MATERIALS TECHNOLOGY LABORATORY
REPORT MTL 2003-4(TR)

CURRENT SITUATION OF SCMs IN CANADA

by

N. Bouzoubaâ and B. Fournier

SUMMARY

Action Plan 2000 on Climate Change - Mineral and Metals - Supplementary Cementing Materials (SCMs) is a program with the objective to increase the use of SCMs in concrete production, thus contributing to the reduction of the "CO_2 signature" associated with the production of every cubic metre of concrete. The first step taken by the program is the determination of the current situation of SCMs in Canada namely, production, cost, availability, and current usage and areas of high potential for expanded usage of SCMs in Canada including local barriers as well as guidelines and specifications. This exercise should then lead to an identification of a strategy to increase the use of SCMs in Canada.

The data gathered on the current situation of SCMs in Canada have shown that around 524,000, 347,000, and 37,000 tonnes of fly ash, Ground Granulated Blast Furnace Slag (GGBFS) and silica fume were used in cement and concrete applications in 2001, which represent 11, 90, and 185% of the quantity produced, respectively. For GGBFS, the remaining 10% of the quantity produced was used in the USA, and for silica fume, 17,000 tonnes were imported from the USA and Norway to meet market demand. Fly ash appears to be the only material that is underused and that represents a potential for increased use of SCMs in Canada. For the GGBFS, the quantity produced can be increased if the demand increases.

However, this investigation has shown that there are policy, technical and economic barriers to the increased use of SCMs in Canada. Policy barriers: although these materials have been in the Canadian market for 20 to 30 years, and many projects, including high-profile projects such as Hibernia and the Confederation Bridge, have successfully used high volumes of fly ash and slag, there are still municipalities and provincial agencies that ban or limit the use of fly ash and slag to a certain percentage of replacement for some applications.

Technical barriers: the slower setting times and strength development of concrete incorporating fly ash and slag are limiting the use of these materials in applications that need fast form-work removal. The reduced resistance of these concrete mixtures to the freezing and thawing cycles in the presence of de-icing chemicals is also considered a hurdle. The quality of the fly ash, which is related to the type of coal used for the production of electricity in the thermal power plants, is a concern in the Eastern part of the country.

The economic barriers are not related to the costs of the materials, except for the silica fume, but rather to the costs of transportation and silos storage.

The following are some solutions that were proposed to overcome the above barriers. They can be considered as the basis of a strategic plan for Action Plan 2000 to increase the use of SCMs in the construction market in order to decrease the CO_2 emissions related to the use of Portland cement:

- Develop clear specifications and national guidelines for the use of SCMs in cement and concrete. The guidelines must be stronger and simpler than those currently in use, must be agreed upon by all interested parties and must be issued under the auspices of the Canadian Standards Association (CSA).
- Organise workshops in different cities of Canada with a major effort being made to get all the significant specifying authorities, concrete suppliers, users and engineering inspection and testing companies of each city to attend. The prime objective of the workshops would be to adopt the above developed guidelines in the provinces (with modifications if necessary).
- Organise forums to discuss ways to resolve technical issues, including developing a more rational and consistent approach to the use of SCMs under different exposure conditions.
- Support R&D programs in resolving technical barriers.

It was also mentioned that the cement industry should be encouraged to produce more blended hydraulic cements (as is the case in the province of Quebec) to overcome the technical issue related to the quality control of fly ash, and also to overcome the economic barriers related to the costs of transportation and silos.

LABORATOIRE DE LA TECHNOLOGIE DES MATÉRIAUX
RAPPORT LTM 2003-4(TR)

SITUATION ACTUELLE DES AJOUTS CIMETAIRES AU CANADA

par

N. Bouzoubaâ et B. Fournier

RÉSUMÉ

Le Plan d'action 2000 sur le changement climatique – Minéraux et métaux – Programme d'ajouts cimentaires est un programme dont l'objectif est d'accroître l'utilisation des ajouts cimentaires dans la production du béton, contribuant ainsi à la réduction des émissions de CO_2 associées à la production de chaque mètre cube de béton. La première mesure prise dans le cadre du programme est la détermination de la situation actuelle des ajouts cimentaires au Canada, c'est-à-dire la production, le coût, la disponibilité et l'utilisation actuelle de ces matériaux ainsi que les domaines qui offrent un potentiel élevé pour l'utilisation accrue des ajouts cimentaires au Canada, en tenant compte des obstacles locaux ainsi que des lignes directrices et des spécifications. Cet exercice devrait alors mener à la détermination d'une stratégie en vue d'accroître l'utilisation des ajouts cimentaires au Canada.

