities determine the specific requirements of the actual cleaning process. The different processes are discussed in the paper. The newest developments of Outokumpu Technology Oy for electric slag cleaning furnace design are presented as well as the characteristics which the furnace shape gives to the process.

Paper #0883—14:30

Intensive electrodynamic slag cleaning

A. Warczok, G. Riveros, T. Marin, Universidad de Chile,
R. Degel, J. Kunze, H. Oterdoom, SMS Demag AG

Metal losses in discard slag are the main factor determining overall recovery. The metals are present both in dissolved form and as matte or metallic inclusions, varying in size from 2 to 1000 μm. Pyrometallurgical slag cleaning usually consists of heating the slag, reduction of oxides and settling of matte/metal droplets. Heating the slag decreases viscosity and accelerates reactions. Reduction of magnetite liberates inclusions and facilitates co-reduction of dissolved metal oxides. A significant amount of the matte and metal is present as very fine metallic inclusions, too small for settling. The coalescence of these matte or metal inclusions is required to remove them from the slag. The developed new concept of slag cleaning combines DC furnace technology with an extra magnetic field for vigorous slag stirring, enhancing mass transfer to the reductant surface, accelerating the rate of reduction, and destabilizing the emulsion of matte or metal inclusions. Intensive slag stirring increases the probability of collision of inclusions, will accelerate their growth and will therefore improve settling. The process is carried out in a patented DC channel furnace, where the liquid metal or matte layer acts as a cathode and the floating coke bed on the slag surface is the anode. In the first part of the furnace, a superimposed magnetic field induces a Lorentz's force causing the slag to start an intensive circular motion. The next furnace zone does not experience any stirring and is

dedicated for quiet sedimentation of the inclusions. A mathematical model of gravitational coalescence combined with forced slag motion showed the possibilities of effective removal of copper matte inclusions. The results of laboratory pilot scale tests of continuous slag cleaning showed fast slag reduction and confirmed the improved matte removal from the slag. Conceptual analysis shows the potential use of the technology in various other non-ferrous industries, like for example nickel plants. It is also possible to use this technique batch wise.

Paper #0801—14:55

Computer simulator of slag cleaning in an electric furnace

A. Waczok, G. Riveros, Universidad de Chile,
R. Degel, J. Kunze, H. Oterdoom, SMS Demag AG

The computer simulator of slag cleaning in an electric furnace is based on a set of mathematical models describing heat liberation, the rate of slag reduction and gravitational coalescence of matte and metallic copper inclusions. The simulator consists of a mass and heat balances as a frame, in which the kinetic equations of the slag reduction and phase separation are incorporated. Friendly user-screen interface allows for dynamic control of process parameters in real time together with simulation of typical operations, such as furnace charging with liquid slag, solid reverts and coke, tapping out of the slag and matte, motion of electrodes and control of the transformer. The batch, semi-continuous or continuous process can be simulated. The process parameters are displayed and continuously recorded for further analysis. The computer simulator is a powerful tool for process optimization, training of furnace operators and the design of new slag cleaning installations.

Coffee Break—15:20 – 15:40

Paper #0804—15:40

Slag reduction and cleaning with calcium carbide

A. Warczok, G. Riveros, Universidad de Chile,
R. Parada, Anglo-American Chile

The cleaning of copper smelting slag requires magnetite and cuprous oxide reduction. The slag reduction with coke, injected coal powder or bunker oil is strongly endothermic and requires heat generation by fuel combustion or the use of electric energy. The reduction of fayalitic slag with calcium carbide is slightly exothermic and the formed calcium silicate modifies the slag. Thus, the additional energy is required only for covering furnace heat losses. Results of crucible scale tests showed the rate of slag reduction approximately five times higher in comparison of the slag reduction with coke under the same conditions. It seems that the effect of exothermic reaction and slag modification with CaO at the reaction interface results in very high rate of slag reduction. Industrial scale tests carried out in the Anglo-American Chagres Smelter demonstrated the

possibilities of effective reduction and cleaning of the slags from a flash smelter and Peirce-Smith converters in a Teniente Slag Cleaning Furnace. The slag reduction was carried out without any reductant or stirring gas injection, simply by calcium carbide charging through a furnace mouth, and was very fast.

Paper #0828—16:05

Estimating thermodynamic properties of slags by empirical methods

J.W. Matousek, Consultant

The heat content of the waste slag from a typical smelting operation makes up from 30 to 80 percent of the out-put energy. It is important, therefore, even with computer modeling of thermochemical process and energy balances that the occasional reality check on the results be performed using short-cut methods. It is even hoped that such empirical modeling will lead to new lines of research and the incorporation of more rigorous procedures into commercial software packages. This paper reviews some methods for estimating the thermodynamic properties of smelting slags, to include:

- Heats of formation
- Heat capacities (specific heats)
- Heat contents
- Melting temperatures
- Heats of fusion.

The techniques are illustrated with the analyses of a nickel reverberatory furnace slag from Copper Cliff, an iron-making blast furnace slag, and a "lateritic" slag from a ferronickel operation in Colombia.

