CANMET Materials Technology Laboratory

Technical Review
2003 and 2004

Natural Resources Canada
Ressources naturelles Canada

Canada

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CANMET Materials Technology Laboratory
Minerals and Metals Sector
Natural Resources Canada
568 Booth Street
Ottawa, Ontario
CANADA K1A 0G1

Telephone: (613) 992-5095
Facsimile: (613) 992-8735
E-mail: canmet-mtl@nrcan.gc.ca

It is also available on the Internet at www.nrcan.gc.ca/canmet-mtl.

For information about services to industry or joint business ventures with the CANMET Materials Technology Laboratory, contact our Business Development Office by telephone at (613) 995-8814.

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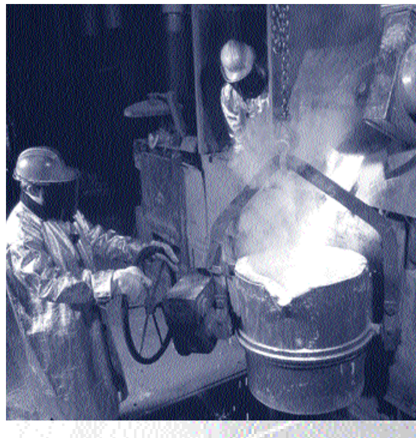
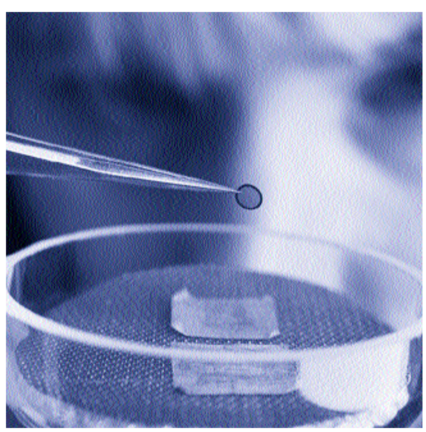
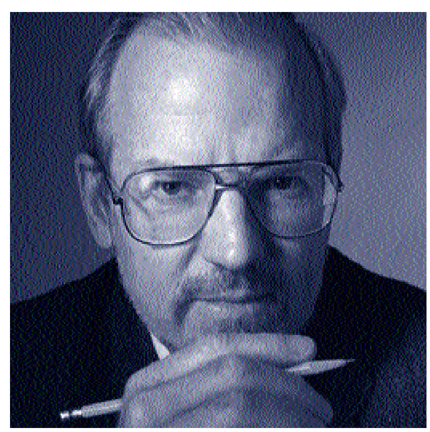
The CANMET Materials Technology Laboratory (CANMET-MTL) is a federal research laboratory equipped with specialized facilities for metals- and minerals-based materials research and performance assessment. With a staff of approximately 140 people (86% of whom are scientists, technicians or technologists), it is unique in Canada and, in terms of scale and comprehensiveness within one facility, unique internationally. CANMET-MTL is also Canada's Certifying Agency for Non-Destructive Testing personnel.

A division of the Minerals and Metals Sector of Natural Resources Canada (NRCan), CANMET-MTL has been in operation and serving the industrial and academic communities since 1942.



TECHNICAL REVIEW 2003 and 2004





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Director's Note

This *Technical Review* describes research activities of the CANMET Materials Technology Laboratory (CANMET-MTL) during the 2003 and 2004 calendar years. Within these pages you will read about an intriguing portfolio of scientific projects that are directed at developing or improving mineral- or metal-based materials and the processes that are used in their production.

These materials are used in a wide variety of applications, products and technologies that span key sectors of the Canadian economy, but principally the transportation, construction and energy sectors. The research activities of this laboratory are therefore necessarily diverse, but the overarching criteria common to all of them is that they must enhance the competitiveness of Canadian companies that produce or use these materials while meeting or exceeding safety and environmental requirements. In this manner, CANMET-MTL contributes to the fulfillment of departmental objectives of Natural Resources Canada (NRCan), particularly in the areas of sustainable development and climate change.

A very important dimension of CANMET-MTL is the way in which it works with academic and international partners and, for this reason, I would like to make special mention of the 2003 launch of the Academic User Access Facility (AUAF). This initiative, the result of a Major Facilities Access grant awarded by the Natural Sciences and Engineering Research Council of Canada in response to a proposal led by McMaster University with seven other Canadian universities, allows researchers and graduate students from all Canadian universities to conduct research using CANMET-MTL's pilot-scale materials processing facilities. This is only the second time a Canadian federal laboratory has been the recipient of an award of this type, and I am very excited about the opportunities it is providing not only for academic researchers, but also for employees at CANMET-MTL. We anticipate that AUAF research projects will not only advance materials research,

but will also create synergies among the Canadian university and government research communities – a theme that the new National Science Advisor to the Prime Minister, Dr. Arthur Carty, strongly advocates. Furthermore, it will provide essential experience to students who will one day provide an innovative force in Canadian industry. At the time of this writing, some 16 projects were under way.

Our achievements are realized through the efforts of a dedicated management team and a highly skilled scientific, engineering, technical and administrative staff. Thank you for taking the time to read our *Technical Review*. As we continue to build on our reputation as Canada's leading R&D centre in metals fabrication, processing and development, we welcome the opportunity to discuss the specific interests of our stakeholder community in Canada and abroad in more detail. Meetings with staff, as well as visits to our laboratories, can be arranged through our Business Development Office.

Jennifer Jackman, Ph.D.
Director
CANMET Materials Technology Laboratory

Overview

CANMET-MTL's mandate is to develop and deploy technologies that improve all aspects of producing and using products derived from minerals and metals. Particular emphasis is placed on solving technological problems relevant to NRCan's mandate in sustainable development and on transferring materials technology to Canadian companies. Approximately 50% of CANMET-MTL's annual $14 million budget is A-base appropriations, about 20% is from other government programs, and approximately 30% comes from sources external to the Government of Canada.

Toward the fulfillment of its mandate, CANMET-MTL's research focuses on three industrial sectors that are enormous users of Canada's natural resources and, therefore, central to the mandate of NRCan. Laboratory staff work closely with clients and stakeholders in the transportation industry (particularly the manufacturers of vehicles, parts and components, who use large tonnages of metal- and mineral-based resources), the construction industry (particularly users of cement and concrete, copper-based alloy materials used for water distribution, and construction steel), those elements of the energy industry that are associated with the use of pipelines to transport oil and gas, and the use of value-added materials related to fuel cells and sensors for process control.

CANMET-MTL also undertakes various scientific activities that benefit the Canadian innovation system through means other than direct research work. The development of testing procedures, codes, and national and international standards related to materials and materials technologies is vital to ensuring public safety, protecting the environment, and facilitating the uptake and deployment of new technologies. These procedures, codes and standards are used in risk assessment and management of materials used in civil and energy infrastructure, marine vessels, and offshore structures. Additionally, the Standards Council of Canada and Le Bureau des normes du Québec seek the services of CANMET-MTL specialists to act as auditors of laboratories that seek certification. These auditing services are provided on a partial cost-recovery basis.

CANMET-MTL research focuses on three industrial sectors that are enormous users of Canada's natural resources.

Significant Initiatives and Consortia
Toward the fulfillment of its mandate, CANMET-MTL coordinates, manages or participates in several multi-player initiatives that involve researchers outside the organization. These collective research efforts represent an important contribution toward research that is strategic to Canada and important to fulfillment of the mandate of the Minister of Natural Resources Canada.

The **Canadian Lightweight Materials Research Initiative (CLiMRI)** is a government-industry research initiative whose mandate is to develop high-strength, lightweight materials to achieve weight reductions in ground transportation vehicles. To improve the competitive performance of Canadian companies in the primary metals, automotive, truck, bus, and railcar manufacturing industries and their associated parts suppliers, CLiMRI also funds projects that focus on manufacturing processes of these materials. CLiMRI is coodinated by CANMET-MTL and is funded through the Program of Energy Research and Development (PERD).

The Director of CANMET-MTL also acts as Theme Coordinator for the Materials and Manufacturing Theme (Theme C) of the **AUTO21** Network of Centres of Excellence. This theme, the largest area of study in the AUTO21 program, involves more than 100 researchers from 18 Canadian universities and the participation of numerous industry and government partners. Research focuses on developing and improving new techniques for using lightweight materials and on improving welding, joining and machining procedures associated with these materials.

CANMET-MTL is a signatory to the international **Light Metals Alliance**, which includes the CAST program (Australia), the LKR Research Centre (Austria), the GKSS Research Centre (Germany), and the Worcester Polytechnic Institute (United States). CANMET-MTL is also Canada's representative on the International Energy Agency's **Implementing Agreement on Transportation Materials** (sub-committee on Lightweight Materials).

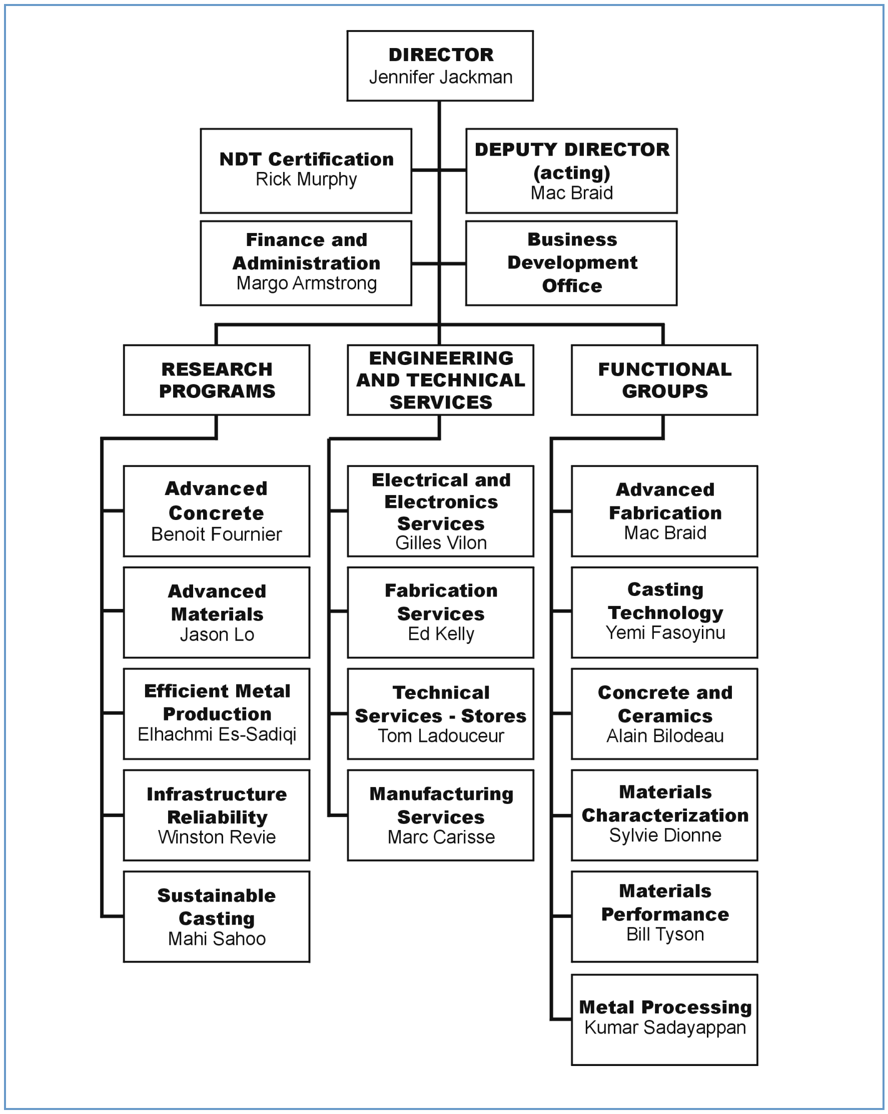
Leadership is also provided on the integrity of materials used in Canada's oil and gas pipeline infrastructure. Through its coordination of the PERD-funded **Pipelines program**, CANMET-MTL ensures that federal pipeline regulations, national standards, and the advancement of pipeline technologies are based on sound science. This involves extensive research and development on materials evaluation, corrosion and fracture control, and welding, monitoring and inspection technologies. CANMET-MTL also participates in another consortium, **External Pipeline Coatings for Prevention of Corrosion and Stress Corrosion Cracking**, with industry and the National Research Council Canada.

CANMET-MTL also promotes the use of supplementary cementing materials by leading **comparative field and laboratory R&D consortium projects** intended to develop practical solutions for two critical durability aspects of concrete incorporating supplementary cementing materials: de-icing salt scaling resistance and alkali-aggregate reaction (AAR). Both consortia involve representatives from federal, provincial and municipal public agencies, private-sector companies and associations from across North America (and overseas for the AAR project), and Canadian universities.

In a multi-partner international project, CANMET-MTL is implementing high-volume fly ash concrete (HVFAC) technology in India through a partnership between Canada and the Confederation of Indian Industry. This $4.2 million technology transfer project, funded by the Canada Climate Change Development Fund through the Canadian International Development Agency (CIDA), is contributing to India's capacity to reduce its greenhouse gas emissions.

CANMET-MTL administers the Canada-wide **Non-Destructive Testing Certification Program** to certify personnel who apply non-destructive methods (for example, industrial radiography and ultrasonic technology) to inspect safety-critical components in engineered structures, including aircraft, power plants and pipelines. The NDT Certifying Agency has also signed letters of cooperation with counterpart organizations in South Korea, the People's Republic of China, Japan, and the United Kingdom.

The **Academic User Access Facility** (AUAF) for materials innovation cooperation with Canadian universities provides Canadian academics and their post-doctoral fellows and graduate students from across the country with access to CANMET-MTL's unique research facilities. Funded by the Natural Sciences and Engineering Research Council of Canada, NRCan, and users' fees, this facility and its users represent a cooperative network of researchers focussing on innovation in structural materials throughout Canada.