Les données recueillies sur la situation actuelle des ajouts cimentaires au Canada ont montré qu'environ 524 000, 347 000 et 37 000 tonnes de cendres volantes, de GGBFS (laitier de haut fourneau granulé broyé) et de fumées de silice ont été utilisées dans des applications faisant appel au ciment et au béton en 2001, ce qui représente 11, 90 et 185 % de la quantité produite, respectivement. Dans le cas du GGBFS, les 10 % restants de la quantité produite ont été utilisés aux États-Unis et pour les fumées de silice, 17 000 tonnes ont été importées des É.-U. et de la Norvège pour répondre à la demande du marché. Les cendres volantes semblent être le seul matériau qui soit sous-utilisé et qui offre des possibilités pour accroître l'utilisation des ajouts cimentaires au Canada. Dans le cas du GGBFS, la quantité utilisée peut être accrue si la demande augmente.

Toutefois, cette recherche a montré qu'il existe des obstacles techniques, économiques et politiques à une utilisation accrue des ajouts cimentaires au Canada. En ce qui concerne les obstacles politiques, bien que ces matériaux aient été sur le marché canadien depuis 20 ou 30 ans, et que de nombreux projets, notamment des projets ayant été l'objet de beaucoup de publicité comme Hibernia et le Pont de la Confédération aient utilisé avec succès de grands volumes de cendres volantes et de laitier, certaines municipalités et certains organismes provinciaux interdisent encore l'utilisation des cendres volantes et du laitier ou limitent cette utilisation à un pourcentage restraint de remplacement dans certaines applications.

Dans le cas des obstacles techniques, le temps de prise et le développement plus lent de la résistance du béton incorporant des cendres volantes et du laitier limitent l'utilisation de ces

matériaux dans les applications pour lesquelles les coffrages doivent être enlevés rapidement. On considère aussi que la résistance de ces mélanges de béton aux cycles de gel-dégel en présence de sels-fondants constitue un obstacle. La qualité des cendres volantes, qui est liée au type de charbon utilisé pour la production de l'électricité dans les centrales thermiques, constitue une source d'inquiétude dans l'Est du pays.

Les obstacles économiques ne sont pas liés au coût des matériaux, sauf dans le cas de la fumée de silice, mais plutôt aux coûts du transport et des silos additionnels utilisés pour entreposer les ajouts cimentaires.

Voici certaines solutions qui ont été proposées pour surmonter les obstacles mentionnés plus haut et qui peuvent être considérées comme un plan stratégique dans le cadre du Plan d'action 2000 en vue d'accroître l'utilisation d'ajouts cimentaires dans le marché de la construction afin de diminuer les émissions de CO_2 liées à l'utilisation du ciment portland:

- Élaborer des spécifications/lignes directrices claires, plus strictes et plus simples, pour l'utilisation d'ajouts cimentaires dans le ciment et le béton, aux fins d'approbation par toutes les parties et de publication sous les auspices de la CSA;
- Organiser des ateliers dans différentes villes du Canada et déployer tous les efforts nécessaires pour garantir la participation des organismes de normalisation et autres autorités compétentes, des fournisseurs de béton, des utilisateurs et des sociétés d'inspection et d'essai techniques, dans chaque ville. L'objectif principal des ateliers serait l'adoption, dans les provinces, des spécifications/lignes directrices dont il est question au paragraphe précédent (après modification, le cas échéant);
- Organiser des tables rondes afin de discuter des façons de résoudre les problèmes techniques, y compris l'élaboration d'une méthode plus rationnelle et plus uniforme d'utilisation des ajouts cimentaires selon des conditions d'exposition différentes;
- Appuer les programmes de R&D pour la résolution des problèmes techniques.

On a aussi mentionné qu'il faudrait encourager l'industrie cimentière à produire davantage de ciment mélangés (comme c'est le cas dans la province du Québec) afin de surmonter les problèmes techniques liés au contrôle de la qualité des cendres volantes et aussi pour surmonter les obstacles économiques liés au coût du transport et des silos.