Paper #0882—16:30

Slag cleaning in circular and rectangular electric furnaces

A. Warczok, G. Riveros, Universidad de Chile,
R. Degel, J .Kunze, H. Oterdoom, SMS Demag AG

Smelting slags contain payable metals in a dissolved form and as mechanically entrained matte or metallic inclusions in the size range from 2 to 1000 μm. Slag cleaning requires reduction of magnetite and metal oxides and sedimentation of inclusions. Slag cleaning in an electric furnace is carried out in batch or semi-continuous mode. The strong trend for continuous slag cleaning generates the basic question about the optimal geometry of the electric furnace. Results of combined CFD, potential distribution and heat transfer modeling allowed for the determination of the fluid flow pattern and the temperature distribution in a classical, circular electric furnace as well as in a rectangular furnace. For the rectangular furnace, various length/width ratios and position of electrodes have been simulated. Analysis of key phenomena pointed out the advantages of the rectangular electric furnace over the circular furnace, particularly for continuous slag cleaning. Phenomena that have been analyzed were mass transfer, the rate of slag reduction, coalescence and settling of inclusions, all on the basis of the calculated slag flow pattern and the temperature distribution.

Paper #0877—16:55
Investigation of the silica slag of Norddeutsche Affinerie´s flash furnace
T. Loos, Norddeutsche Affinerie AG

The Norddeutsche Affinerie operates an Outokumpu-Flash-Furnace as a smelting unit. The pyrometallurgical slag cleaning process is based on the slag reduction and settling in the electric furnace. Since 1972 when the slag cleaning furnace was built the throughput could be increased fourfold. However, an extensive optimisation effort is required in order to keep the copper loss low. A parameter study with a neuronal network model based on real process data was conducted to identify parameters impacting on the copper loss in the slag. It could be demonstrated that the main parameters responsible for copper loss in the final slag are fixed parameters of the flash furnace. For a better understanding of the copper loss in the electric furnace microscopic analyses of the slag structure and viscosity measurements were performed. Based on these results the reduction and settling of the copper containing droplets could be increased in both pilot plant studies and industrial scale.

Cu2007: International Symposium on **Mineral Processing**
Session 45: Flotation Optimization
Sponsors: Canadian Mineral Processing Society of CIM, Mineral Science and Engineering Section of Metsoc, MMIJ, GDMB, IIMCh
Chair(s): J. A. Finch, McGill University;
B. K. Gorain, Barrick Gold Corporation
Room Tudor 8—13:40

Paper #0719—13:40
Forcing air into self-aspirating flotation machines
C.O. Gomez, C. Acuña, J.A. Finch, McGill University,
F. Cortés-López, G. Berkowitz-Arendt, CODELCO Chile

A line of nine self-aspirating Wemco cells, part of the Rougher circuit at Division Salvador, CODELCO Chile, was retrofitted to allow operation with forced air. Each cell could be operated self-aspirated or with compressed air supplied through a 4-inch line equipped with a mass flow meter. Gas dispersion was characterized for the two modes of operation. Metallurgical performance was compared under self-aspirated conditions and with different gas profiles under forced air conditions. Cell characterization demonstrated that with forced-air the cells could not evenly distribute air across the cell volume. Bubble size increased with gas velocity, as expected, with no difference between self-aspirated and forced-air operation. A systematic increase in bubble size down the bank was found. Cumulative bubble surface area flux down the bank showed no major differences between surveys. However, grade-recovery curves revealed that the highest recoveries were invariably obtained with forced air operation. Plotting concentrate mass recovery vs. enrichment ratio showed that

the line performance could be controlled over a wider range when forced air was used.

Paper #0721—14:05

Using gas dispersion measurements to optimize the operation of tank cells in the Cu/Mo separation circuit at Highland Valley copper mine

J.R. Hernandez-Aguilar, S. Reddick, Highland Valley Copper

The effect of superficial gas rate distribution (J_g profile) on down-the-bank metallurgical response was tested in the rougher-scavenger bank (eight 10-m^3 tank cells, 4 roughers and 4 scavengers) at Highland Valley Copper Mine's Cu/Mo separation circuit. Three J_g profiles were tested: (a) as found (i.e., typical practice), (b) increasing-decreasing (i.e., increasing from cell 1 to 4 and decreasing from cell 5 to 8), and (c) decreasing-increasing (i.e., decreasing from cell 1 to 4 and increasing from cell 5 to 8). The J_g profile approach proved to be of considerable value. Profile (b) gave the best metallurgical results, i.e., the highest down-the-bank grade/recovery (increase in grade at constant recovery was approx. 3-4% compared to the as found case) and the most efficient Cu/Mo separation (cumulative Cu recovery was reduced by almost half – approx. from 20% to 12%, at 99% Mo recovery). The success of the evaluation prompted the implementation of profile (b). Detailed gas dispersion characterization tests (J_g and D_b (bubble size)) showed significant discrepancies between the J_g measured directly (using the McGill University sensor) and the J_g calculated from field instrument readings (volumetric gas flowmeter) and machine dimensions (cell cross-sectional area). Tests were designed to reveal the source of disagreement. It was observed that a significant number of bubbles were not able to float (i.e., they were entrained with the tailings), the evidence appearing to be a significant number of very small bubbles (approx. 200-300 μm) which did not have sufficient buoyancy to rise. Consequently, rather than relying on the field instrument, the evaluation depended on the McGill University J_g sensor, which collects bubbles in a tube near the pulp-froth interface, thus providing significance to the data as the measurements were obtained from bubbles that almost certainly floated.