Highlights

Each year, CANMET-MTL reports on some 80 significant technical outputs from its five research programs. While all of these outputs are linked to specific outcomes, projects of particular interest are noted here.

Contract research for Canadian companies and strategic involvement in research partnerships constitute a significant portion of researchers' efforts. During the reporting period, CANMET-MTL staff published 126 reports for clients and participated in 15 national and international consortia.

Advanced Concrete Technology Program

Implementation of High-Volume Fly Ash Concrete Technology in India

Fly ash is a by-product of coal combustion. Its disposal is a serious environmental problem in India, where coal-fired power plants provide most of the country's electricity requirements. CANMET-MTL collaborated with the Confederation of Indian Industry in a four-year, $4 million project funded by the Canada Climate Change Development Fund (CCCDF) and administered by the Canadian International Development Agency (CIDA). The project's objective is to implement the use of high-volume fly ash concrete technology, developed at CANMET-MTL in the mid-1980s, in the Indian construction industry. The use of this industrial by-product as a supplementary cementing material (SCM) to partially replace portland cement (the principal ingredient in concrete) produces concrete with a significantly lower CO_2 signature compared with conventional cement concrete.

Since the start of the project in August 2002, 11 seminars and workshops have been conducted in 10 Indian cities for more than 2000 scientists, engineers and technical personnel from industry, academia, and central and state governments. Short-course training was given to more than 100 Indian technical personnel, and focused group meetings were conducted with over 300 state and central government authorities. These sessions significantly increased awareness about HVFAC technology, as well as the willingness to try the technology in construction projects. Additionally, three Indian government departments published circulars recommending the increased use of fly ash in concrete structures, while two central government research institutes and one university initiated technology adaptation programs to ensure that HVFAC technology would be effectively transferred.

Four of the 13 demonstration projects were also completed during the reporting period. These will significantly contribute to increasing the acceptance of HVFAC technology, especially for large government projects. One of the demonstration projects, the Bandra-Worli Sea Link, is a 4.2-km cable-stay bridge linking the Bandra and Worli districts of Mumbai. Part of the bridge is constructed with high-volume fly ash concrete in what is believed to be the largest "pour" of HVFAC ever conducted.

As the environmental, technical and economic benefits of this technology are demonstrated, the Indian construction industry has shown a strong buy-in, and project stakeholders unanimously agree on the successful outcomes of the project.

De-Icing Salts

There is consensus among researchers that the current ASTM test (ASTM C 672) used to evaluate the de-icing salt scaling resistance is not adequate for concrete incorporating SCMs. Most specifications from government agencies are based on the results from that test and, consequently, have strict limits (usually 20% or less) on the proportions of SCMs that can be used in concrete potentially exposed to de-icing salts. This creates barriers that limit the use of large amounts of SCMs in concrete for many applications and has a negative impact on the industry perception of the overall performance of concrete incorporating SCMs.

With the objective of increasing the general acceptance of SCMs, investigations were completed on sidewalk test sections in Montréal. Recommendations for optimum percentages of SCMs to be used in applications subject to de-icing salts were prepared and sent to project partners in late 2004, and to engineers for the construction of a concrete highway in Edmonton, Alberta. Recommendations will also be given (in 2005) to the ASTM technical committee in charge of the test procedure for the evaluation of the de-icer salt scaling resistance of concrete for possible modifications to the existing test method.

Advanced Materials Technologies Program

Hydroforming and Warm Forming of Tubes

Hydroforming is a metal-shaping process that uses high-pressure fluid to form tubes into complex structural shapes. Warm forming uses gas at elevated temperatures to shape tubes when even greater pressures are required to form specific materials. In addition to reducing the weight of a vehicle, tube hydroforming and warm forming allow for increased strength and stiffness, parts consolidation, and cost reductions.

CANMET-MTL is working to extend the commercial use of hydroforming to lightweight metals and ultra-high-strength steels. To achieve this goal, a seam-welding process was developed to manufacture tubes using aluminum alloys and high-strength steels. In 2004, CANMET-MTL produced ultra-high-strength aluminum-alloy tubes for evaluation by industrial partners. A new method was also developed to fabricate tubes made with various experimental high-strength steels.

Research on warm forming of aluminum and magnesium alloys also produced some important achievements. Prototype aluminum and magnesium tubes were successfully produced for evaluation by clients, and the team demonstrated that magnesium tubes can be shaped to make parts. Furthermore, the team demonstrated that the CANMET-MTL tube-forming method can produce tubes that exceed the quality of many other laboratories and industries in the United States and Europe. These achievements in hydroforming and warm forming both make significant contributions to expanding the use of lightweight materials in automotive production.

Corrosion Protection for Magnesium Used in Automobiles

Corrosion of automobiles is a serious problem in Canada and the northern United States because of the pervasive use of de-icing salts on roads in cold climates. Although the use of magnesium and its alloys in automotive parts offers great potential to reduce vehicle weight, their acceptance will ultimately depend on successful corrosion control of these metal parts. CANMET-MTL researchers led the North American corrosion team for the United States Automotive Materials Partnership project on the development of a technology to produce magnesium engine cradles. The team identified five cost-effective corrosion protection systems and determined that galvanic corrosion is effectively mitigated using compatible fastener and spacer joining materials. Researchers also designed a three-layer coating system to protect the alloys from stress corrosion and corrosion fatigue damage in high-stress areas.

Sustainable Casting Program

Materials for the Mining Industry

Austenitic manganese steels are used in applications requiring high-impact abrasion resistance. Examples of their use are comminution equipment for mining and mineral processing, coal pulverizers for power generation, railway frogs for transportation, and shredder hammers for automotive recycling. Although these materials are brittle in their as-cast condition, their high toughness is obtained after a solution annealing and quenching heat treatment. Even with these improvements, thick sections and slack quenching can result in materials with inadequate properties that lead to expensive failures in the field. Specimen testing of each shipment is expensive because of the difficulty of machining these steels. CANMET-MTL researchers, working with the North American foundry industry, developed a reliable method that relates the microstructure of candidate materials to their mechanical properties that could be carried out on a routine basis. Additionally, a process control procedure for the quenching operation was developed based on quench water temperature measurements that could be used while the steels are being processed. These methods have been implemented in five North American foundries.

Lost-Foam Casting

Lost-foam casting can produce parts with complex internal cavities that are difficult to achieve by other casting methods. The Casting group examined the feasibility of casting thin-walled, near-net shapes using the lost-foam process. Vacuum-assisted and low-pressure pouring were also investigated. Casting trials with magnesium alloy AZ91E indicate that the application of a partial vacuum during pouring allows 2-mm-thick castings to be produced, about half the normal thickness filled during the conventional gravity casting process.

Efficient Metal Production Program

Galvanized TRIP Steel

High-strength hot-rolled steel is attractive to the automotive industry because of its potential to reduce vehicle weight and material costs. CANMET-MTL, in partnership with the International Lead-Zinc Research Organization and Noranda Inc., established a range of galvanizing parameters for selected hot-rolled steels. The research identified galvanizing conditions for producing good-quality coatings on hot-rolled steels containing 0.5-1.5 wt% manganese and up to 1.5 wt% silicon, while maintaining target tensile strengths of 500-800 MPa and elongations of 20-25%, depending on the specific steel grade.

The elimination of the cold-rolling process for flat-rolled sheet with a thickness greater than 1.5 mm will result in significant energy savings and greenhouse gas (GHG) reductions. Assuming that 30% of all steel shipments are greater than this thickness, an energy savings of 231 billion BTU per year has been estimated, with an accompanying estimated CO_2 reduction of 47 000 tons per year (based on 1996 production of hot-dip galvanized sheet by members of the American Iron and Steel Institute). This technology will also provide environmental benefits through the reduction of GHGs accruing from improved fuel economy in vehicles.

Welding

In consultation with the Automotive Steel Partnership, the metal inert gas (MIG) welding process with surface tension transfer technology, which allows for good control of the arc during welding, was selected for welding trials on a range of advanced high-strength steels (AHSS). Following trials on several AHSS steel grades, tensile shear results showed excellent weld integrity with ductile failures occurring outside of the weld area. The ability to use low heat input and high travel speeds makes this MIG welding process suitable for joining thinner lightweight steels in automotive applications.

Infrastructure Reliability Program

Intelligent Systems for Pipeline Infrastructure Reliability

With support from PRECARN Inc., CANMET-MTL teamed up with two small companies, Fiber Optic Systems Technology, Inc. (FOX-TEK) and TISEC Inc., to develop Intelligent Systems for Pipeline Infrastructure Reliability (ISPIR). ISPIR can be used to monitor critical pipeline elements on-line, in real time, all the time, to evaluate structural integrity, including pressure and temperature changes, internal corrosion, cracking, and crack propagation. Coupled with data management, the system detects leaks, buckling, bending, soil movement, and other activities. The ISPIR system could provide valuable technology that not only increases public safety and environmental protection, but also protects the Canadian sunk investment in pipeline infrastructure, estimated at more than $15 billion. This technology is most applicable at critical locations and remote areas, and could also be a counter-terrorism measure used to instantly detect any encroachment on a pipeline in a critical area. The ISPIR project was completed in March 2004 and the technology is now in the marketplace.

Software for Corrosion Control and Risk Management of Pipelines

Internal pitting corrosion causes about one failure per day in Canadian production pipelines, many of which transport highly toxic hydrogen sulphide gas. Using SToPS (Systematic Treatment of Pitting Sequence) and Condensate software, critical locations for the occurrence of pitting corrosion in oil and gas pipelines can be identified. Implementation of SToPS will help companies to decrease the number of failures. This software is important for the Mackenzie Valley Pipeline because it can be used to predict critical locations for water accumulation. The software can also be used to identify locations for the attachment of non-intrusive monitoring techniques to minimize the long-term risk of internal corrosion.

Certifying Agency for Non-Destructive Testing

In addition to its principal function as Canada's certification body for personnel performing non-destructive testing techniques, the NDT Certifying Agency continued to broaden its expertise in certification and non-destructive testing standards through the following two achievements:

Certification of X-Ray Fluorescence Operators

In 2004, in cooperation with Health Canada, the NDT Certifying Agency developed a program for the certification of operators of portable x-ray fluorescence (XRF) analyzers. Operating in compliance with the provisions of the International Standard ISO 20807:2003, the Agency certified 25 XRF operators in 2004.

Revision to ISO 9712:2005

The International Standard ISO 9712, "Non-Destructive Testing - Qualification and Certification of Personnel," is used by more than 35 countries to assure competent inspectors for aircraft, oil and gas pipelines, and nuclear power plants, among other applications. As Convener of the ISO Working Group, CANMET-MTL's Dr. Richard Murphy led the five-year revision process that produced ISO 9712:2005 in March 2005.

Patents

Hydrogen Sensor Using a Solid Hydrogen Ion Conducting Electrolyte

Hydrogen is an odourless, colourless, highly flammable and potentially explosive gas, and quick detection of any leakage is essential. The advent of a hydrogen economy will require a hydrogen sensor in every hydrogen-powered fuel cell vehicle. Homes that will use a hydrogen fuel cell for power generation will also require a hydrogen sensor, just as every home today requires a smoke detector.

Areekattuthazhayil Kuriakose and Nicola Maffei obtained U.S. and Canadian patents (US Pat. No. RE38,344; Cdn. Pat. No. 226053) for a sensor that detects and measures hydrogen when it is present in a gaseous system. The device uses a disc comprising a solid-state ceramic hydronium conductor together with a silver-based electrode system on one side and a catalytic noble electrode (such as platinum or palladium) on the other. By measurement of the output voltage across the electrodes, both the presence and the amount of hydrogen in a gaseous system can be determined. Although several types of hydrogen monitors and detectors have been developed, many of them are useful at only low hydrogen concentrations (typically 3-4%) or have low sensitivity or slow response times. Additionally, some of these sensors require a supply of pure hydrogen as a standard reference or only operate at elevated temperatures. This device's reasonably rugged construction makes it potentially suitable for commercial exploitation.

Reinforcement Preform for the Production of Magnesium Composite and Other Metal Matrix Composite Materials

It is well known that many metals, particularly the light metals such as aluminum, magnesium and their alloys, have relatively low strength properties. This disadvantage has limited their usefulness in the past, even though they have the important advantages of being lightweight and weldable. One method to compensate for the lack of strength in a material is through the addition of a reinforcing material to form a metal matrix composite. The reinforcing material is fabricated as a preform and is held together with a binder, typically a ceramic material such as silica. Techniques for making metal matrix composites are already well known and, although these methods are generally successful with aluminum and aluminum alloys, they are less successful with magnesium and magnesium alloys. This is because molten magnesium is a highly reactive material which, when it interacts with silica, leads to the formation of magnesium oxide crystals. These brittle and weak crystals make the composite prone to crack formation, which limits its usefulness for applications where higher strength and greater wear resistance are required.

Jason Lo, Areekattuthazhayil Kuriakose, and Raul Santos have obtained a patent (US Pat. No. 6,506,502; Cdn. Pat. No. 2,313,865) for the development of a reinforcement preform for a magnesium metal matrix composite. The binder used in the preform is sintered magnesium fluoride, which avoids the known problems resulting from the high reactivity of magnesium metal with commonly used binders such as silica or alumina. This reinforcement preform may also be used for aluminum and aluminum alloy composite materials. This patent is a continuation-in-part of US Pat. No. 6,247,519, obtained by the inventors in 2001.

Rechargeable Battery Electrode Testing Device

It is well known that the charge-discharge cycle for rechargeable batteries induces dimensional changes of the electrode material used in an electrochemical energy source. This cycle eventually leads to irreversible mechanical degeneration of the electrode material to the point where the battery can no longer sustain an electrical charge.