TABLE OF CONTENTS

BACKGROUND

Action Plan 2000 on Climate Change - Mineral and Metals - Supplementary Cementing Materials (SCMs) is a program with the objective to increase the use of SCMs in concrete production, thus contributing to the reduction of the "CO_2 signature" associated with the production of every cubic metre of concrete. Specifically, it is proposed to optimize the use of SCMs, recycled materials and other industrial by-products in concrete for every particular application in full compliance with performance requirements. The first step taken by the program is the determination of the current situation of SCMs in Canada namely, production, cost, availability, and current usage and areas of high potential for expanded usage of SCMs in Canada including local barriers as well as guidelines and specifications. This exercise should then lead to an identification of a strategy to increase the use of SCMs in Canada.

ICON/CANMET acted as the main contractor for the work and hired a consultant from each of the regions of Atlantic, Quebec, Ontario, Prairies, Alberta, and British Columbia (BC) to gather the information listed below (1-6). ICON/CANMET prepared a survey questionnaire to assist the consultants with their mandate. The questionnaire was formatted in a manner conducive to find answers to the following:

- Determination of current production levels of all SCM resources in each region of Canada.
- The quantity of SCMs imported into Canada for construction and other uses;
- Identification of the uses of SCMs in various applications and the quantity of these materials used as SCMs in such applications;
- Assessment of potential for beneficiation of the materials that do not meet the current standards for use as SCMs;
- Existence of local barriers in the regions, including policy, technical and economic barriers, against the utilization of SCMs in construction and other uses;
- Existing specifications and guidelines for SCMs used by various organizations ranging from the Canadian Standard Association (CSA) to the various local municipalities across Canada;
- Market analysis of SCMs usage in the different regions, including current applications, tonnage used, cost of cement, SCMs and other concrete materials at various locations, suggestions for increased use of SCMs in localized areas and ways to overcome the existing barriers;
- Assessment of potential sources of SCMs that are not exploited at present, but might have applications in the future.

The various regional reports were then reviewed for the preparation of this summary report on the global situation about the production and use of SCMs across Canada.

DEFINITIONS

The following are the definitions of the various materials used in this report.

Binary Blended Hydraulic Cement – A product obtained by blending Portland cement and a single supplementary cementing material or by intergrinding Portland cement clinker, and a single supplementary cementing material to which the various forms of calcium sulphate, limestone, water, and processing additions may be added.

Blended Hydraulic Cement – A product consisting of:

1. The blending of Portland cement and one or more of granulated blast-furnace slag, fly ash, or silica fume; or

2. The intergrinding of Portland cement clinker and one or more of granulated blast-furnace slag, fly ash, or silica fume to which the various forms of calcium sulphate, limestone, water, and processing additions may be added at the option of the manufacturer.

Cementing Materials – See Cementitious materials

Cementitious Material - Portland cement, blended hydraulic cement, supplementary cementing materials, masonry cement, and mortar cement, for example, used as binders to make concrete or mortar.

Fly Ash – the finely divided residue that results from the combustion of pulverized coal and that is carried from the combustion chamber of a furnace by exhaust gases. Fly ash is classified in Canada as F, CI, or CH by its calcium oxide content. Fly ash can be used as a pozzolan or cementing material in concrete.

Granulated Blast-Furnace Slag – the glassy granular material formed when molten blast-furnace slag is rapidly chilled.

1. Granulation may be achieved by immersing the molten slag in water, by the palletizing process, or by other satisfactory methods that will ensure a high percentage of glass or vitrification. This may be accomplished in the initial melt or after remelting air-cooled slag.

2. Small percentages of silica and alumina may be added while the slag is molten to enhance desired characteristics.

Ground Granulated Blast-Furnace Slag – a result of grinding granulated blast-furnace slag to which the various forms of calcium sulfate, water, and processing additions may be added at the option of the manufacturer.

Metakaolin – highly reactive pozzolan made from kaolin clays.

Natural Pozzolans – a natural material that may also be calcined and/or processed; for example, diatomaceous earth, metakaolin, rice husk ash, volcanic ash, or calcined shale.

Portland Cement – a product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates to which various forms of calcium sulphate, limestone, water, and processing additions may be added at the option of the manufacturer.

Pozzolan – a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts at ordinary room temperatures with calcium hydroxide, released by the hydration of Portland cement, to form compounds possessing cementing properties.

Silica Fume – the finely divided residue, resulting from the production of silicon, ferro-silicon, or other silicon containing alloys, that is carried from the burning area of a furnace by exhaust gases. Silica fume is commonly used as a pozzolan in concrete, and especially in high-performance concrete.