Paper #0722—14:30

Characteristics of modern copper flotation circuits

S. Schwarz, D. Alexander, R. Coleman, University of Queensland

As part of the Australian Mineral Industries Research Association (AMIRA) P9 project, methods of characterising both the ore and the machines in flotation circuits have matured considerably over the past 15 years. Machine characteristics include gas dispersion measurements, such as bubble size, gas hold-up and superficial gas velocity. Ores can be characterised in terms of floatability parameters on a size and mineral basis. Measurements have been performed on various copper plants in many countries around the world over the last 5 years. This paper outlines the cell and ore floatability characteristics of each copper plant and provides a discussion on the differences between these

plants. In general, most porphyry copper ore bodies are processed at high tonnage through several parallel banks of cells at each stage of flotation. The floatability parameters of these copper ores are very similar in terms of rate of flotation and proportion of fast, slow and non-floating material. The cell characteristics are also similar, with superficial gas velocity, bubble sizes, and gas hold-up values being of similar magnitude. Investigation of the similarities and differences of the modern copper flotation circuits has allowed an increase in understanding of the particularities of copper flotation. Comparison against other copper circuits provides a benchmark and opportunities for future optimisation.

Paper #0723—14:55

Impact of frother on bubble production and behaviour in the pulp zone

C. Acuna, Universidad Católica del Norte,
J. Nesset, J.A. Finch, McGill University

The case is presented that the key role of frother is control of bubble size in the pulp zone. Compared to water alone, the addition of frother produces a narrower distribution and finer bubble size. An empirical model is presented for bubble size as a function of frother type using a normalized concentration. The model provides a benchmark for assessing operations. There is no agreed upon mechanism of how frothers act to reduce bubble size. Prevention of coalescence is a common explanation and this action is illustrated. The case against the 'coalescence' model alone is presented and a breakup mechanism is introduced based on pilot cell and single bubble studies. Phenomena associated with bubble shape, velocity and surface flows are used to illustrate the force associated with surface tension gradients. Breakup mechanisms resulting from this force are proposed. The concept can be extended to high salt concentrations which also promote small bubbles.

Coffee Break—15:20 – 15:40

Paper #0724—15:40

Measurement of wide bubble size distributions in flotation columns operated with jet-type spargers

W.A. Kracht, C.O. Gomez. J.A. Finch, McGill University

The McGill Bubble Size Analyzer, with the original image-capturing device (digital video camera), has a proven record for measuring bubble size distributions that are relatively narrow, such as in mechanical cells with frother. However, some problems arise when dealing with bubble size distributions characterized by a bi-modal shape and wide range of sizes such as found in some flotation columns. To measure wide bubble size distributions it is necessary to increase both the resolution to image the small bubbles and the viewing area to include the large bubbles. This can be done using a digital still camera: digital still cameras can have higher resolution than the digital video cameras currently used and with the proper lens the viewing area may be increased without resolution loss. The

digital still camera approach was used to measure bubble size distributions in flotation columns at different operations in Chile. A comparison with typical bubble size distributions generated with mechanical cells is presented.

Paper #0725—16:05

Relationships between process conditions and froth stability in a copper rougher-Scavenger bank

G. Bartolacci, M. Ourriban, A. Lockhart, F. Michaud, A. Faucher, COREM,
D. Knuutila, J. Finch, McGill University,
A. Fortin, G. Goyette, Inmet Troilus Division

In a COREM-McGill collaborative research and development project, gas dispersion parameters and froth properties were manipulated in a copper flotation plant to study interactions between the collection and the cleaning zones. In this paper, specific work on developing some relationships between operating conditions and froth stability in several different types of flotation cells is reported. Froth stability, measured by image analysis, was related to the following process conditions for specific flotation machines in an industrial case study: Gas flow rate, collector dosage, pH, frother type and dosage. Across the range examined, froth stability was improved through an increase in gas flow rate and/or frother dosage. Metallurgical results (grade and recovery) showed that both gold and copper were dependent on froth stability. Results indicated that flotation conditions could be optimized by monitoring froth stability.

Paper #0726—16:30

Optimization of froth washing system in columns in rougher flotation circuits

M. Massinaei, M. Oliazadeh, M. Kolahdoozan, M. Noaparast, A. Oliazadeh,
Tehran University

Recently constructed circuits have included multiple stages of columns in a variety of applications, from roughing to cleaning. The Miduk copper concentrator (in south-eastern Iran) is one of the unique mineral processing plants which use column flotation cells as rougher. As the bulk of final concentrate is produced by rougher columns, optimized metallurgical performance of these cells is crucial. This paper will present the study and optimization of, a froth washing system of columns. For this purpose, the cross-sectional area of orifices was increased and their orientation altered. Concentrate assay for copper and silica, in addition to bias rate were found to be the assessment criteria. Modification of the wash water system resulted in increasing the purity of rougher and final concentrate. Negative bias and short-circuiting of wash water into the concentrate launder were the main causes of improper froth zone washing in the former system.