Daniel Martineau and Zbigniew Wronski obtained a patent (Cdn. Pat. No. 2,329,410) for their development of a new method and device for real-time and in-situ monitoring of swelling of electrode materials used in electrochemical energy sources. The device, an electrode dilatometer, measures minute changes of electrode dimensions, which are critical for maximizing operating conditions in either battery or proton exchange membrane (PEM) cell electrodes. The electrode dilatometer monitors two concurrent processes involved in the swelling of electrodes. One is the reversible swelling of active mass in an electrode; the other is the irreversible swelling of the electrode, which adds to the cumulative swelling. Only the undesired cumulative swelling is measured by battery producers, and only after many charge-discharge cycles. Contrary to irreversible swelling of the electrode material, reversible swelling is beneficial for battery cycle life since it provides chemical species (hydrogen ions) with better access into the electrode active mass. This two-step measurement technique can prolong battery life.

Similarly, there is a need to optimize swelling of the PEM electrode assembly in PEM fuel cells. This will permit better access of hydrogen and removal of water during the electrochemical conversion of chemical energy into electric current. Here again, reversible and irreversible (cumulative) swelling are measured. The separation of these two components can be achieved using the electrode dilatometer developed at CANMET-MTL. A U.S. patent (US Pat. No. 6,177,799 B1) was obtained by the inventors in 2001.

Sulfide Biosensor and Bio-Corrosion Probe

Sankara Papavinasam, William D. Gould, Winston Revie, Fraser MacLeod, and Michael Attard have obtained a patent (US Pat. No. 6,673,222) for a biosensor developed at CANMET-MTL and the CANMET Mining and Mineral Sciences Laboratories. The biosensor, which is designed to detect microbiologically influenced corrosion (MIC) on pipelines, should also have applications wherever MIC is an issue. Although it has been estimated that 20 to 30 percent of all corrosion on pipelines is MIC-related, there are currently no definitive methods or indicators to monitor this type of corrosion. The CANMET Biosensor and Bio-Corrosion Probe can be used to measure, instantaneously and on-line, the activity of sulphate-reducing bacteria (SRB), the most common cause of MIC. CANMET-MTL is currently working on producing the probes on a larger scale for laboratory verification and field validation.

Publications

Publication in books, peer-reviewed journals and conference proceedings is the principal method to communicate research findings among the global scientific community. During 2003 and 2004, CANMET-MTL scientific and technical staff contributed to the knowledge base in materials science through the publication of 65 refereed articles in peer-reviewed journals, 94 refereed conference and workshop proceedings, and 3 books.

Training of Highly Qualified Personnel

In 2004, seven CANMET-MTL staff held adjunct professorships at Canadian universities. The training of 20 highly qualified personnel (including international students, post-doctorate fellows, visiting professors, and student participants in the Academic User Access Facility) also took place.

Technical Duties

CANMET-MTL scientific staff also serve as reviewers of research proposals submitted to granting institutions such as the Industrial Research Assistance Program of the National Research Council Canada, NSERC, the Canadian Foundation for Innovation, and the Atlantic Innovation Fund. Outputs include comments on the proposals and recommendations regarding funding. In this capacity, CANMET-MTL staff contribute to the effectiveness with which government research funds are expended.

At the national and international levels, CANMET-MTL staff members sit on technical committees, providing scientific advice on industry concerns. This work extends to the broader technical community where CANMET-MTL provides not only its scientific and technical expertise, but also impartiality in the area of standards development. Additionally, staff members sit on organizing committees of conferences, facilitating the transfer of technology to industry.

In 2004, CANMET-MTL staff participated in 32 national and international scientific organizations and committees, including the Canadian Standards Association, the American Society for Testing and Materials, the National Association of Corrosion Engineers, the American Foundry Society, the Conference of Metallurgists, ASM International, the International Institute of Welding, the International Microscopy Society, the International Organization for Standardization, and the Réseau international des laboratoires d'essais des matériaux, among others.

Academic User Access Facility

In September 2003, a group of academics from eight universities, led by Prof. David Wilkinson of McMaster University, were awarded a Major Facilities Access (MFA) grant by the Natural Sciences and Engineering Research Council of Canada (NSERC). Under the terms of the agreement between McMaster University, NSERC and NRCan, researchers from all universities in Canada may apply for access to the pilot-scale research facilities and equipment at CANMET-MTL. Proposals must be made in one of four theme areas: Steel, Lightweight Metals, Concrete, or Emerging and Composite Materials.

The grant is valued at $265 000 per year for four years. It is only the second-ever grant awarded for access to an off-campus federal facility and therefore represents a significant recognition of the value of CANMET-MTL expertise to a large group of academics. Resources are allocated on the basis of approximately 35% from NSERC, 10% paid by the academic clients, and 55% from NRCan.

After development of a proposal intake and review process, the first project was approved in January 2004. By the end of the 2004-2005 fiscal year, some 17 projects from 9 universities in 5 provinces were under way, with a further 13 proposals currently under preparation that involve another 5 universities. Approved projects represent research interests in oil and gas pipelines, automotive materials, and primary metals.

The Academic User Access Facility (AUAF) web site (www.auaf.gc.ca) has received nearly 6000 visits since October 2003. Plans are under way to form an AUAF Users Group that would have its first meeting at the 2005 Conference of Metallurgists in Calgary.

Given that some 30 universities in Canada possess some form of materials research capability, the fact that approximately half of them are involved with the AUAF demonstrates that the Canadian materials science community is becoming increasingly aware of CANMET-MTL's unique capabilities in material processing and evaluation.

Approved Projects, as of March 31, 2005

Short-Form Title	Researcher	University
• Corrosion control of new magnesium alloys	E. Ghali	Laval
• Effect of casting variables and defects on fatigue of diecast magnesium alloys	M. Mahfoud	Saskatchewan
• Hot-gas forming of polymer tubes	M. Jain	McMaster
• High strain rate hot deformation of high-strength steels	M. Militzer	British Columbia
• Induction welding of new-generation automotive steels	L. Mallory	Queen's
• Damage and ductility in composites	D. Wilkinson	McMaster
• Effect of stirring on melts of automotive Al-Si alloys	R. Ghomaschi	Québec (Chicoutimi)
• Kinetics precipitation in micro-alloyed pipe steels	D. Ivey	Alberta
• Formability of advanced tube materials	M. Worswick	Waterloo
• Advanced very high-strength steels	S. Yue	McGill
• Hot tearing-prone light metals	R. Smith	Queen's
• Initiation of environmentally assisted pipeline cracking	R. Eadie	Alberta
• Stress corrosion cracking of pipeline steel	J. Luo	Alberta
• The effect of focussed ion beam sample preparation on certain minerals	R. Herd	Alberta
• Hydrogen-assisted cracking for pipeline steels	A. Alfantazi	British Columbia
• Development of metallic coating technology for certain steels	J. McDermid	McMaster

Awards and Recognition

Awards are important indicators of the capabilities of personnel in any scientific organization. This is particularly true when recognition of that expertise is accorded to scientific and technical personnel by their peers. During the two-year review period, CANMET-MTL staff received 13 national and international awards. A sampling of these is presented below.

NACE Technical Achievement Award: Dr. Winston Revie, Manager, Infrastructure Reliability Research Program, received the 2004 Technical Achievement Award from NACE International, the Corrosion Society. The award recognizes achievements in corrosion engineering that have a significant impact on the practice of corrosion control or the enhancement of the profession. Dr. Revie was recognized for his outstanding research work on pipeline integrity and for promoting the sharing of knowledge by organizing, since 1993, the ongoing series of pipeline workshops in Banff, Alberta.

Dr. Winston Revie

American Society of Materials (Canada Council) M. Brian Ives Lectureship: Dr. Revie was awarded the 2004-2005 ASM (American Society of Materials) Canada Council M. Brian Ives Lectureship. Nominated for the award by the Ottawa Valley chapter of ASM International, Dr. Revie will give lectures to Canadian chapters of ASM International on oil and gas pipelines R&D, trends in corrosion R&D, and intelligent systems for pipeline infrastructure reliability.

Technical Cooperation Program Award: Mr. Jim Gianetto, a Certified Engineering Technologist and senior project leader in the Advanced Fabrication Group, received a 2003 Technical Cooperation Program (TTCP) award for his contributions to the project "Low Heat Input Welding of Nickel-Aluminum-Bronze and Related Materials." He was one of a team of 10 co-authors who received the award for significant contributions to developing the scientific knowledge and proof-of-concept for the confident use of laser-weld cladding for the repair, fabrication and life extension of nickel-aluminum-bronze components of naval ships and submarines.

Mr. Jim Gianetto (left) receiving a Technical Cooperation Program award from Dr. L.J. Leggat, Assistant Deputy Minister (S&T), Department of National Defence

CSA Recognition Award: Dr. Mac Braid, Leader, Advanced Fabrication Group, received this award from the Canadian Standards Association (CSA) in recognition of his leadership and technical contributions to the development of two standards. The S470

Dr. Mac Braid

series of standards, which govern the design, fabrication and operation of offshore oil and gas structures, were developed to provide minimum requirements for the safety of the public, workers and the environment. S473, the standard for steel fixed offshore structures, includes clauses on welding, fatigue, materials and fracture control, which are based on CANMET-MTL (and Dr. Braid's) research. The new edition includes several improvements such as the test requirements for sampling heat-affected zone material.

The Morris Cohen Award:
Dr. Mimoun Elboujdaini, Materials Performance Group, was presented this award by the Materials and Performance and Integrity Section of the Metallurgical Society (MetSoc). Dr. Elboujdaini received the award for his contribution to the advancement of corrosion science and engineering in Canada. The award honours the memory of the eminent Canadian Scientist, Morris Cohen, a renowned expert in the field of electrochemistry.

Dr. Mimoun Elboujdaini

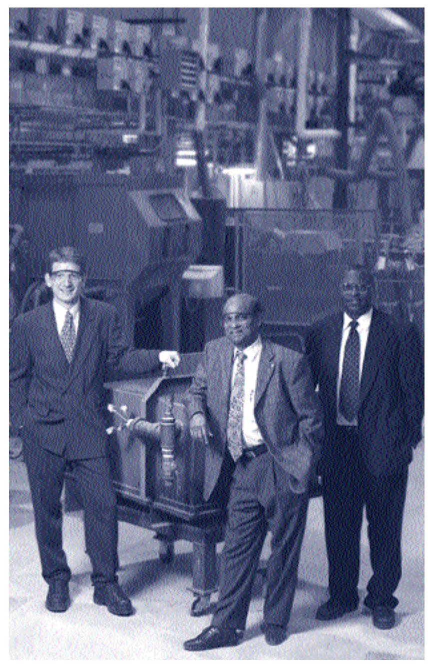
Best Paper Award, Magnesium Division, American Foundry Society:
Mr. Jim Thomson and Drs. Yemi Fasoyinu, Kumar Sadayappan, and Mahi Sahoo, of the Casting Technology Group, will receive the Best Paper Award for "Casting Characteristics of Permanent Mold Cast Magnesium Alloy AZ91E," for the paper's contribution to the advancement of the magnesium foundry industry. The paper describes work done at CANMET-MTL that established the casting characteristics for a magnesium alloy using the permanent-mould casting process.

AFS Award of Scientific Merit:
Dr. Kumar Sadayappan, Leader, Metal Processing Group, will receive the American Foundry Society's (AFS) award for his outstanding contributions to the development of a lead-free copper alloy, copper alloy permanent-mould casting, light metals casting technologies, and technology transfer to non-ferrous foundries. The award is the highest recognition for technical achievements by a member of the Society.

Dr. Kumar Sadayappan

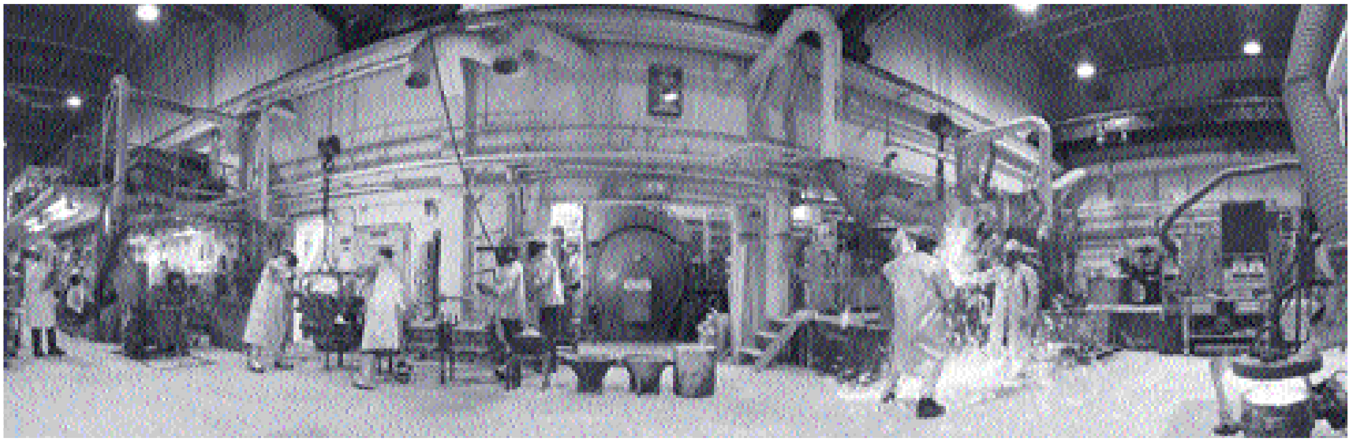
Merit Award, Minerals and Metals Sector, Natural Resources Canada:
Mr. Alain Bilodeau, Leader, Concrete and Ceramics Group, was presented a Sector Merit Award for his efforts in promoting the use of high-volume fly ash concrete in the construction of the Liu Centre for Global Studies (Vancouver, B.C.). In his capacity as NRCan project leader, Mr. Bilodeau provided advice on the composition of the concrete used during construction of the Centre.

Merit Award, Minerals and Metals Sector, Natural Resources Canada:
Dr. Mahi Sahoo, Manager, Sustainable Casting Research Program, Dr. Yemi Fasoyinu, Leader, Casting Technology Group, and Mr. Peter Newcombe, Foundry Supervisor, were presented a Sector Merit Award for their contribution to the development of the vacuum casting method for magnesium alloys for Haley Industries of Haley, Ontario. Their work led to reductions in casting defects, scrap rate, and a corresponding increase in service life of the cast aerospace components.