Supplementary Cementing Material – a material that, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both.

Ternary Blended Hydraulic Cement – a product obtained either by blending Portland cement and a combination of any two supplementary cementing materials or by intergrinding Portland cement clinker and a combination of any two supplementary cementing materials to which the various forms of calcium sulphate, limestone, water, and processing additions may be added.

SUPPLEMENTARY CEMENTING MATERIALS (SCMs)

Supplementary cementing materials are materials that when used with Portland cement contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity or both. Typical examples are fly ash, ground granulated blast furnace slag (GGBFS) and silica fume. The benefits derived from the use of SCMs in the cement and concrete industries can be divided into three categories: engineering, economic and ecological benefits (7).

ENGINEERING BENEFITS

First, the incorporation of finely divided particles into a concrete mixture tends to improve the workability, and to reduce the water requirement at a given consistency (except for materials with a very high surface area, such as silica fume). Secondly, in general, there is an enhancement of ultimate strength, impermeability, and durability to chemical attack. Thirdly, an improved resistance to thermal cracking is obtained due to the lower heat of hydration of blended hydraulic cements and increased tensile strain capacity of concrete incorporating SCMs.

ECONOMIC BENEFITS

Typically, Portland cement represents the most expensive component of a concrete mixture, as it is a highly energy-intensive material. On the other hand, most of the supplementary cementing materials are industrial by-products, which require relatively little or no expenditure of energy for their use as an SCM. The cost of fly ash and slag is therefore significantly less than that of Portland cement. However, for locations far from the sources of these materials, the use of SCMs based on the economic benefits becomes very slim due to the transportation costs.

ECOLOGICAL BENEFITS (GHG EMISSIONS)

Every ton of Portland cement production is accompanied by a similar amount of carbon dioxide as a by-product, which is released into the environment. Therefore, for every quantity of Portland cement replaced by SCMs, there is a saving of CO_2 by almost the same quantity. While fly ash and silica fume, in general, do not necessitate any further energy-intensive processing to be used as SCMs, slag on the other hand needs grinding that releases around 0.07 tonnes of CO_2 for every ton of GGBFS produced (8). The transportation of these materials to the job site also marginally increases the CO_2 emissions related to their use. A study on this subject has shown that the transportation (truck and rail) of 1 ton of SCMs for a distance of 1000 km releases around 0.022 tonnes of CO_2 (9). All these parameters should then, be taken into account when praising the ecological benefits of SCMs.

SCMS CURRENTLY BEING USED IN CONSTRUCTION IN CANADA

Four types of SCMs are currently being used in Construction sector in Canada; these are fly ash (all the three CSA classes i.e., F, CI and CH), ferrous and non-ferrous slag, silica fume and metakaolin. Fly ash and silica fume are used in all parts of Canada, ground granulated blast furnace slag (GGBFS) is mainly used in Ontario and occasionally in Quebec and the Prairies, non-ferrous slag was recently used in Alberta, and metakaolin is used in small quantities in BC. Natural pozzolans such as natural shales, diatomaceous earth and pumice are also found in BC and Nova Scotia but they are not used for concrete manufacturing. In BC, attempts were made to bring these materials to commercial viability in the late 1970s and through the 1980s, but with limited success. In Nova Scotia, these materials have not been exploited to date. Table 1 presents the SCMs currently used in Canada, their sources, and the period of time these materials have been in the market.

PRODUCTION OF SCMS IN CANADA

Three of the four types of SCMs that are being used are produced in Canada. These are fly ash, slag and silica fume. Metakaolin is being imported in small quantities from the USA. Table 2 gives the quantities of these SCMs being produced in Canada during the year 2001; it also gives the quantities that are potentially useable as SCMs in concrete construction, i.e. without any major processing, such as grinding or removal of carbon, prior to their use as SCMs. However, it is understood that some fly ashes need classification (i.e. separating the fine and the coarse particles) for acceptance as an SCM.

It should be noted that all the blast furnace slag is produced in Ontario, the silica fume is produced in Quebec and more than 60% of the fly ash is produced in Alberta. At the present, most of the fly ash potentially useable as SCMs is produced in Saskatchewan and Alberta.

Figure 1 shows the map of Canada with the locations of the potentially useable SCMs that are produced in the country. It is understood that some fly ash and silica fume that are used in Canada are produced elsewhere and therefore, do not appear on the map.