Paper #0727—16:55

Decentralized control of a pilot flotation column: a 3x3 system

M. Maldonado, A. Desbiens, R. del Villar, Université Laval

This work details the application of a decentralized control strategy to a pilot flotation column working with a two-phase system (water-air). The process is represented by a multivariable system composed of three inputs and three outputs. The selected control variables are the froth depth, the air hold-up and the bias rate, whereas the corresponding manipulated variables are the set-points of the local flow controllers of tailings, air and wash water. All controlled variables are estimated using electrical-conductivity based techniques. In particular, the results of a new method for estimating the bias rate, based on the measurement of the volumetric fraction of wash water under the interface, is presented. This method reduces the coupling problem associated to the bias estimation as a difference between feed and tailing water rates. Moreover, the nominal system transfer matrix can be represented by an upper triangular matrix, in such a way that the closed-loop system stability reduces to the stability of the independent control loops. The experimental results show that the closed-loop system performance, particularly that of the bias rate loop, is strongly dependent on the air flow rate, reaching in some cases the saturation point of the controller.

Cu2007: International Symposium on **Process Control, Optimization and Six-Sigma**

Session 46: Six Sigma, Lean Manufacturing, and Improved Management

Sponsors: EDP of TMS, MetSoc, MMIJ, GDMB, IIMCh

Chair(s): R. Stephens, Teck Cominco Metals Ltd.;
E. Nurminen, Helsinki University of Technology

Room Confederation 6—13:40

Paper #0991—13:40

Morenci hydrometallurgical process improvement - application of six sigma in process improvement

R. Blosser, B. Sircy, Phelps Dodge Morenci Inc.

Phelps Dodge introduced a process improvement model known as Quest for Zero in 2001. In 2004, the focus of Quest for Zero shifted from corporate-led initiatives to projects led by site personnel. The Hydrometallurgical Division at Morenci focused on two (2) significant process improvements: reducing electrolyte bleed and organic losses. In September 2004, Morenci kicked off a bleed reduction project to reduce electrolyte bleed by 45%. By the end 2005, electrolyte bleed was reduced by 55% through understanding and reduction of variance. Significant process changes made during this time period include changes in acid-addition strategy, reduction of uncontrolled bleed, and optimization of bleed placement. In April 2005, the organic reduction project began with the goal of reducing losses by 15%. Operational improvements during this project included improved organic recovery systems, mixer speed

optimization, and picket fence installation. By the end 2005, this project reduced organic losses by 35% and current losses are 48% lower than at the start of the project. These projects and smaller Quest for Zero projects have resulted in sustainable annualized savings of $13 million in Morenci hydrometallurgical operations. Through the use of Six Sigma tools, process variances can be controlled and reduced.

Paper #0993—14:05

Innovations in hydrometallurgical performance management: heap leaching solvent extraction and electrowinning plants

O.A. Bascur, R. Linares, L. Yacher, OSIsoft Inc.

Several new hydrometallurgical plants have been built in the past years, new processes and equipment as well as advanced process control systems are being used to deal with the increasing requirements of safety, quality and production. Plant Information Management Systems are now being recognized as a key infrastructure component of the plant, giving the management, the operators, process engineers, finance, maintenance, and regulatory agencies an integrated view of the operation and providing the links for the (increasingly) multidisciplinary organization. This paper reviews several implementations of Plant Information Systems; real time performance management infrastructure examples are reviewed as a key component of business strategies, such as Mine to Port Planning and Supervision, Metallurgical Mass Balances, Solvent Extraction Composition Statistical Process Control, methods to minimize organic losses, reduce variable costs and to improve metal extraction. Several examples are provided to illustrate how companies are using the real time and historical information from assets and metallurgical processes to enable and empower people to improve the operations quality, safety and throughput, as well as continuous improvement and innovation initiatives.

Paper #1004—14:30

Process management innovations at Sociedad Minera Cerro Verde - Peru

G. Velarde, Sociedad Minera Cerro Verde S.A.A.

Sociedad Minera Cerro Verde S.A.A leaches secondary copper sulfides. In recent years, the mine has introduced innovations that have improved the management of mineral crushing, agglomeration, curing, and leaching. The crushing plant, for example, uses the concepts of degree of balance and percentage of time in an operationally balanced state which, displayed in real time, facilitate more intensive and uniform utilization of the crushers. High agglomerate quality is ensured with the correct dose of moisture, which is adjusted to the changing characteristics of the mineral through the use of electrical conductivity measurements. The amount of acid used for curing the agglomerate is also adjusted by using quality control information. Finally, the stockpile irrigation regime is managed using the criteria established by the “Lixiviant Request Rate”, which optimizes the addition of leaching solution,

creating such benefits as faster recovery, and reduced acid and energy consumption.

Paper #1058—14:55

Using the six sigma approach towards a metallurgical project: nickel loss reduction and general improvements to the Raglan rougher flotation circuit

C. Ciriello, J-D. Fournier, Xstrata

Six Sigma methodology, as applied within Xstrata (formerly Falconbridge and Noranda), involves a disciplined approach to managing projects, solving problems, improving performance, and leveraging information. The four (4) cornerstones of Six Sigma are the use of Philosophy (customer driven, desire to improve and discipline), Metrics (measurement systems), Methodology (scientific method and sequence of deliverables), and Tools (such as statistics, change management, and root cause analysis). This paper will outline the general steps of the Six Sigma methodology and demonstrate how each phase directly applies to a real plant metallurgical project aimed at reducing nickel losses of the rougher flotation circuit at Raglan. The main concepts of Six Sigma are described, along with the specific challenges, successes, and deliverables related to the project. It is also the authors' aim to demystify the basic Six Sigma principles.