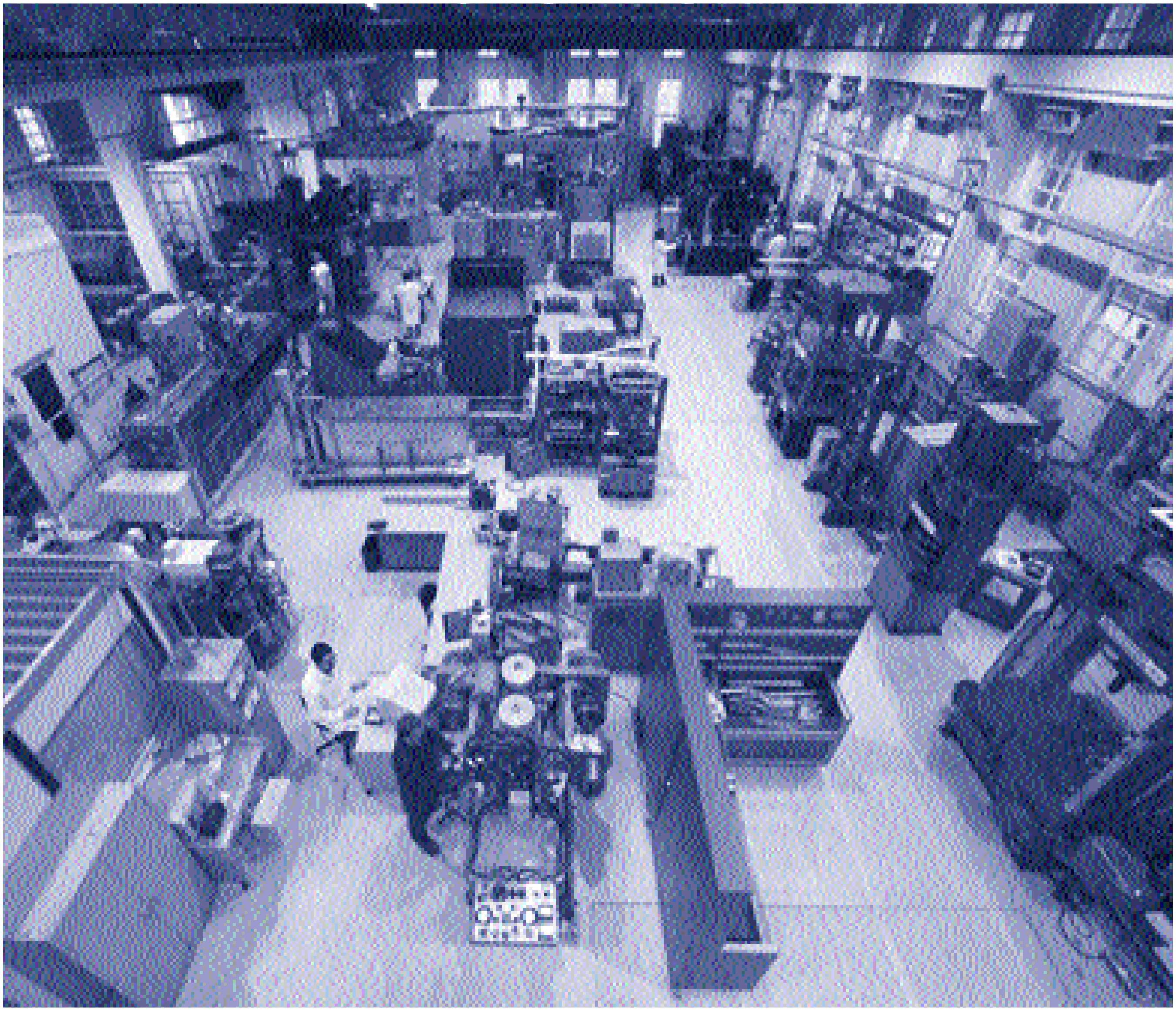
Minerals and Metals Sector Merit Award (left to right): Mr. Peter Newcombe, Dr. Mahi Sahoo, Dr. Yemi Fasoyinu

Major Facilities and Equipment

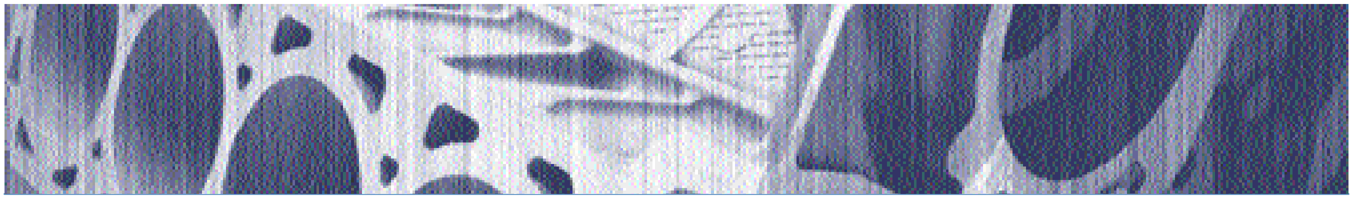


Experimental Casting Laboratory: This time-lapse image shows the tapping and pouring of a 200-kg batch of grey iron. First, the ladle (right foreground) is flame-preheated. Three foundry crew members (right) then tap the molten iron from an induction furnace. Four foundry crew members (left) then pour the iron into sand moulds, while a scientist (far left) records observations. The moulds contain a ceramic preform that will become part of the final casting. The ceramic material is used to selectively reinforce specific areas of the casting to improve its wear resistance. Other equipment shown here include a low-pressure die casting machine (background right, 120 kg aluminum, 80 kg magnesium); a 220-kg (steel) vacuum induction furnace (centre); a 100-kg (steel) tilt induction furnace (far left); and a push-out induction furnace (far left) for non-ferrous alloys (120 kg brass, 40 kg aluminum).

Mechanical Testing Laboratory: Part of the 350-m^2 (4000-sq.-ft.) Mechanical Testing Laboratory, showing universal testing frames with capacities up to 1000 kN. Testing performed here serves all of CANMET-MTL's five research programs, and includes tensile, compression, flexion, peel, and fracture toughness testing. The Mechanical Testing Group also conducts instrumented impact testing, drop-weight tear testing, the ring-hoop tension test (developed at CANMET-MTL for measuring transverse mechanical properties of hydroformed tubes), the Charpy test, fatigue testing, and hardness testing.



Metal-Forming Laboratory: CANMET-MTL's 565-m^2 (5500-sq.-ft.) Metal-Forming Laboratory is equipped with a broad array of metal-forming equipment, including a 450-kN Dominion reversing rolling mill; a Stanat heated-roll reversing rolling mill; a high-strain rate (200 s-1) cam plastometer; a 45-kN quench-deformation dilatometer; a 10,000°C/s Gleeble 2000; a 500-ton Interlaken hydroforming and hot-gas forming press; a 100-ton squeeze-casting press; 2-4 die hot and cold swaging machines; three hydraulic presses (75-, 200-, and 500-ton); and five variable-temperature furnaces (20°-1250°C).



Materials Used by the Transportation Sector

Reducing the weight of a vehicle is the easiest and least expensive route for manufacturers to reduce the energy consumption and emissions of their products. The benefits of weight reduction apply to all types of vehicles, whether they are powered by fossil fuels, fuel cells, electricity, or biofuels.

A typical approach to save vehicle weight is the substitution of conventional materials for higher-strength materials of the same density or by materials of lesser density but similar strength. In the first case, less material is needed (as with high-strength steel); in the second, the higher strength-to-weight ratio of lighter metals (aluminum, titanium, magnesium) results in direct weight reduction. New welding, forming or joining procedures can also lead to weight reduction by enabling design modifications and by reducing the amount of material needed for rigid structures. For example, hydroforming – a metal-shaping process that uses fluid at high-pressure to form tubes or sheet into the required structural shape – allows for increased strength and stiffness, parts consolidation, and cost reductions.

The light metals, however, are not as strong as steel, are less easily formed and welded, and are more prone to fatigue and (in the case of Mg) corrosion than steel. For these materials to be used in vehicles, new alloys and engineered materials with improved and consistent properties need to be developed. This includes cast materials, wrought (sheet, extrusions and forgings) materials and very novel materials such as composites that have been reinforced by the addition of powder or fibres and that have been produced in laminar structures.

Furthermore, production methods for the 45 million cars produced annually (worldwide) must be cheap, rapid, automated, reliable, and effective. Considerable research will be required for lightweight materials to achieve full market penetration. Given the increasing pressure globally to produce energy-efficient vehicles, the potential payoff for such research is high. Several nations (for example, the United States, Germany, Australia, Japan, China, India) are aggressively pursuing well-funded R&D programs on lightweight materials.

The benefits of weight reduction apply to all types of vehicles, whether they are powered by fossil fuels, fuel cells, electricity, or biofuels.

Additionally, there are significant opportunities for minerals and metals usage in transportation applications for non-structural applications such as ceramic sensors, fuel cell membranes, and hydrogen storage in the form of metallic hydrides. The potential volumes of minerals and metals used in these applications can be large; for example, it is estimated that a hydride storage system could require as much as 100 kg of magnesium per vehicle.

The following projects demonstrate the multi-disciplinary approach used at CANMET-MTL to develop technologies that will enable Canadian companies to benefit from the demand for vehicle weight reduction.

Emerging Materials for Automotive Components

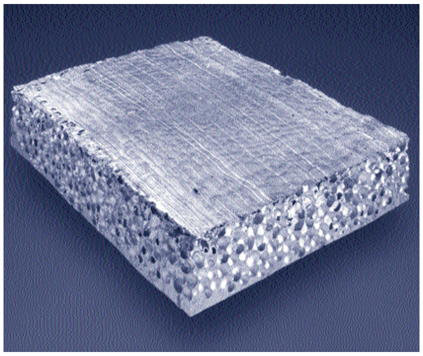
Metal Matrix Composites

Specialized processes using composite materials offer new opportunities to reduce vehicle weight. The average weight of a conventional automotive brake rotor is 5 kg. Prototype aluminum-ceramic brake rotors are being developed at CANMET-MTL that are 60 percent lighter (weighing 2.1 kg) and are expected to last six times longer than conventional rotors. Commercial-type brake rotors are now being produced in a fully commissioned fabrication facility in-house using CANMET-MTL patented materials.

Titanium Powder Processing

Titanium, because of its light weight, high strength and excellent resistance to corrosion, has potential applications in automobiles. Metal powder injection moulding (MPIM), a process derived from plastic injection moulding, is used in the large-scale production of components with complex shapes. Injection-moulded components are very close to their final (or near-net) shape; hence, it is an appropriate production method to produce metallic parts, such as titanium alloys, that cannot be easily machined. Additionally, MPIM is a low-cost process because scrap and secondary processing operations are minimized.

Although current technologies for making powders used in injection moulding are expensive, producing lower-cost titanium powder is of global interest and new processes for powder-making hold promise for revolutionary advancements. During the reporting period, CANMET-MTL developed both a binder system and solvent debinding process for titanium powder injection moulding. Efforts are under way to test their effectiveness with low-cost titanium powder.



The uniform size of the cells of this closed-cell aluminum foam, fabricated at CANMET-MTL, is essential to providing predictable mechanical properties of the material.

Metallic Foams

Metal foams are a new class of materials that are being used in various fields. In particular, they find applications in the transportation, architectural, engineering and construction industries, where the materials display very desirable properties including light weight, a high stiffness-to-weight ratio, impact absorption, vibration damping, and sound absorption, and they are fire-resistant and environmentally friendly. The most promising of the metal foams is aluminum foam, given its low density (~0.3 g/cc) and melting point (~660°C). These properties facilitate processing and the choice of foaming agents, with the temperature of decomposition in the range of 500-700°C. During the reporting period, CANMET-MTL developed two techniques for processing metallic foams in-house. These new capabilities enable CANMET-MTL to better assist Canadian industry in producing such materials.

Magnesium Composites

Although magnesium alloys have a low density, their mechanical properties, especially those at elevated temperatures (>150°C), are far from perfect for use in automotive applications. In a recent meeting with the U.S. Automotive Materials Partnership on the target properties of a prototype magnesium engine cradle, a major concern was expressed that certain localized regions of the cradle will need to be strengthened to withstand temperatures of 150°C. One means of overcoming this drawback is to increase the wall thickness of the component. This solution, however, will increase the weight of the cradle.

An alternative solution is to develop a technology to strengthen only the weak regions of the component. A novel means to achieve localized strengthening of magnesium automotive components is to develop a very porous film or preform that can be inserted into a die during the casting of an automotive component. The porous film or preform will consist of fine ceramic particles (possibly nano-particles) and other ingredients that would encourage the infiltration of magnesium alloy into it during the casting operation. The final product is a magnesium product with a localized composite material that will have significantly improved properties at elevated temperatures.

During the reporting period, CANMET-MTL developed a novel process to make magnesium-based composites. A patent application has been submitted to the U.S. Patent Office. CANMET-MTL also developed a magnesium composite material that is lighter, stronger, and has a much higher modulus than wrought aluminum alloys. This higher modulus improves the material's creep resistance, which is an important property for high-temperature automotive applications.