USES AND QUANTITIES

The following sections refer to the SCMs use in applications including quantities site-batched as an ingredient of concrete, quantities in blended cements, in kiln feed and others.

SCMS USE IN CONCRETE APPLICATIONS

Concrete Production in Canada

The Ready-mixed concrete Association of Ontario (RMCAO) estimates that in 2001, 21.342 million m^3 of ready-mixed concrete were produced in Canada. For 2002, a 0 to 2% increase was first anticipated; however, at this point it looks like the actual volume of concrete produced was about 0.5% lower than in 2001. Beyond 2002, RMCAO projects a 4.5% increase in 2003, a 3% increase in 2004, and a modest increase of 0.5% in 2005.

The figures presented in Table 3 are a composite of information provided by the ready-mixed concrete associations and the major ready-mixed concrete and concrete product suppliers in the different regions of Canada.

Concrete Applications

The main applications of concrete in Canada are summarized in Table 4.

Residential mainly includes ready-mixed concrete supply to applications such as: basement walls and floors, driveways, steps, sidewalks, etc. *Residential* would also include a small amount of concrete products such as: paving blocks, retaining walls, masonry blocks, etc.

Commercial/industrial/institutional mainly includes concrete supplied to applications such as: high-rise structures, parking structures, commercial building foundations and slabs-on-grade, industrial warehouse floors and tilt-up, governmental institutions, and a relatively small amount of concrete products such as masonry blocks.

Infrastructure would be comprised mainly of applications such as: roads pavements, bridges median barriers, curb and gutters, bus-stands, bridges, storm water drains and a smaller quantity of concrete products such as catch basins, utility vaults, manholes etc. *Infrastructure* would also include precast products such as I-beams, T-shaped girders etc. It should be noted, however, that the quantity of the concrete used in *Infrastructure* presented in Table 4 might be underestimated. In fact, some consultants divided the concrete applications into three classes, i.e. *residential, structural and others*; therefore, it was impossible to know the exact quantity of concrete used in *infrastructure* in that region. In that case the quantity used in *structural* applications was totally included in the *Commercial/industrial/institutional* application.

Special concrete applications, which represents only a small fraction of the market, would include applications such as high-performance concrete, roller-compacted concrete, self-compacted concrete, shotcrete, fibre reinforced concrete, repair materials, etc.

Other applications were not defined by some consultants.

Figure 2 shows that 44% of the concrete is produced in Ontario, 22% is produced in Quebec. Alberta and British Columbia combined for 25% and the rest is produced in Atlantic Canada and the Prairies (9%).

Various Concrete Applications of SCMs

Table 5 shows the quantities of SCMs used in the various applications of concrete across Canada.

Ready-Mixed Concrete

SCMs have been used in a wide range of concrete applications ranging from the low 15 to 20 MPa concrete for residential housing basements to special high-performance and/or high-strength concrete applications.

Fly ash is generally used in all concrete in Atlantic Canada with the exception of Newfoundland (due to transportation costs). The amount of fly ash used ranges from 10 to 25% of the mass of the total cementitious materials. Due to the decreased set time, particularly in cold weather, less fly ash is used in winter than in summer.

In Quebec, SCMs are used mostly in the mining sector or in concrete applications through blended hydraulic cements. Only a small amount of Class F ash is being used in residential concrete.

In Ontario, RMCAO (Ready-mixed concrete Association of Ontario) estimates that about 60% of the contractors use SCMs in production of ready-mixed concrete. In warm weather during the summer months they use up to 25% fly ash or 40% GGBFS. During the colder months of the year, because of the slower setting time of the SCMs-containing concrete, the GGBFS and fly ash usage typically drops to about 10 to 15%.

In Manitoba, Saskatchewan and Alberta, 80 to 90% of the concrete produced contains fly ash, and the fly ash quantities used range from 10 to 40% by mass of cement depending on the application. For example, much of the concrete used in residential construction contains between 10 and 25% fly ash by mass of cement. In contrast, the percentage of fly ash used in many infrastructure applications ranges from 0 to 15% by mass of cement. Several provincial and municipal specifying authorities either totally prohibit the use of fly ash in infrastructure applications or limit the amount that can be used to no more than 15%. This will be discussed in the section dealing with technical barriers.

In British Columbia, up to 25% of cement replacement by fly ash is commonly used today. Usage is higher in the Lower Mainland. For the interior, usage is lower due to the transportation factor increasing the cost as delivered to a concrete plant. However, percentage replacements are reduced, or sometimes eliminated, in winter concrete where early strength is important for form removal/stripping and finishing schedule. At least 90% of the concrete produced in ready-mixed concrete plants will have some level of fly ash replacement in warmer weather.