Coffee Break—15:20 – 15:40

Paper #1065—15:40

Increasing competitiveness in the Atlantic Copper metallurgical complex

R. Fernández-Gil, J. Hurtado, Atlantic Copper S.A.

In the period 2003-2004, the situation of the copper concentrate market was unfavourable for smelters and refineries, with low TC/RC values and euro-dollar parity affecting European companies negatively. Within this scenario, Atlantic Copper decided to develop a plan to increase its competitiveness and to improve its results in these market circumstances. The plan affected all departments in the Company and was based mainly on cost reduction in energy and manpower. A general analysis of the Complex's overall efficiency was carried out and, based on this analysis, two major Projects emerged, "Primavera" and "KF". Each Project consisted of smaller sub-projects which aimed at improving the areas which could perform better according to our general analysis. The paper describes how this entire project developed and the final results obtained by the Company.

Paper #1068—16:05

Managing assets using performance supervision

M. Ruel, Top Control Inc.

In today's highly competitive worldwide market, it is becoming extremely important for managers to make sure that all resources are used where needed

the most. That way, all resources are generating added value, process control equipments are maintained in an optimal state for best performance, and final product is produced at least cost. Performance monitoring is the only way to ensure that everyone is working on top priorities toward the same goal. How can we add value to these warehouses of data? The data is there and the information is hidden; it is just waiting to be extracted. A process performance monitoring system is able to determine if a loop, a system, a unit, or a plant meets the expected performances. The system prioritizes the areas that need attention. It also provides historical reports of the plant status by areas, by loops, and by identified problems. This information is provided to different categories of users in an appropriate format for each one. The system also includes diagnostics and tools to detect and analyze problems.

Paper #1078—16:30

Metallurgical balance as a management tool in processing plants

V.H. Valenzuela, E. Perez de Arce

Materials in process or in stocks are quite relevant items in almost every plant, particularly in mining operations, where efficiency in rate of recovering material of interest becomes a key issue when production costs are evaluated. A manager requires information to do an effective use of the resources, especially when raw materials are involved. Losses associated to leaking, efficiency in the transformation process, performance of equipment, and operating conditions are a short list of items which must be properly identified and evaluated. Operations supervisors require information in order to keep key process variables under control. Because of these information needs, it is absolutely necessary to carry on a series of activities related with installation and maintenance of measuring equipment, sampling equipment, sample preparation, chemical analysis, statistical analysis, data handling and reports generation. These pieces of data must be managed on a wise manner in order to get the most of it, keeping always on mind data reliability. Normally, information related with metallurgical balance and even more, the metallurgical balance concept, is handled under an accounting criteria which does not allow dealing with the real world. This situation happens because the criteria utilized do not consider aspects such as bias and uncertainty associated with every measurement that affect the quality of the information and therefore conclusions drawn from it. The purpose of this paper is to give a few rules, necessary to follow, in order to develop an adequate Metallurgical Balance System for an operational point of view. The Gaussian approach for error propagation is used as a basis, allowing one to know the actual uncertainty of the balance and the way how it can be improved. A few real applications of this concept are listed, detailing experiences obtained from practice.

Paper #1187—16:55
Lean/six sigma - unique applications in the mining and metals sector
K. Kelton, B. Chertow, Affiliation not available

Abstract not available.

Cu2007: International Symposium on **Sustainable Development, HS&E, and Recycling,** Incorporating the 6th Waste Processing and Recycling Symposium
Session 47 – Life Cycle, Recycling and Risk Management (13:40 – 15:20), Process Developments for Environment and Safety (15:40 – 17:20)
Sponsors: The Environmental Society of CIM, the Environment Section of Metsoc, MMIJ, GDMB, IIMCh
Chair(s): R. Rao – McGill University
Room Confederation 3—13:40

Paper #0920—13:40
Evaluation of uses-LCA for deriving life cycle impact characterization factors for metals
W.J. Adams, A. Russell, Rio Tinto,
F.A.M. Verdonck, P.A. Van Sprang, Euras-Rijvisschestraat

It is recognized that within life cycle assessment that the eco-toxicity potentials (TPs) derived for metals require additional research to improve their reliability. Current models used to develop TPs do not include important fate process for metals such as speciation and bioavailability. Toxicity potentials are standard values used in LCA to enable a comparison of potential toxic impacts between substances. Huijbrechts (2001) calculated toxicity potentials for 181 substances utilizing the USES model for six impact categories, i.e. freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, freshwater sediment ecotoxicity, marine sediment ecotoxicity, terrestrial ecotoxicity and human toxicity (not considered here). Marine ecotox potential for metals is typically high using this approach, whereas most open ocean metal concentrations are very low. A sensitivity analysis of the USES-LCA model was undertaken using copper as an example. Results indicate: fate processes on the global scale are driving the marine water and sediment TPs for copper most; the second most important fate parameter is sedimentation from the water and burial in deep sediment layers; inclusion of speciation and bio-availability processes would be very beneficial; more accurate estimates of input parameters should be used, and the PNECwater and PNECsediment and all partition coefficients for metals should be updated in the model.