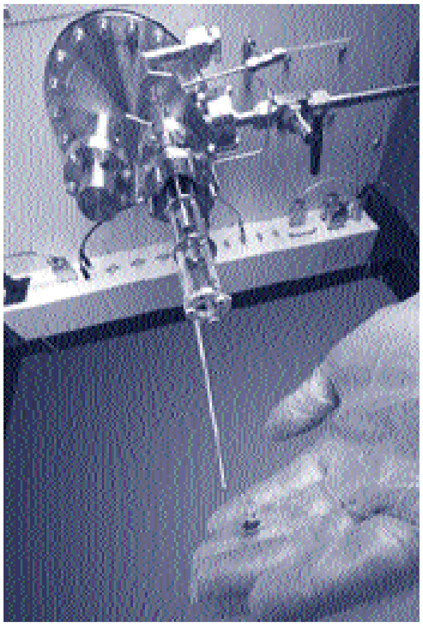
Materials for Fuel Cell Technology

Advanced Coating Technology for Cooling Systems for Automotive Fuel Cell Engines

The development of new fuel cells, such as the proton exchange membrane (PEM) fuel cell, will require specialized cooling systems. Heat exchangers must be able to withstand corrosion and avoid the contamination that can occur in a functioning PEM fuel cell. In a project with Dana Corporation, Long Manufacturing Division (Oakville, Ontario), CANMET-MTL fabricated and tested prototype heat exchangers in fuel cell test stations. While analysis showed that some corrosion of the heat exchanger took place, a significant amount of the corrosion product originated from other components in the fuel cell system and not from the heat exchanger itself. Modified sol-gel coatings were developed, and testing of these optimized coatings showed that they provide significant protection in the fuel cell environment.

Lightweight Thermal Management Materials

One method to obtain hydrogen for use in fuel cells is through on-board reforming of hydrocarbon or alcohol fuels. Reformers operate at high temperatures (450-750°C) and require durable components made of materials that will not degrade in this operating environment. Additionally, materials must be cost-effective, lightweight, and able to withstand dense packing. Dana Corp., Long Manufacturing Division and CANMET-MTL investigated the high-temperature durability and degradation mechanisms of candidate materials. Several promising materials for the high-temperature reformer application have been identified. The material responses to temperature cycling and variation of gas composition



This IGA model gravimetric hydrogen analyzer is used to determine storage capacity and charge-discharge characteristics of materials used for hydrogen storage applications in fuel cells.

during operation were identified as critical performance issues.

New Nanophase Materials for Advanced Solid-State Hydrogen Storage
Given that hydrogen-powered automobiles must carry enough hydrogen to provide a range of 500 km, safe on-board storage of hydrogen is critical. While most research efforts worldwide are directed at storing hydrogen as a compressed gas, CANMET-MTL and the University of Waterloo are collaborating to develop a solid-state compound that will store and release at least 6.5 wt% hydrogen, which will enable a range of 500 km.

During the reporting period, the project team developed a novel process that produced a new magnesium-iron hydride with a storage capacity of 5.5 wt% hydrogen. The essential and unique aspect of this new technology is the formation of nanometric-scale structures that are produced by mechanically milling metals in a hydrogen atmosphere with a high-energy ball mill. The synthesis of a magnesium-aluminum hydride from the respective metal powders is also under way. New facilities were built to characterize candidate metal hydrides suitable for storing hydrogen in automotive PEM fuel cell systems.

Hydrogen Sensor for Solid Oxide Fuel Cells
Hydrogen is an odourless, colourless, highly flammable and potentially explosive gas, and quick detection of leakage is essential. The advent of a hydrogen economy will require a hydrogen sensor in every hydrogen-powered fuel cell vehicle. A prototype hydrogen sensor for solid oxide fuel cells was developed and U.S. and Canadian patents were issued during the reporting period. Armstrong Monitoring Corp. of Nepean, Ontario, is evaluating the sensor for possible commercialization.

Casting of Light Metals

Commercial casting processes typically involve reusable sand and permanent metal moulds, as well as expendable wax and foam replicas. Production rates by sand casting are about ten times that of the permanent-mould process. However, the surface finish of permanent-mould castings is superior to the surface finish from sand-mould castings, resulting in fewer finishing operations. Lost-foam casting can produce parts with complex internal cavities that are not achievable by other processes. It is critically important to understand the limitations and capabilities of each of these techniques, and to comprehensively document the casting characteristics of new alloys for acceptance in automotive applications. Research at CANMET-MTL focused on new or better process controls, improved product performance and reliability, and the production of thinner-walled castings.

Grain Refinement of Magnesium
One way to improve strength, ductility, corrosion and fatigue performance is through grain structure engineering. Grain refinement refers to the use of an additive to reduce the final grain size during solidification. CANMET-MTL researchers learned that hexachloroethane increased the strength of AZ91 magnesium alloy by approximately 12% and the ductility by 25% through grain refinement. More importantly, it reduced the tendency of castings to hot-tear while cooling in the mould. The use of magnesium can result in a 35% weight saving over conventional cast aluminum.

Aerospace Alloys
Work to improve the properties of the aerospace aluminum-copper alloys A201-206 is continuing, and it is hoped to extend their use to ground vehicles. It was found that the addition of an alloy of cerium and lanthanum improved the resistance to hot tearing of these difficult-to-cast alloys.

Sand Casting of Magnesium
Sands that are used for moulding contain inhibitors that suppress the tendency of molten magnesium alloys to burn and react with the sand. Because these inhibitors contain noxious sulphur, boric acid or fluorides, their use complicates reclamation, re-use and disposal of used sands. CANMET-MTL has developed mould coatings that eliminated the need for inhibitors in sand castings.

Lost-Foam Casting
CANMET-MTL examined the feasibility of casting thin-walled, near-net shapes by the lost-foam process. Vacuum-assisted and low-pressure pouring were also investigated. Casting quality is

being assessed for different foam densities, backing media, applied pressure, metal-running systems, and pouring temperatures. Casting trials with magnesium alloy AZ91E indicate that the application of a partial vacuum during pouring allows 2-mm-thick castings to be produced, about half the normal thickness. Future work will be coordinated with Oak Ridge National Laboratories.

Gravity and Low-Pressure Permanent-Mould Casting

In permanent-mould casting, liquid metal is either poured by gravity (downwards) or pushed upwards with the application of low pressure. These methods reduce emissions from sand binders and minimize sand reclamation and disposal issues. During the review period, prototype permanent-mould castings for automotive and marine applications were produced to demonstrate the advantages of these processes. Castings were produced in an aluminum alloy and two magnesium alloys. Grain refinement improved the hot-tearing resistance of the aluminum alloy.

Graphite Mould Casting

CANMET-MTL also made improvements to the graphite mould casting process. Graphite moulds, which are commonly used for zinc castings, were not previously used for aluminum because of the cost and casting defects. Because of improvements made to several casting parameters, including mould design, melt, and heat treatments, components with excellent mechanical properties were produced. A client reports that A357 aluminum castings made using the graphite mould technology had mechanical properties that exceeded the requirements for aerospace applications. The company states that the process has generated considerable interest among several of its Canadian and American clients who want to use it to produce high-integrity thin-wall components.

Quality Control Tools

Standard foundry practice requires that test bars for mechanical testing be cast regularly as a means of ensuring quality control. The standard (and variant) test bar moulds currently in use do not consistently or accurately predict mechanical properties. The causes were identified and recommendations were made for their use.

As another method to manage quality, a computer program, Property Predictive Software, was developed from available processing variables (such as melt composition, modification, sand or permanent-mould casting, heat treatment, and mechanical properties). The software uses artificial neural networks (ANN) to predict mechanical properties on-line from alloy chemistry. The ANN model was found to be more accurate than conventional multivariate regression analysis in predicting properties.

Research into the use of cooling curve analysis to generate alloy data continues. This technique continuously monitors the temperature of liquid metal samples during solidification. From a detailed analysis of the shape of the cooling curve, it is possible to discern the presence of certain alloying elements and to estimate the thermodynamic properties of the alloy. These properties are required by engineers to design castings. Additionally, analysis of the curves generates factors that correlate with the alloy microstructure and hence to the mechanical properties. Cooling curve analysis shows great potential as a quality-control tool for aluminum foundries.

Forming and Joining of Metals

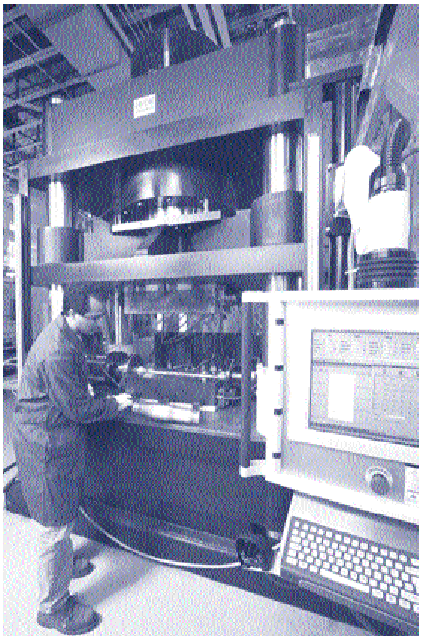
Rolled Magnesium Sheet for Automotive Applications

Magnesium sheet could be a very cost-effective way to reduce the weight of stamped inner panels for doors, roofs, hoods and deck lids, but currently there is no supplier in the world that can produce consistent material with the combined strength and ductility. In partnership with McGill University and General Motors Canada, CANMET-MTL identified several key parameters that are influential in the hot-rolling and hot deformation of three magnesium alloys. Computer models that simulate the hot-rolling process were also developed. Additional useful technical insights were obtained on the heat treatment of magnesium sheet, and data were aquired on microstructures and physical properties. Grain orientation studies and the rolling of other alloys are currently under way.

Sheet metal is often produced from repeated rolling of massive ingots. To produce sheet with finer microstructures, magnesium alloy AZ31 was cast in thin sheets using a moving plate caster designed by CANMET-MTL researchers. Casting conditions (alloy composition, trace additives, cooling rate, and plate thickness) are being investigated to establish the best formability for rolling.

Rolled Dual-Phase Steel Sheet

The excellent ductility and high strength of dual-phase steels make them suitable for automotive applications. Working with Dofasco, numerous processing routes were investigated to improve the mechanical properties of high-strength steel to a yield strength (YS) of 550 MPa and an ultimate tensile strength (UTS) of 900 MPa with 11% elongation. A process was developed that increased the elongation to 20-25% without seriously affecting strength (400 MPa YS and 800 MPa UTS). This



CANMET-MTL's 500-ton hydroforming/ hot-gas forming Interlaken Press is used to determine material forming limitations under various deformation modes and strain paths.

advanced, hot-rolled, high-strength steel is currently being produced at CANMET-MTL to make material for a hydro-forming project with AUTO21.

Tube Hydroforming and Warm Forming

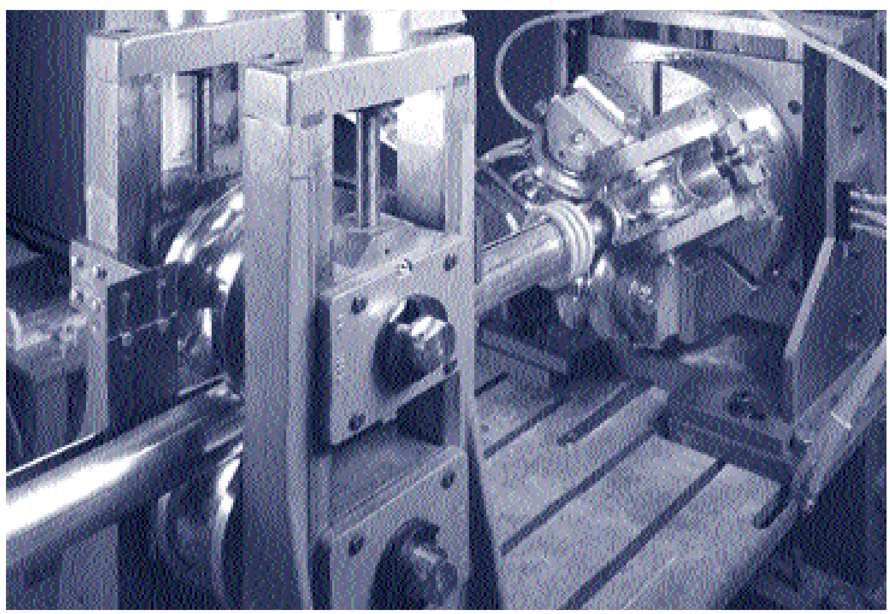
Hydroforming is a metal-shaping process that uses high-pressure fluid to form tubes into complex structural shapes. Hydroformed components from low-carbon steel tubes have become more common in today's vehicles, especially in truck frames and engine cradles. In addition to reducing the weight of a vehicle, tube hydroforming allows for increased strength and stiffness, parts consolidation, and cost reductions. Forming at elevated temperatures ("warm forming") using gas improves the formability over conventional hydro-forming, particularly for light metals such as aluminum and magnesium, which are more difficult to shape than steel.

CANMET-MTL is working to extend the commercial use of hydroforming to lightweight metals and ultra-high-strength steels. To achieve this goal, a seam-welding process was developed to manufacture tubes using aluminum and high-strength steels. In 2004, CANMET-MTL produced ultra-high-strength tubes with tensile strengths approaching 1000 MPa for evaluation by industrial partners. A new method was also developed to fabricate tubes made with experimental steel grades.

Research on warm forming of aluminum and magnesium alloys also produced some important achievements. New testing procedures were developed and implemented to assess the tensile properties of metals at elevated temperatures. Tensile properties can now be measured at strain rates significantly higher than by conventional methods. Prototype aluminum and high-strength steel tubes were successfully produced for evaluation by clients, and the team demonstrated that magnesium tubes can be shaped to make parts. Furthermore, the team demonstrated that the CANMET-MTL tube-forming method can produce tubes that exceed the quality of many other laboratories and industries in the United States and Europe.

Equal-Channel Angular Processing

Normal extrusion processes subject material to plastic deformation and can reduce grain sizes to between 5 and 10 microns, thereby greatly improving strength and ductility. Researchers used CANMET-MTL's equal-channel angular press and equal-channel angular rolling equipment to simulate severe plastic deformation that produced material with grains of less than 2 microns in diameter. Dies for each process were designed and manufactured and are currently being optimized in preparation for pilot-scale trials with aluminum and magnesium alloys.



The fin pass, welding coil, and weld box of CANMET-MTL's pilot-scale tube welding system – this equipment is used to seam-weld aluminum and advanced high-strength steel tubes required for hydroforming and hot-gas forming.