Concrete Products and Pre-Cast

In general, producers of concrete products do not like to use SCMs due to the slow initial set and strength development of concrete incorporating such materials, as the concrete products process (batching, casting, curing, demolding) is usually running on a 24-hour schedule and any slow-down affects the production efficiency and cost competitiveness. However, in Ontario, 30,000 to 40,000 tonnes per year of GGBFS is usually used in the manufacture of concrete products and precast concrete elements. In Saskatchewan, Manitoba and Alberta, concrete products such as concrete blocks, paving stones, retaining walls, sound barrier walls, utility vaults, concrete pipes, etc. include an average of 15% of fly ash.

In British Columbia, some large plants have used up to 25% cement replacement by fly ash in concrete products strictly for reasons of economy. One company has experimented with up to 50% cement replacement by fly ash in regular pre-cast production and achieved adequate early strength. They found that they could use up to 30% by modifying their curing cycle and slightly increasing the total cementing materials factor. The 30% fly ash concrete was used in prestressed precast concrete beams supplied to one of the Millennium Lines Stations (Skytrain).

An interesting recent development is the recognition of the potential for DEF (Delayed Ettringite Formation) in accelerated cured pre-cast concrete (10). The addition of SCMs may mitigate DEF in pre-cast (6).

Reasons for the Use of SCMs in Concrete

The reasons for the use of SCMs in concrete range from a purely economic reason to a mandatory reason. In Atlantic Canada, for example, many quarries contain meta-sediments which are alkali-aggregate reactive (AAR). The use of fly ash or other SCMs becomes mandatory in this case to reduce the risk of premature concrete deterioration due to AAR. The other benefits are cost savings to the concrete producer and lower pumping costs due to increased workability.

In Ontario, the main reasons for using SCMs, apart from the lower costs, are the performance enhancing aspects. Fly ash is used in various concrete applications because of improvement in workability, reduction of heat-of-hydration, increase in water tightness and ultimate strength, and enhanced resistance to sulfate attack and to alkali-aggregate reaction. On the other hand, slower strength development and changes in bleeding that can lead to plastic shrinkage cracking are of concern. GGBFS, like fly ash, is effective in reducing the temperature rise in large concrete pours (although not as effective as fly ash in that regard) and in improving the durability of concrete by countering the effects of alkali-aggregate reactivity and sulfate attack. Silica fume (SF), mainly in the form of 10SF blended hydraulic cement, is used wherever high strength and low permeability are required.

In the Prairies, the main reasons for the use of fly ash are once again the cost savings, the reduction of heat of hydration and the mitigation of sulphate attack in concrete exposed to sulphate bearing soils or ground water. In Alberta, fly ash is used for the above-mentioned reasons and also to mitigate the effects of AAR. Silica fume is used in Alberta in concrete bridge-deck overlays and in pre-cast concrete bridge components for high-early strength development.

In British Columbia, SCMs are mainly used for economy, and enhanced workability and durability (alkali-aggregate reaction and sulphate attack).

Table 5 shows that approximately 450,000 tonnes of fly ash, 216,000 tonnes of slag and 3,350 tonnes of silica fume were used in concrete applications across Canada in 2001. These represent about 20%, 55% and 17% of the quantities of fly ash, GGBFS and silica fume produced and potentially useable as SCMs. It should be noted that these figures do not include the quantities of SCMs used in concrete applications through blended cements.

If we assume that each m^3 of concrete used in residential, commercial/ industrial/ institutional**,** and infrastructure applications contains, on average, 250 kg, 300 kg and 350 kg of cementitious materials, respectively. The average percentage of cement replacement by SCMs in each application is then 9.5%, 10.5% and 13%. However, it should be noted that in infrastructure applications, the fly ash and slag are mostly used in pre-cast elements and efforts need to be made to increase their use in the other infrastructure applications.

Figure 3 shows that most of the fly ash used in concrete applications was used in Western Canada where fly ash is produced abundantly. Similarly, all the slag used in concrete was used in Ontario. However, for silica fume, it was used mostly in Alberta and the Prairies and a small amount was used in British Columbia. In Eastern Canada and especially in Quebec where silica fume is produced, this material is often used in blended hydraulic cements.