Paper #0921—14:05

Summary of the EU voluntary copper risk assessment

K. Delbeke , I. Schoeters, T. Gerschel, European Copper Institute,
S. Baker, B. Dwyer, R. Danzeisen, International Copper Association,
W. Adams, R. Gaunt, Rio Tinto,
P. Van Sprang, M. Vangheluwe, M. Vandenbroele, D. Heijerick, F. Verdonck, A. Van Hyfte, Euras bvba,
H. Cross, S. Sadhra, A. Wheatley, University of Birmingham,
R. Binetti, L. Attias, S. Marchini, B. Pennelli, E. Testai, P. Di Prospero Fanghella, M. Rubbiani, Instituto Superiore di Sanità

Within the framework of the EU Existing Substance (93/793/EEC) and REACH regulations EC/1907/2006), the copper industry initiated in 2000 a comprehensive Voluntary Risk Assessment of copper and several copper compounds. The Italian Government's Istituto Superiore di Sanità, reviewed the process and reports on behalf of the European Commission. Copper exposure levels to man and the environment from production of copper anodes and cathodes, copper powders and copper chemicals as well as fabrication and use of semi-fabrication products and down stream user products were collected across Europe. Environmental and human health effects data were obtained from literature as well as novel research programs and used to deduct safe threshold

Paper #0924—14:30

Methodogy for aquatic hazard classification of massive metal forms: the copper case

P.H. Rodrigues, CIMM,
W. Adams, Rio Tinto,
K. Delbeke, European Copper Institute

The aquatic hazard classification system of the OECD and EU requires that sparingly soluble metal substances (SSMS) be tested using the OECD Dissolution/Transformation protocol in order to quantify the release of the ecotoxicological relevant species (dissolved ions). The SSMS category contains massive forms of metals, which due to their low solubility and slow transformation characteristics are a special case. The main factors that produce the release of metal into solution are exposed surface loading, pH, and stirring rate. The classification system at present prefers the use of mass loading as opposed to surface loading, in which case the amount of metal released will primarily be a function of the pH, and mass loading. Within the framework of the European Copper Voluntary Risk Assessment, coordinated by the European Copper Institute, we have proposed and developed a methodological procedure in which we demonstrate that surface area is an intrinsic property of a SSMS and we link the exposed surface loading to the toxicity reference value in order to obtain an aquatic hazard classification for massive metals. As example, the aquatic hazard classification for copper massive will be discussed. This approach is recommended for metal massives and metal powders.

Paper #0925—14:55

Recent approach to recycling business in Naoshima smelter and refinery

K. Komori, T. Shimizu, N. Usami, A. Kaneda, Mitsubishi Materials Corporation

Naoshima Smelter and Refinery has treated shredder residue and incinerator fly ash in Japan since 2003. As a highlight, a new incinerating and melting furnace, as well as fly ash washing treatment plant were newly constructed for pre-treatment of shredder residue and fly ash respectively, and the pre-treated materials are ultimately treated in the existing Mitsubishi continuous copper smelting and converting process line. Since wastes such as shredder residue tend to vary in size and in shape, and contain some chlorine, the installation of a new pre-treatment line was required. The combination of the new pre-treatment line with the existing Mitsubishi Continuous Copper Process line has created a highly efficient and environmentally friendly system for recovering and recycling of valuable metals that previously used to be sent to a landfill. This paper reviews the approach that Naoshima took to establish its current recycling business strategy

Coffee Break—15:20 - 15:40

Paper #0901—15:40

Effect of oxygen potential on sulphur dioxide activation of oil sands fluid coke and characteristics of activated coke in mercury adsorption

E. Morris, C.Q. Jia, University of Toronto,
S. Tong, Wuhan University of Science and Technology

It has been shown that Alberta oil-sands fluid coke can be effectively used to reduce SO_2 to elemental sulphur while simultaneously producing sulphur-impregnated activated carbon (SIAC). In the capture of mercury from industrial flue gases, SIAC has proven to be a highly effective adsorbent material. The current research aims at developing an existing SIAC technology to meet the needs of copper smelters for mitigating both mercury and SO_2 emissions, while making elemental sulphur as a co-product. The challenge behind this undertaking is that these flue gases generally contain percent levels of O_2 and H_2O vapour (2-12%). The focus of this study is therefore on the feasibility of reducing SO_2 using fluid coke under copper smelter flue gas conditions, as well as the optimisation of SIAC properties for capturing vapour phase mercury. It is hypothesised that mercury capacity is strongly affected by the O_2 potential of the activation gas due to changes in surface sulphur types arising from different reduced sulphur species. To verify this, gas chromatography is used to analyse the reaction products while XPS and XANES will be used to describe the nature of sulphur on the SIAC surface. CVAFS analysis of mercury capacity will finalise the hypothesis assessment. Preliminary results indicate that O_2 at 5% does not play a significant role in SSA or pore development. As expected, increased residence time contributes to SO_2 reduction and elemental S yield.