Joining
Maintaining the tightness of bolts and other fastenings is critical in automotive applications, and assemblers must have confidence that the clamp load will be retained at critical bolt joints. This is a challenge for magnesium (which has a tendency to creep at high temperatures), especially in applications such as engine cradles or powertrains.

In a project with the United States Automotive Materials Partnership (USAMP), CANMET-MTL developed a new procedure for bolt-load retention testing of magnesium alloys for automotive applications. This involved a comprehensive review of existing test procedures and the stress-relaxation behaviour of magnesium alloys, followed by construction of a bolt-load retention test fixture with the necessary heating and data acquisition instrumentation to perform tests under conditions similar to those related to the engine cradle application. This methodology has now been adopted by automotive companies and represents the first common approach to measuring bolt-load retention. The technique was used to demonstrate that the magnesium alloy used for the engine cradle development project would retain bolt loads satisfactorily for production vehicles and was an important contribution to the project. A Canadian company (Meridian Technologies Inc.) has been awarded a contract by General Motors to produce the first production-volume magnesium engine cradle as a result of this substantial project.

Welding
In consultation with the Automotive Steel Partnership, the metal inert gas (MIG) welding process with surface tension transfer technology, which allows for good control of the arc during welding, was selected for welding trials on a range of advanced high-strength steels (AHSS). Following trials on several AHSS grades, tensile shear results showed excellent weld integrity with ductile failures occurring outside of the weld area. The ability to use low heat input and high travel speeds makes this MIG welding process suitable for joining thinner lightweight steels in automotive applications.

A CANMET-MTL welding technician performing an experimental MIG (metal inert gas) welding trial to establish optimum welding conditions for the production of lap welds for advanced high-strength steels.

Coatings

Galvanized TRIP Steel
High-strength hot-rolled steel is attractive to the automotive industry because of its potential to reduce vehicle weight and material costs. CANMET-MTL, in partnership with the International Lead-Zinc Research Organization and Noranda, established a range of galvanizing parameters for selected hot-rolled steels. The research identified galvanizing conditions for producing good-quality coatings on hot-rolled steels containing 0.5-1.5 wt% manganese and up to 1.5 wt% silicon, while maintaining target tensile strengths of 500-800 MPa and elongations of 20-25%, depending on the specific steel grade.

Protective Coatings for Magnesium
Corrosion of automobiles is a serious problem in Canada and the northern United States because of the pervasive use of de-icing salts on roads in cold climates. Although the use of magnesium and its alloys in automotive parts offers great potential to reduce vehicle weight, their acceptance will ultimately depend on successful corrosion control of these metal parts. CANMET-MTL researchers were selected to lead the North American corrosion team for the USAMP project on the development of a technology to produce magnesium engine cradles. Following evaluation of 18 coatings for magnesium, 5 cost-effective corrosion protection systems were identified. Furthermore, it was determined that galvanic corrosion is effectively mitigated using compatible isolator and spacer joining materials. New aluminum-magnesium alloys were developed that have minimal galvanic potential toward magnesium alloys. A three-layer coating system was designed to protect the alloys from stress corrosion and corrosion fatigue damage in high-stress areas. This work attracted considerable international attention and established CANMET-MTL's reputation in the important area of corrosion mitigation for automotive magnesium.

Concrete and Other Construction Materials

Concrete is by far the most widely used building material in the world; its consumption is more than double that of all other building materials (wood, steel, plastic and aluminum) combined. The use of cement and concrete is growing rapidly in emerging economies. In India, for example, the current production of portland cement, the principal ingredient in concrete, is about 100 million tonnes per year, an amount that could double within 10 years. In China, current production is greater than 600 million tonnes per year.

The production of portland cement, however, is responsible for approximately 2% of this country's total greenhouse gas emissions. For every tonne of portland cement produced, almost one tonne of CO_2 is released into the atmosphere. Worldwide, 1.7 billion tonnes of portland cement were manufactured in 2000, an amount responsible for 5-7% of the world's entire greenhouse gas emissions. This amount is expected to increase to 2 billion tonnes per year by 2010. As with lightweight materials, CANMET-MTL's research directed at the development of supplementary cementing materials (SCMs) to partially replace the portland cement in concrete makes a significant contribution toward both the value-added and climate change aspects of NRCan's mandate.

During the reporting period, significant progress was made on a major project, funded by the Canadian International Development Agency (CIDA), to transfer CANMET-MTL's high-volume fly ash concrete (HVFAC) technology to India. Contributions were also made in areas of research devoted to improving the long-term performance of concrete incorporating SCMs, as well as in the development of technologies to combat alkali-silica reaction and alkali-aggregate reactivity. These latter two phenomena significantly affect the durability and service life of concrete infrastructure.

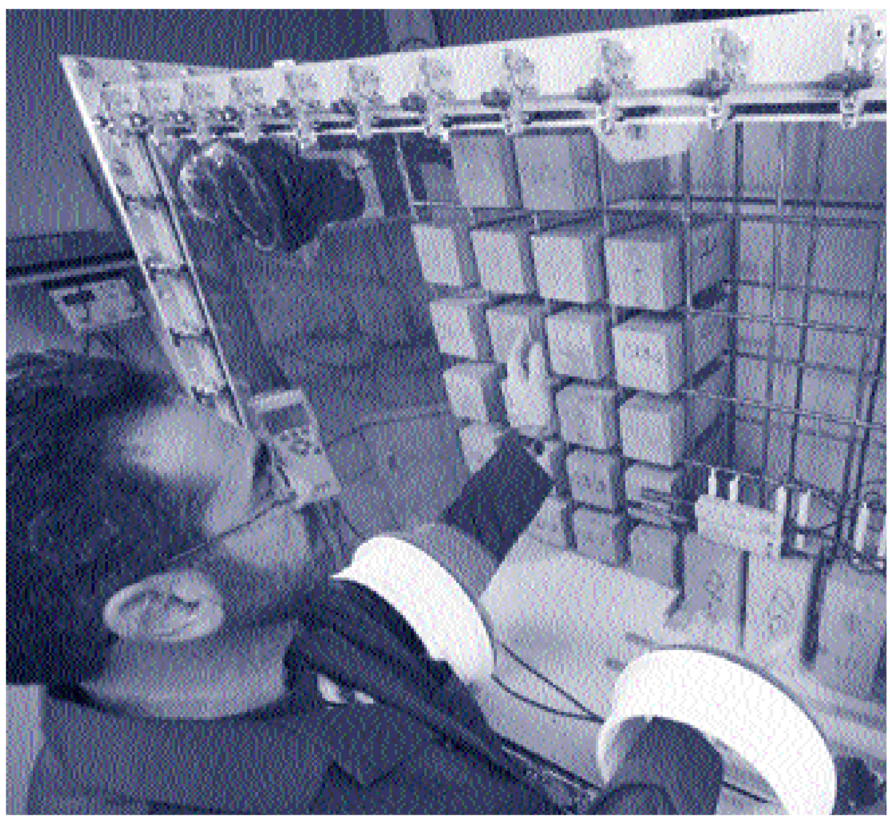
CANMET-MTL performs research on other construction materials where the expertise on metal properties and processes can be used to improve the corrosion resistance of structural beams and reinforcing rod or rebar. In line with NRCan's mandate of sustainable development and public safety, the division continues its program to eliminate or reduce public exposure to lead, particularly in drinking water supplies.

CANMET-MTL successfully developed three copper alloys for domestic plumbing fittings in the 1990s. This expertise was used in an attempt to develop a new dairy alloy and a new standard permanent mould for copper-based alloys.

Advanced Concrete Technology

Supplementary Cementing Materials

De-icing salts: Improving the long-term performance of concrete incorporating SCMs is critical to expanding its use in the construction industry. To this end, investigations directed at increasing the durability of concrete to scaling



In this accelerated carbonation test machine, concrete prisms are exposed to 65% humidity and 3% CO_2 at 23°C to accelerate the diffusion of CO_2 into the concrete. At various time intervals, a slice of concrete is sawn from the concrete prisms and sprayed with a phenolphthalein indicator. The uncoloured zone identifies the carbonation depth.

resistance caused by de-icing salts were completed on a sidewalk test section in Montréal. Recommendations for optimum percentages of SCMs to be used in applications subject to de-icing salts were prepared and sent to project partners in late 2004, and a CANMET-MTL scientist provided these recommendations to consulting and provincial government engineers for the construction of a concrete highway in Edmonton, Alberta. Recommendations will also be given (in 2005) to the ASTM technical committee in charge of the test procedure for the evaluation of the de-icer salt scaling resistance of concrete (ASTM C 672) for possible modifications to the existing test method.

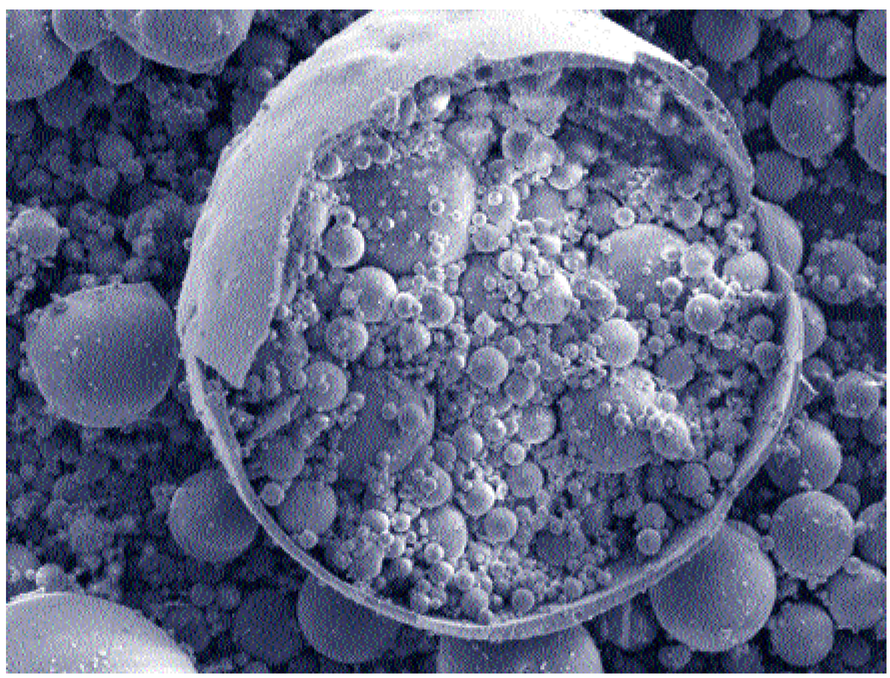
Marine Environments: CANMET-MTL also monitors the performance of test specimens exposed to a marine environment at an outdoor weathering facility in Treat Island, Maine. The latest results on the performance of block specimens with 25 years of exposure, in combination with laboratory investigations undertaken in collaboration with the University of New Brunswick, have shown that the performance of concrete in a severe marine environment is strongly dependent on the quality of the concrete (especially the water-to-binder ratio). Furthermore, this performance can be improved significantly by the use of supplementary cementing materials such as fly ash and slag.

Alkali-Silica Reactivity: Similarly, in a project investigating the resistance of concrete incorporating SCMs to alkali-silica reactivity (ASR), test specimens are monitored annually at NRCan's outdoor weathering facility in Bells Corners, Ontario. The results of the investigations in progress confirm that the performance of SCMs in controlling expansion due to ASR is strongly dependent on the nature and the reactivity level of the aggregates, as well as the composition of the SCMs used. Additionally, some accelerated tests performed in the laboratory were found to reproduce relatively well the long-term performance of concrete specimens exposed outdoors.

Extending the Life of Concrete Infrastructure

Lithium-Based Admixtures: Alkali-silica reaction, which causes expansion and cracking in concrete, is a common factor in reducing the service life of concrete structures. Preliminary results from a project investigating the effectiveness of lithium-based admixtures to prevent ASR in concrete, performed in collaboration with Laval University and Euclid North America, have shown that although lithium-based admixtures have the potential of controlling expansion due to ASR in concrete, the dosage required for efficient control of the reaction is strongly dependent on the nature and reactivity level of the aggregates. Progress has also been made in the development of an accelerated test procedure for lithium-based admixtures to control ASR. These preliminary results have already influenced the recommendations in the Canadian Standards on Concrete (CSA A23.1 and A23.2-04) regarding the use of lithium-based admixtures to control ASR.

High-Calcium Fly Ash and Silica Fume: Comparative field and laboratory testing is in progress to investigate the effectiveness of blends of high-calcium fly ash (ASTM Class C) and silica fume in controlling ASR. Project partners include the Electric Power Research Institute and the Portland Cement Association. The results of this study have shown that the composition of the



A cross-section of a 75-micron-wide fly ash particle – a fine powder by-product emitted by coal-fired electricity generating stations, fly ash has long been championed by CANMET-MTL as a means of improving concrete properties and reducing greenhouse gas emissions.

fly ashes, particularly their calcium oxide and alkali contents, can have a significant influence on the capacity to control ASR expansion. Low-calcium/low-alkali fly ashes were found to be effective in controlling ASR expansion with the aggregates selected when used at replacement levels between 20 and 30%. Much larger proportions of high-calcium ashes (greater than 40%) are required to control expansion due to ASR, which make their use difficult in common practice. The use of small quantities (for example, 5%) of silica fume in combination with such ashes in ternary systems significantly improved their effectiveness in reducing ASR expansion. Progress is being made in the development of an accelerated test procedure for evaluating SCMs to control ASR in concrete.

Alkali-Aggregate Reactivity: An accelerated method for determining the potential alkali reactivity of aggregates is also in development. An inter-laboratory study on the test method was completed. The results, which were presented at the 12th International Conference on Alkali-Aggregate Reactivity in Beijing, China, have shown that the test has the potential to differentiate the various forms of alkali-aggregate reactions in concrete, which has not been done successfully to date with existing AAR tests.