SCMS USE IN BLENDED HYDRAULIC CEMENTS

Blended hydraulic cements still constitute a very small portion of the total cement production in Canada. The concrete industry generally prefers to incorporate SCMs, especially fly ash and GGBFS, into the concrete mixtures on their own at the batching plant, as it gives them more flexibility in concrete mixture proportioning. Silica fume, due to the difficulties in its handling, is the SCM material that is found more often in the blended hydraulic cements. The use of silica fume in blended hydraulic cement also assures a better dispersion of the material in concrete. Because silica fume is produced in Quebec, in general, blended hydraulic cements are commonly produced and used in eastern Canada. The total volume of blended hydraulic cements produced across Canada is around 2% of the total cement production. Silica fume blended hydraulic cements represent about 70% of the blended hydraulic cements produced across the country, while the balance include ternary (slag-silica fume and fly ash-silica fume) (~ 20%), and other binary (fly ash or GGBFS) (~10%) blended hydraulic cements. Table 6 shows the different blended hydraulic cements produced in Canada.

Approximately 19,000 tonnes of silica fume was used in blended hydraulic cements in 2001. For the year 2002, about 22,000 tonnes of silica fume, 16,000 tonnes of slag and 6,000 tonnes of fly ash were expected to be used in the production of blended hydraulic cements, mostly in Quebec and Ontario.

Blended Hydraulic Cements Applications

Table 6 presents the quantities of blended hydraulic cements produced in Canada, and Table 7 summarises the type and quantities of blended cements used for various applications across Canada.

Silica Fume Blended Hydraulic Cements

High Performance Concrete: The main application for silica fume blended hydraulic cements is in high performance concrete (HPC). Such concrete is used in demanding applications, anywhere where the long-term durability (> 100 yrs.) is paramount, where high compressive strength (50 MPa and higher) and/or low permeability (< 1000 Coulombs at 28 days) are required. Secondary benefits due to the use of SF blended hydraulic cements cited include improved resistance to sulphate attack, freeze/thaw, and alkali-aggregate reaction. HPC is usually used in infrastructure applications such as bridges, bridge decking and deck overlays, parking garages and in structural applications such as high-rise construction.

Shotcrete: Because of the significantly improved adhesive and cohesive characteristics of SF-containing cement, this has been found to work well in shotcrete applications. The rebound is reduced, reportedly, by up to 50%, and it is possible to apply it in layers of up to 200 mm thickness. Thus, the number of layers required to build the desired shotcrete thickness might be reduced, resulting in a more efficient, lower cost application.

Roller compacted concrete (RCC): RCC is increasingly popular not only in dam construction, but also in flat-paving areas (airports, marshalling yards, container terminals and similar applications), where high-wheel loadings demand high-compressive strength, resistance to abrasion and resistance of freeze/thaw over a long lifespan at a relatively low-initial cost. SF blended hydraulic cements have been used in some RCC projects.

Other applications: SF blended hydraulic cements also bring some advantages to the precast concrete industry, where faster early strength development, in order to maintain the desired production cycle, is important. Traditionally, high early-strength Portland cement (CSA Type 30) and steam curing is used in the pre-cast industry. Type10SF cement also provides an alternative.

Cement board producers have also experimented with the use of silica fume and 10SF cements for the same reasons. Since such boards are generally reinforced with PVC-coated glass scrims, the alkali-scavenging properties of silica fume can provide an additional benefit of preventing the alkali attack of glass, and thus improving the long-term durability of the boards.

Combinations of 75% of CSA Type 10 cement and 25% of Type 10SF blended hydraulic cement are used frequently in sidewalks in the city of Montreal. This mixture has proven to be very effective in producing durable sidewalks.

Ternary Blended Hydraulic Cements (Fly Ash-Silica Fume, Slag-Silica Fume)

They are used in applications where the durability and also better pumpability and less heat-of-hydration are required.

Fly Ash and GGBFS Blended Hydraulic Cements

As shown in Table 6, a small amount of this type of blended hydraulic cement has been produced; it was supplied mainly to smaller rural ready-mixed concrete producers with only one silo and also to the mining industry for various uses.

SCMs USE IN OTHER APPLICATIONS

Table 8 presents the quantity of SCMs used in other applications. However, it should be noted that the quantities given in the table might be underestimated since it was difficult to get this information in some regions. The following are other applications in which SCMs are being used.