Paper #1113—16:05

Control of acid mine drainage by means of immobilizing agents, electrochemical study on a grain mold

S.H. Jordanov, A. Dimitrov, P. Paunovic, University UKIM Skopje

The nature of processes that take place on top of copper bearing grains during the suppression of copper acid drainage from mine tailings was studied on a grain model. Cyclic voltammetry (C.V.) was employed as an experimental technique suitable for indirect measuring of copper leaching. Experiments were done in sulfuric acid (pH=2) at electrodes that progressively approach the real situation during acid main drainage, starting with Cu-metal, then with CuO and finally with CuO covered with $CaSO_4$**.** Oxidation was found to be the only process that takes place on metallic copper electrode anodically polarized up to 2 V vs. $Cu/CuSO_4$ reference electrode. Dissolution is intensive and reaches up to 50 $mA.cm^{-2}$. When the same was repeated, but on CuO electrode, anodic currents were some 4 times lower than on the bare metallic surface. This indicates that the electrode material is not completely oxidized to copper(II)oxide and the Cu(0) or Cu(I) residues are oxidized during the anodic polarization. This explains the diminished dissolution. Dissolution is further restricted at electrodes covered with $CaSO_4$. It is some 20 times lower than on the bare oxide electrode. When the second layer of $CaSO_4$ was applied, anodic currents were another 15 times lower. Total decrease of anodic currents when transition is made from Cu-metal to CuO covered with 2 layers of $CaSO_4$ reaches up to 7.500 times. C.V. measurements produced a proof that mechanical blockage is the way how lime prevents leaching of copper bearing grains in immobilization experiments referred elsewhere.

Paper #0900—16:30

Designing and implementing of noise control method due to ball charge in primary ball mill division of Sarcheshmeh Copper complex

E. Esmaeilzadeh, M.N. Farrokhi, H.A. Hakimi, Sarcheshmeh Copper Complex

There are 8 primary ball mills in the concentrator plant and their task is material crushing. At the time of balls charge to mills, a lot of noise is produced. This noise would affect all grinding areas. The aim of this research was a reduction about 16 dB at source sound power level (SWL was 129.1 dB). With considering two noise control principles, noise producer sources and propagation paths were specified. For removing and reducing of noise producer sources, rubbers with a thickness of 5-20 mm were used on the all inside surfaces of charge box, ball transferring box and exit canal. For increasing transmission loss and damping coefficient of charge box body, rubber with thickness of 1 cm at outside surface of box was used. For reduction of noise propagation a secondary metal cover was designed and made. This cover includes two parts and was set around the charge box. Glass wool (75 kg/m^3) with 10 cm thickness was used as acoustical absorbent between free space of two body's layers and from secondary cover side. The of the rest space was left empty. After installing of secondary cover on

the ball charge box no.4, SWL showed a reduction about 16 dB. For studying of control system effect on noise reduction at points far from of charge place, measuring results at these points showed the maximum reduction 12.1 dB and the minimum 11.8 dB.

Paper #0913—16:55
Arsenic immobilization of teniente furnace dust
R. Ichimura, Japan Oil, Gas and Metals Naitonal Corporation,
H. Tateiwa, Mitsui Mining and Smelting Co.,
C. Almendares, CIMM,
G. Sanchez, CODELCO-Chile

Japan Oil, Gas and Metals National Corporation (JOGMEC) and Centro de Investigación Minera y Metalurgica (CIMM) commenced a five year project from 2001 to modify the treatment of the furnace dust from Teniente converter containing harmful elements like arsenic and lead. The project was supported by Japanese and Chilean governments, and a demonstration plant was installed and operated at Las Ventanas Smelter and Refinery (Division Ventanas CODELCO). The basic and detailed engineering was made by Mitsui Mining and Smelting Co., Ltd (MMS) based on the joint study among JOGMEC, CIMM and Division Ventanas CODELCO. Arsenic in flue dust is lixiviated by sulfuric acid and fixed as crystalline ferric arsenate, where leachability of arsenic will be lower enough than the regulation, 5mg/l by TCLP (Toxicity Charactaristic Leaching Procedure) of USEPA. On the other hand, the recovered copper from the dust will be fed to the copper production process at Las Ventanas Smelter and Refinery, while zinc will be recovered as the exportable product. As introducing the crystallization and growing stage, the stable crystalline ferric arsenate formation can be achieved under the normal pressure.

Cu2007: International Symposium on **Downstream Fabrication and Applications**
Session 48: Development and Characterization of Alloys
Sponsors: SME, Metsoc, MMIJ, GDMB
Chair(s): K. Sadayappan, CANMET
Room Tudor 7—13:40

Paper #1049—13:40
Development of copper foil products for PCBS
K. Sakamoto, Nippon Mining & Metals Co.

Copper foil is an indispensable material for Printed Circuit Boards (PCBs). PCBs in turn are essential elements of all electronic equipment today and thus important for our living in the new age of IT. The requirements from the copper foil market have lately been increasingly strict and diversified due to the rapid technical advancements in miniaturized high-density electronic equipment and

highly integrated semiconductors. Tight control of thickness, metallurgical properties, surface morphology and characteristics is needed. In this paper, both electrodeposited copper foil for PCB and rolled copper foil for the flexible printed circuit board are discussed, and the recent technical developments in these copper foil products are reviewed.

Paper #1048—14:05
Development of a new low lead alloy for plumbing applications
K. Sadayappan, CANMET

The increasing cost of selenium made the conventional low lead alloys such as EnviroBrasses not economically viable. Efforts were made to develop newer alloys without selenium for plumbing applications. Recently a new copper alloy, C89836, was introduced. This paper discusses the properties of the new alloy including mechanical properties at ambient and elevated temperatures as well as corrosion behaviour.