Technology Transfer Activities in India

This $3.5 million project, which began in August 2002, is funded by CIDA ($2.5 million), CANMET-MTL ($600 000), and the Confederation of Indian Industries ($150 000). Completed in March 2005, the various technical and technology transfer activities of the project will contribute to the implementation of CANMET-MTL's HVFAC technology in several buildings and civil infrastructures in India.

Knowledge Dissemination: CANMET-MTL staff travelled to India to monitor progress in seven demonstration projects around the country, to assist in technology adaptation, and to participate in various technology transfer activities. The latter activities took place principally through 12 seminars and workshops that involved more than 2000 participants. Additionally, several short courses were given in five Indian cities with 100 attendees from industry, government and universities.

During the reporting period, a project Internet site containing technical information for use by participating Indian companies was launched. This is an important technology transfer tool since it makes available to participating Indian companies a database of cementing-related properties of Indian fly ashes. This information is critical to the success of the demonstration projects.

Technology Adaptation: HVFAC technology adaptation programs were established in three institutes in India during this period. The purpose was to adapt the technology to Indian materials and climatic conditions, and to generate test data for dissemination to various Indian stakeholders. Technology adaptation programs began at the Central Building Research Institute (Roorkie), the Structural Engineering Research Centre (Chennai), and Bengal Engineering College (Kolkata). A global review of fly ash production in India also began during the reporting period. Collection of state-by-state test results is under way and all information generated in the above activities will be placed on the Internet site.

Demonstration Projects: Five of the seven demonstration projects in India began during the review period. One project, the Bandra-Worli Sea Link in Mumbai, incorporated what is believed to be the largest amount of high-volume fly ash concrete ever used. The Sea Link is an eight-lane, 4.0-km cable-stay bridge that will connect the Bandra and Worli districts of Mumbai (formerly Bombay) across a bay in the Arabian Sea. When completed, the bridge is expected to play a key role in reducing travelling time between the northern and southern parts of the city. In total, the use of HVFAC technology for the Bandra-Worli Sea Link project will result in a saving of approximately 4200 tonnes of CO_2, a remarkable quantity for a single construction project. The following paragraphs describe other demonstration projects:

- Construction of a 2-km road began at Saurashtra University campus in Rajkot (west-central India) and was completed in late 2004. The volume of HVFAC used in this construction project amounts to 2800 m^3 incorporating 50% fly ash and 700 m^3 incorporating 30% fly ash. This project resulted in the reduction of approximately 600 tonnes of CO_2.

- In 2004, real estate developers in Hubli, Karnataka, performed field trials of HVFAC. This group housing project comprises more than 2000 dwellings that will be built in two phases. The applications where HVFAC was used included foundation blocks, bricks and paving blocks in and around one housing unit in the complex. If HVFAC is used on the entire project, the projected reduction of CO_2 emissions will be 18 230 tonnes.

- Road projects with Associated Cement Companies in Delhi are in the final planning process. A 30-metre section of road in Greater Noida, Uttar Pradesh, will be constructed consisting of both control and HVFAC.

Although this demonstration project is small, it is considered important because of the large array of testing planned, including instrumentation for stress and strain measurements, thermal expansions, abrasion, drying shrinkage, and modulus of rupture.

- HVFAC will be used in the construction of an exhibition complex in Bangalore. This project is located in an industrial area that includes three exhibition halls, each with an area of about 10 000 m^2. HVFAC will also be used in concrete-masonry structures, paving blocks, and landscaping. The projected CO_2 reduction on completion is 8250 tonnes.

Other Technology Transfer Activities

National Master Specification: The Government of Canada owns or leases approximately 25 million m^2 of floor space. In a project to facilitate increased use of SCMs in concrete for construction projects supported by Public Works and Government Services Canada (PWGSC), a draft version of best-practice guidelines for concrete incorporating SCMs in buildings and other structures was prepared by CANMET-MTL and selected contractors. The final version of the guidelines was published in December 2004. These guidelines will be incorporated in the National Master Specification for Canada. A series of information seminars, sponsored by Action Plan 2000 on Climate Change, are being held across the country during which the guidelines are presented to designers and practitioners for further implementation and use.

Metals in Construction

Corrosion Resistance

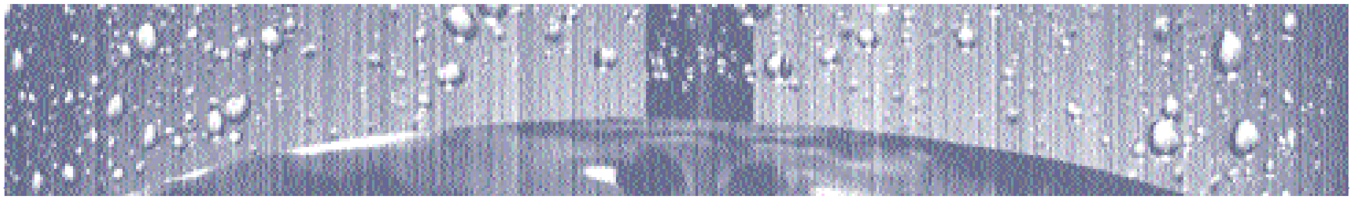
Research for the International Lead-Zinc Research Organization and Teck Cominco on the cracking and subsequent corrosion of galvanized structural steel beams is continuing. It was determined that cracking is caused by a complex interplay of contributing factors of the galvanizing operation. CANMET-MTL evaluated the susceptibility of structural beams to liquid metal embrittlement caused by the composition of galvanizing baths. The results clearly show that impurities are detrimental and make the beams more prone to cracking.

Lead Avoidance in Alloys for Food- and Water-Bearing Applications

Plumbing Fittings: In the mid-1990s, CANMET-MTL developed a lead-free silicon brass alloy for the permanent-mould casting process to minimize lead-contaminated waste sand in foundry operations. An outstanding issue with the development of this new alloy (and one that is common to all plumbing alloys) was the elimination of hard spots that blemish the polished chrome finish. CANMET-MTL determined that these spots are caused by an iron intermetallic whose formation can be avoided by grain refinement. The effect of the grain refiner diminishes, however, with holding time in the furnace. An on-line procedure using commercially available instrumentation was developed to monitor the refiner and make appropriate adjustments. The technology was demonstrated in two foundries.

Dairy Alloy: The chemistry of a new lead-free alloy for use in valves by the dairy and food industries was optimized and casting parameters were established. Compared with conventional materials, the new dairy alloy has good casting characteristics and does not bond to itself, an important property for threaded parts. Further work is required to meet ductility requirements before this alloy can be used commercially.

Moulds for Standards Testing: Both existing ISO and ASTM test bar moulds for the permanent moulding of copper-based alloys produce bars with centre-line shrinkage (a line of porosity down the centre of the bars that affects mechanical properties); therefore, the test results from these bars are unreliable. A new mould design was developed at CANMET-MTL that minimizes this defect. Casting trials of the new design are under way at two companies.



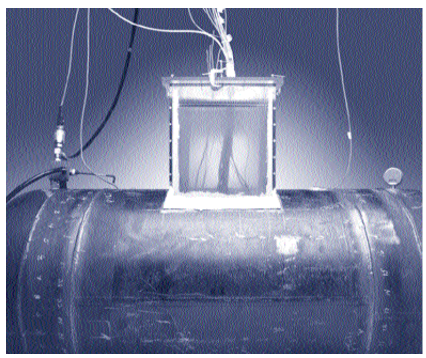
Reliabillity of High-Pressure Oil and Gas Pipelines

The integrity of Canada's oil and gas pipeline infrastructure is important not only because of its vital economic role as a provider of essential energy to Canadians and, through export, to Americans and others, but also because of the public safety and environmental hazards that can result from leaks and ruptures of high-pressure pipelines. Pipelines are susceptible to various forms of corrosion, including stress corrosion cracking (SCC), a phenomenon caused by the combined effects of the environment and stress on steel. Effective control of stress corrosion cracking of Canadian pipelines is therefore both a public safety and an environmental issue.

CANMET-MTL research on pipeline SCC has been a major contributing factor in the development of technologies for managing this type of corrosion. Between 1991 and 1996, there were seven major SCC ruptures in Canada. Since the introduction of measures to manage SCC, this has been reduced to only one failure in the last seven years. During the current review period, CANMET-MTL designed and constructed a unique, full-scale pipe testing facility that is critical to the reliability assessment of modern line pipes for SCC resistance.

Researchers at CANMET-MTL study other factors that influence the integrity and reliability of the materials used in pipelines. These include the effect of construction procedures (such as welding) and the technologies used to monitor, assess and detect defects, impending failures and other problems. This work is based on materials technologies that are used in risk management and in the development of codes and standards. Specifically, CANMET-MTL has expertise in the development of new high-strength steels, the assessment of mechanical and corrosion properties of steels, welding technologies used in pipelines, corrosion protection strategies, defect detection and sizing using advanced non-destructive testing techniques, and the development of software and sensors to detect potential problems.

With the impending construction of high-pressure pipelines in northern Canada and Alaska to meet increasing demand for natural gas, CANMET-MTL re-focused its research direction in 2004 to address special challenges to the construction, operation and maintenance of pipelines in the fragile environment of



An environmental test chamber containing soil is used to simulate in-situ pipeline conditions on a pipeline sample. The chamber surrounds instrumented cracks that measure susceptibility of pipeline steels to stress corrosion cracking.

the North. To help ensure pipeline reliability, CANMET-MTL is also performing R&D on methodologies and procedures that are required to evaluate coatings that will be used in the North, the corrosion behaviour of the steel, fracture control, monitoring techniques, and test methodologies to evaluate the properties of welds that are made in the production of linepipe as well as those made in the field during pipeline construction.

Managing Pipeline Integrity

Corrosion and its inhibition in pipelines are highly complex processes. Pipeline operators must use risk management procedures to balance maintenance costs and corrosion failures. During the reporting period, CANMET-MTL developed several tools to aid in risk management.

Corrosion Management Tools

A computer model to predict the corrosive properties of liquids in pipelines was developed. Validation of another software program (Systematic Treatment of Pitting Sequence [SToPS]) to predict pitting corrosion, a major cause of failure of production pipelines, was also completed. Using SToPS and the condensate software, operators can predict whether, and where in the pipeline, the extent of internal pitting corrosion is a risk to pipeline operation.

The performance of a corrosion inhibitor is greatly influenced by pipeline operating conditions. Accordingly, most improvements to corrosion test methodologies are directed at simulating field environments in the laboratory in a compressed time scale. But simulation of field operating conditions in the laboratory is often problematic. Before the current reporting period, CANMET-MTL developed the Rotating Cage, an apparatus used to evaluate corrosion inhibitors under flow conditions that simulate pipeline operations. Research showed that the Rotating Cage is more accurate than other test methodologies in predicting the field performance of corrosion inhibitors. During the reporting period, a software program, Corrosion Inhibitor Selection Software (CISS), was developed. CISS is used to set the parameters for operating the Rotating Cage Test (and also other non-standardized tests), for interpreting the results, and for selecting the inhibitor. In 2004, new features that integrate the effect of solution concentrations, the compressibility of gases, and cost analysis were added. Companies can now select effective corrosion inhibitors and predict their performance in the field from laboratory experiments.

The Rotating Cage is designed to help select corrosion inhibitors for use in oil and gas production and transmission pipelines, as well as in oil refineries. It can also be used to select materials for pipes and fittings and to assess the effects of flow on the corrosivity of liquids.

Intelligent Systems for Pipeline Infrastructure Reliability

This project successfully developed and validated methods to enhance pipeline infrastructure reliability by on-line monitoring. With support from PRECARN Inc., CANMET-MTL worked with two small companies, Fiber Optic Systems Technology, Inc. (FOX-TEK), specializing in fibre-optic systems, and TISEC Inc., which specializes in structural integrity monitoring, data management and knowledge engineering. The Intelligent System for Pipeline Infrastructure Reliability (ISPIR) uses sensors, fibre-optic communications and data interpretation systems that provide on-line monitoring and inspection of key pipeline elements to evaluate structural integrity.

The ISPIR system has grown to include sensors that monitor pressure and temperature changes, internal corrosion, cracking, and crack propagation. Coupled with data management, the system has adequate sensitivity to cost-effectively detect leaks, buckling, bending, soil movement, and other activities, particularly at critical locations. This technology can be used for real-time detection and monitoring of fault conditions and to generate strain data for prioritizing and scheduling maintenance activities. Unlike other technolgies that are either used periodically or that detect changes at a point, ISPIR monitoring is continuous and detects changes over an extended section of pipeline.

The ISPIR project was completed in March 2004. This technology is most applicable at critical locations and remote areas. It is now in the marketplace and could increase public safety and environmental protection. ISPIR could also be a counter-terrorism measure used to instantly detect any encroachment on a pipeline in a critical area.

The ISPIR system could provide valuable technology for protecting the Canadian investment in pipeline infrastructure, estimated at more than $15 billion, and for ensuring pipeline security, integrity and reliability, as well as energy deliverability. Potential sales of ISPIR technology over the next three years are estimated to be at least $4 million.

Advanced High-Strength Steels for Pipelines

Canadian Technology for Use in Northern Pipelines

Canadian suppliers are likely to benefit from their proximity to the proposed Mackenzie Valley pipeline, which will bring natural gas from the Mackenzie River Delta in the Northwest Territories to markets in Canada and the United States. The 1220-km pipeline will be made of high-strength steel pipe that is externally coated, shipped to the construction sites, and welded together in the field.

Much of the pipe will be Grade X-80, that is, the minimum specified yield strength is 80 000 psi. Because the pipeline will traverse unstable terrain where extensive frost heave and thaw settlement may occur, the design of the pipeline is based on the allowable deformation that can take place from these ground movements. There have been increased worldwide R&D activities related to the design, construction and operation of high-pressure pipelines.

During the review period, CANMET-MTL performed evaluations of high-strength linepipe steels and corresponding weld metal and heat-affected zone regions of pipe seam and field girth welds. The added challenges associated with field girth welding are being addressed in ongoing research that aims to develop testing methodologies and techniques for assessing weld mechanical properties. Maintaining a high level of pipeline system integrity and reliability is an integral objective of this research.

A Fracture Control Plan for High-Strength Steel Pipelines

Prevention of long-running fractures is a primary objective of design and material selection for high-pressure pipelines. As design pressures increase to take advantage of higher-strength pipe, provision of adequate material toughness becomes increasingly critical.

Toughness is traditionally measured using the Charpy impact test. However, modern steels are so tough that the small Charpy specimen is simply bent rather than fractured, making it difficult or impossible to characterize fracture using this test. The current trend is to use larger full-thickness specimens that can be made to fracture in a drop-weight test, and to instrument the test machine so that quantitative measures of toughness such as absorbed energy or crack-tip opening angle (CTOA) can be measured. Only by the development and standardization of such tests will it be possible to measure the fracture resistance of modern pipe and thereby enable adequate material specification and quality control to prevent long-running fractures.

Fast ductile fracture is being studied at CANMET-MTL by computer modelling and by impact testing, using both Charpy and drop-weight tests. Modelling of stress has been completed for small (Charpy-sized) specimens; efforts are now being devoted to micro-mechanical modelling of the fracture process to predict the load at which fracture will occur and the geometry (CTOA) of the propagating crack.

Drop-weight impact testing has demonstrated the viability of a laboratory test to measure material CTOA toughness. Additional work is under way to refine the measurement techniques, using a high-speed video camera, and to quantify the effects of varying crack speed. The results of this research will demonstrate the viability or otherwise of the drop-weight CTOA test methodology in assessing the toughness of high-strength steels.

Technology Transfer: Oil and Gas Pipelines

Banff Pipeline Workshop

With industry stakeholders, CANMET-MTL organizes the Banff Pipeline Workshop every second year to provide an interactive forum where the management of the integrity of Canada's pipeline infrastructure can be discussed. The 2003 workshop "Managing Pipeline Integrity - Two Steps Forward," had 370 participants, representing transmission and production companies, regulators, government agencies, consulting firms, vendors and R&D laboratories. The workshop featured 5 tutorials and the 13 working groups held 27 sessions.

At the workshop, delegates join working groups to discuss current issues in specific pre-established areas and to articulate priorities that, in their view, need to be addressed to advance the management of pipeline integrity. The workshop provides an important forum for the exchange of information among industry stakeholders. Some of the key decisions at the workshop held in April 2003 are summarized below.

Leak Reduction: The Upstream Pipeline Integrity Management Association (UPIMA) of the Canadian Association of Petroleum Producers (CAPP) was formed to help the industry achieve the target, agreed upon at the workshop, to reduce, by 2005, the number of leaks that occur annually in production pipelines.

Internal Corrosion: In the aftermath of the major pipeline accident in El Paso, Texas, agreement was reached at the workshop that internal corrosion of transmission pipelines is an important issue that requires more attention. Topics identified include modelling multiphase flow in transmission pipelines; elimination of water, particularly water with elevated levels of CO_2, in transmission pipelines; and development of methods to establish integrity of pipelines in which inspection pigs cannot be used.

High-Strength Steels: Considering the favourable economics for high-pressure, large-diameter pipelines made using high-strength steels (X-80 and above), the following specific technical challenges related to the use of these steels were identified: compatible fittings, crack arrest design, susceptibility to hydrogen embrittlement, fatigue, and corrosion.

Stress Corrosion Cracks: Methods that can be used in the ditch to size stress corrosion cracks in pipelines are required. The current method used is neither reliable nor cost-effective. The development of a more accurate and less time-consuming method to size stress corrosion cracks will in turn enable industry to develop more accurate models and action plans and to predict susceptible locations and conditions for future SCC growth.

Standards: A risk-based annex to CSA Standard Z662 that will provide a common reference for pipeline integrity engineers is now required, including risk levels and thresholds, with the CSA review process determining the ultimate format and level of quantitative rigor.

Pipeline Integrity Internet Icon (PICon)

CANMET-MTL also provides a useful service to the industry through the provision of relevant technical information on the Pipeline Integrity Internet Icon (PICon) site (www.nrcan.gc.ca/picon). In addition to providing the Summary Reports of all the Banff Pipeline Workshops from 1993 to 2003, the site disseminates information on 10 pipeline-related topics and provides links to universities, companies and R&D laboratories. It also publishes surveys of research progress and specialized articles devoted to summarizing particular recent developments. During the reporting period, surveys on infrastructure reliability and coatings were conducted.

Another feature of the site, the PICon Journal, publishes papers written by acknowledged authorities in the field. The aim is to address the practical needs of operators. A new paper is published monthly and the topic changes annually. Through PICon's on-line bulletin board, readers submit questions and comments to the author, whose responses can be read by all registrants. The theme for 2005 is Northern Pipelines.

Metallurgical Process Improvements

Casting

Cast Irons

"Monday Morning Iron": Castings produced from molten cast iron stored in large holding furnaces (20-100 tons, typically over the weekend) have inferior structures and mechanical properties. CANMET-MTL identified the chemical nature of the problem. Several procedures for restoration were developed and are currently being assessed in two foundries to determine the best practice.

Austempered Ductile Iron (ADI): In partnership with Rio Tinto, CANMET-MTL optimized an austempering heat treatment for thin-wall ductile iron, which results in improved mechanical properties compared with conventional cast irons. The strength is improved by a factor of 2.5. Because of their low weight, thin-wall ADI castings are suitable for many automotive applications.

Ductile (Nodular) Iron: Ductile iron was poured into moulds that contained mixes of natural and insulating synthetic sands to determine the potential minimum thickness for castings. Insulating sands are new and the resultant casting properties are of great interest. Plate castings produced in the insulating sand had reduced graphite nodule counts (but increased size) and were ductile to a thickness of 3 mm. Strength was 30% less, but ductility was four times higher and impact resistance was three times better than similar castings made in natural sand.

Materials for the Mining Industry

Austenitic Manganese Steel: Pulverizing equipment for the mining industry uses austenitic manganese steels for parts subjected to wear and high impact. Castings are initially brittle, but high-impact toughness is achieved by a complex heat treatment. CANMET-MTL developed improved heat treatment processes several years ago and these processes are now used in many foundries. However, it is still difficult to achieve consistent mechanical properties with massive castings because of the rapid cooling that is required. Furthermore, determination of mechanical properties from specimens is expensive because this steel is extremely difficult to machine. During the reporting period, CANMET-MTL developed an on-line technique to identify microstructure and thereby predict mechanical properties at low cost. Critical sections can be tested, re-heat-treated if necessary, and the scrap rate can be reduced to zero.

Industrial Process Improvements

Nozzle Sands

CANMET-MTL conducted trials over the last three years to simulate the performance of nozzles packed with sand that temporarily block the flow of molten steel from ladles or furnaces. Simulations demonstrated that formulations developed by CANMET-MTL for both ladle and nozzle sands are accurate. Reliable opening has been improved to better than 93%. The client (Les Sables Olimag) reports improved sales and an enlarged client base, and has adopted scientific methods for product improvement.

Scrap Steel

CANMET-MTL evaluated samples of scrap steel by determining the amount of steel recovered during furnace melting. This work enabled the client (Gerdau Ameristeel) to determine the true purchase price of steel scrap.

Metal Recycling

Two projects are currently under way to evaluate the “state of the art” of metal recycling and improve the re-use and acceptance of recycled metals. Recycling reduces production times and greenhouse gases, minimizes environmental damage, and lowers energy consumption. The recycling industry requires improved processing technologies, more process automation and control, reduced refractory wear, and cheaper refining agents. Their customers want metals with less included dross or slag, lower levels of dissolved gases, fewer trace elements, and well-defined product specifications to cover these items.

Technologies for Metals Recycling

Six reports addressing scrap separation, refining technologies, and the effect of impurities in the recycling of magnesium, aluminum and steel were released during the reporting period. The reports identified that key technology gaps in recycling are scrap management, sorting and classification. These gaps exist because of the inability of current sorting and refining technologies to adequately separate and clean the variety of scrap produced. The accumulation of impurities due to recycling degrades the metal’s properties; better refining systems are required. Furthermore, the effects of impurities in magnesium, aluminum and steel were discussed, as well as refining technologies for steel, the design of recyclable products, energy efficiency, and potential energy savings from recycling. Other work included a review of the literature on sensors for the detection of metallic impurities in molten and scrap metals, and for the separation of various materials from scrap metal.

Advanced Industrial Sensors and Controls

Advanced Ceramics R&D in Sensors, Actuators and Solar Cells

Sensors and control systems are used in different applications in many industries and manufacturing processes, mining operations, aircraft, vehicles, biomedical devices, power stations, and building infrastructure. These technologies are essential for achieving energy efficiency, reducing greenhouse gases, and improving industrial productivity and product quality through process automation.

During the review period, research and development continued on new or improved gas/chemical sensors, and piezoeletric sensor and actuator materials, processes, and laboratory-scale prototype devices. Novel high-temperature (up to 1000°C) sensors employing solid electrolytes for the detection of oxygen and carbon dioxide were designed, fabricated and tested. Sensors with improved sensitivities and response times were also developed for the detection of methane, propane, carbon monoxide, and ethanol. Additionally, a new emitter diffusion process was developed to produce photovoltaic solar cells that consume 50% less energy than the conventional method, use cheaper equipment and materials, and are suited for high-volume in-line manufacturing.

Non-Destructive Testing Certifying Agency

The Non-Destructive Testing (NDT) Certifying Agency administers and develops programs for the certification of personnel who perform non-destructive testing. The Certifying Agency delivers NDT certification programs through nine permanent examination centres, usually located in Canada's community colleges. The Certifying Agency comprises three administrative and five technical staff and serves 4000 individual clients across Canada.

Under Canadian National Standard CAN/CGSB-48.9712:2000, the NDT Certifying Agency issues certificates in radiography, ultrasonics, magnetic particle, liquid penetrant and eddy current testing to qualified personnel. The Agency issued 642 certificates to 519 persons in 2003 and issued 642 certificates to 531 persons in 2004. The average age of clients is 45. The number of certificates issued annually has remained relatively constant over the last five years. NDT certificates must be renewed every three years. The Agency renewed the certificates of 1265 persons in 2003 and 986 persons in 2004. Each year approximately 180 persons fail to renew. Thus, the number of certified NDT personnel shows a growth rate of about 360 persons per year (9% per year).

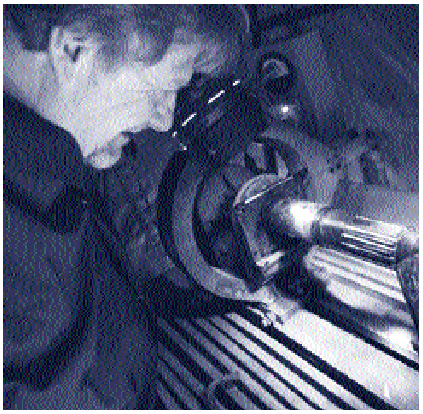
Under contract to the Canadian Nuclear Safety Commission, the NDT Certifying Agency delivers a portion of the Commission's Certified Exposure Device Operator program. In Canada, this certification is mandatory for all inspectors who operate radioisotope cameras used for performing industrial radiography. The NDT Certifying Agency certified 74 operators in 2003 and 68 in 2004.

In 2004, in cooperation with Health Canada, the NDT Certifying Agency developed a program for the certification of operators of portable x-ray fluorescence (XRF) analyzers. Operating in compliance with the provisions of the International Standard ISO 20807:2003, the Agency certified 25 XRF operators in 2004.

A non-destructive testing technician conducts an ultrasonic inspection to check for cracking around bolt holes in the landing gear of this CC144 Challenger aircraft. The same testing can be performed on various parts and components of the aircraft.

Internationally in 2004, the NDT Certifying Agency signed Letters of Cooperation with the Korean Society for Non-Destructive Testing and with the Chinese Society for Non-Destructive Testing. Under a cooperative arrangement with the British Institute of Non-Destructive Testing (BINDT), approximately 18 Canadian holders of NRCan NDT certifications were issued BINDT certificates, allowing them to work in compliance with the European Pressure Equipment Directive.

To better serve Canadians, the NDT Certifying Agency has been working on the development of new programs for visual inspection of industrial components and ultrasonic-thickness gauging of pressure-retaining equipment such as pressure vessels (boilers and heat exchangers) in the power industry. Additionally, the NDT Certifying Agency has been working with the Canadian Aviation Maintenance Council to develop a certification program for aviation-specific applications, and with the Candu Owners Group to develop a certification program for specific applications in the nuclear power industry.



Performing a magnetic particle inspection (MPI) on an aircraft engine spline shaft. MPI is a fast and economical way to detect surface and slightly sub-surface discontinuities in ferromagnetic materials that may render the part unserviceable.

Financial Summary

Revenues and expenditures for the two fiscal years (April 1-March 31) 2003-04 and 2004-05 are shown. During the two-year period, NRCan's A-base funding contributed about 52% of revenues, the Program of Energy Research and Development (PERD), 12%, other government departments (OGD), 19%, and external contracts, 17%. Approximately 27% of revenue from other government departments was flow-through funding for the CIDA projects in India in 2003-04; it was 59% in 2004-05.

	FY 2003-2004	FY 2004-2005
REVENUES		
A-base	8 493 154	7 129 000
PERD	1 783 000	1 956 500
OGD + government programs	2 605 998	3 318 741
AUAF	10 700	0
Collective bargaining	0	492 498
External contracts	2 386 079	2 097 378
Total	**15 278 931**	**14 994 117**
EXPENDITURES		
Salaries (including students)	9 402 046	9 447 812
20% shortfall in salary	157 826	284
Operating	5 119 382	4 691 883
Capital	398 555	736 487
Carried forward deficit	411 058	209 936
Total	**15 488 867**	**15 086 402**
Surplus/deficit	*(209 936)*	*(92 285)*