Paper #1070—14:30
Development of lead free copper alloy "ECOBRASS®"
K. Oishi, Sambo Copper Alloy Co.

We have developed a 76Cu-3Si-21Zn alloy "ECOBRASS®" containing no lead. When 3% Si is added to a 78Cu-22Zn alloy, kappa and gamma phases participate uniformly in the alpha matrix. When being machined, stress concentrates on these hard phases, namely kappa and gamma, and thereby lowering the required cutting force and yielding segmentalized chips without lubricant. Kappa and gamma phases transform into beta phase under high temperature, which makes it easier to extrude and/or forge the alloy. When 0.08% P and 50 ppm Zr are co-added, the grains of ECOBRASS® castings are refined significantly to become as small as several dozens of micrometers. The grain refinement by the co-addition of P and Zr improves castability, tensile strength and elongation of ECOBRASS® castings. Meanwhile, the lead leachate from an ECOBRASS® water meter, field-tested in pH 6.8 drinking water for one year, was less than 5 ppb without correction. No indication of dezincification corrosion was observed, either. ECOBRASS® is equally suitable for rods, forgings and castings, and makes it possible to produce a complete set of plumbing parts (valves, faucets, etc.) by its own. This way, not only improving recyclability, ECOBRASS® also realizes size and weight reduction due to its good corrosion resistance and high strength.

Paper #1045—14:55
Development of high-perfomance copper alloy wire "EFTEC 194W"
I. Takahashi, The Furukawa Electric Co.

Recently, electronic devices have become smaller for some kinds of electronic devices, thermal dissipation and electrical conductivity of conventional Fe based

alloy becomes insufficient. We selected the Cu-Fe based alloy CDA19400 and optimized the wire manufacturing process. Precipitates during aging treatment were observed by TEM. The size and distribution of the precipitates varied according to solution treatment temperature. With solution treatment at 950ºC, the precipitates of γ-Fe as fine as 10 nm were distributed dense in the copper matrix with coherency. For the solution treatment at 750ºC, γ-Fe of approximately 200 nm was observed. Comparing heat resistance of drawn wires, the material at 950ºC treatment was superior. Electrical conductivity decreased from 63% IACS upon aging to 29% IACS by drawing. It is considered as particular phenomena for wires where materials are drawn with high reduction ratio. By the optimized manufacturing process, we successfully developed a new wire that has superior in strength, thermal conductivity, electrical conductivity, heat resistance and repeated bendability.

Coffee Break—15:20 – 15:40

Paper #1042—15:40

Manufacturing and mechanical properties of ultrafine grained, oxide dispersion strengthened copper

U. Martin, Technische Universität Bergakademie Freiberg

Advanced copper materials for conducting applications require an optimal combination of high mechanical strength at ambient and moderately elevated temperatures together with superior electrical and thermal conductivity. Mechanical alloying under repeated cooling of the milling vials in liquid nitrogen has been applied to produce ultra-fine grained (UFG) oxide dispersion strengthened (ODS) copper with a high yield strength at ambient temperature. In the present study ODS copper was manufactured by mechanical alloying of copper powder and 3% by volume of incoherent oxide dispersoids. During the high-energy milling a homogeneous distribution of fine dispersoid particles (diameter nearly 100 nm) can be achieved in the powder. Samples with a density of more then 97% of theoretical value were produced by uniaxial hot pressing under 650 MPa at 600°C for 20 minutes. The high yield strength at ambient temperature can be described by a linear superposition of the Orowan stress for particle hardening and of ultra-fine grain strengthening according to the Hall-Petch mechanism. Simultaneously, a best value of 75% IACS could be obtained for the electrical conductivity. The creep behaviour of ODS copper in the temperature range from 500°C to 700°C is described within the frame of diffusional creep deformation.

Paper #1035—16:05

Atomization and spray forming of Cu and Cu-6Sn

H. Henein, University of Alberta

Atomization provides many advantages in processing such as rapid solidification and near net shaping. Two atomization techniques will be compared and

contrasted in this presentation: Single fluid atomization techniques such as Impulse Atomization (IA) and gas atomization. The characteristics of both processing approaches will be presented. Results in powder structure, size and size distribution as well as microstructure will be discussed. A comparison of spray formed ingots carried out using both techniques will also be presented.

Paper #1106—16:30

OHMIC resistance control for copper tarnishing process

D.M. Bastidas, CENIM-Centro Nacional de Investigaciones Metalúrgicas,
E.M. Mora, Universidad Politécnica de Madrid

The reduction of copper sulfide and copper oxides originated during artificial tarnishing of copper was studied using potentiodynamic potential/current density experiments. Six copper surface treatments were considered: mechanical polishing; indoor exposure for 7 days; chemical etching in 1.6 M nitric acid; chemical etching and heating at 160 ºC; and chemical etching and dipping in a $9´10^{-4}$ M or 0.9 M potassium sulfide (K_2S) solution at 70 ºC. Cuprite (Cu_2O) and chalcocite (Cu_2S) were the main compounds formed. A linear relationship with the square root of the scan rate (n) was obtained by plotting the potentiodynamic potential/current density for the tarnish dissolution processes. A relationship between potential and current density cathodic peaks was not obtained, according to Müller's model, showing a proportionality factor with the dimensions of a resistance.