Grouts, Mortars, Repair Products

The adhesive and cohesive characteristics that silica fume imparts on grouts, mortars, and repair products, resulting in improved bond to the substrate is the main reason for its use in this application. Additional benefits include, of course, high-early strength and increased durability, as well as resistance to wash-out, which affects the use of repair materials in underwater applications. Fly ash and slag are also used in grouts for increasing fluidity and performance.

Mining Applications

The mining industry is a large user of cement, concrete and SCMs too. For instance, silica fume in dry-bag is commonly used for shotcreting applications in mine tunnels and shafts. It is the mining backfill, however, that uses large amounts of SCMs. About 50,000 and 120,000 tonnes of fly ash and slag, respectively, are consumed every year in mining applications in Quebec and Ontario. SCMs are also used in mines in western Canada but the amount has not been determined.

Masonry and Oil Well Cements

In British Columbia, masonry cements traditionally contained significant amounts of fly ash. As such, it was a blended hydraulic cement. Today, masonry cement is replaced with "Mortar

Cement" (Type S in CSA A8). It is expected that it contains some fly ash but no numbers are available here. In Alberta, about 12,000 tonnes of silica fume are annually used in oil well cement.

USE OF SCMs AS PORTLAND CEMENT RAW MATERIAL

Fly ash and slag are used quite extensively as a part of kiln feed in the production of Portland cement in Ontario. It is estimated that about 264,000 tonnes/year of fly ash is used in Ontario for this application. It was also mentioned that in Alberta, fly ash is used as raw material for the production of Portland cement, but for reasons of confidentiality, the quantity is unknown. In British Columbia, about 80,000 tonnes per year of fumed smelter slag are used as raw feed for Portland cement production, primarily for the iron content.

WHICH TYPE OF SCM TO USE

When different types of SCMs are available, such as Class F fly ash, Class CI fly ash, Class CH and GGBFS, the decision to select one or another is generally made on the basis of availability, price, real or perceived technical advantages/disadvantages, and past experience. In Atlantic Canada, the Prairies and Alberta, fly ash is the dominant or most (or sometimes only) readily available SCM; also, since it is by far the cheapest SCM available on local markets and has the longest history of use, it is the material of first choice in those regions. It should be mentioned that fly ash in Atlantic Canada is no longer considered as useable as SCM. In late 2001, the thermal power plants changed the coal used for the production of electricity to petcoke. This resulted in the production of fly ash with high carbon content (12 to 16%). The fly ash presently used in Atlantic Canada is imported from the USA.

In Ontario, where fly ash and GGBFS are commonly available, there is a general preference to use slag as opposed to fly ash. This is because GGBFS is widely available in the province, Class F fly ash (the most readily available fly ash in Ontario) is of relatively low quality, with high LOI and alkali contents, and GGBFS allows the concrete producer higher cement substitution than it would normally be permitted with fly ash.

In Quebec, where SCMs are more commonly used through blended hydraulic cements, it was mentioned that ternary blended hydraulic cements will most likely be more extensively used in the future than silica fume blended hydraulic cement due to better performance achieved by the former. However, it was also mentioned that in late fall and winter, silica fume blended hydraulic cement will replace ternary blended hydraulic cements to accelerate strength gain and obtain improved short-term performance.

Silica fume is mainly used when required by specifications, or to produce special concretes such as high-strength concretes, high-performance concretes, or wash-out resistant concretes. Therefore, silica fume does not compete directly with fly ash and GGBFS, and actually shows synergistic effects when used in concrete in combination with fly ash or GGBFS.

FIELD SUCCESS/ACHIEVEMENT WITH SCMs

The following are examples of field success with SCMs in concrete across Canada.

ATLANTIC CANADA

In Atlantic Canada, history has shown that a superior concrete with enhanced technical properties has been achieved with the use of fly ash (1). Several structures such as Park Lane Hotel/Office Complex and Purdys Wharf Development in Halifax have been constructed with structural elements containing 56% of fly ash by mass of total cementitious material (11). The Hibernia offshore platform and the Confederation Bridge are two good examples of the use of SCMs in concrete. In the Hibernia structure, 8.5% of silica fume, superplasticizer and combination of normal and lightweight aggregates were used to obtain a concrete that would withstand many design and placing constraints (12). The Confederation Bridge was designed for 100 years service life. To achieve such a service life, different concretes made with silica fume blended hydraulic cement and fly ash content ranging from 10 to 30% (by weight of the total cementitious materials) were developed to build the different structural elements (13, 14). Roller compacted concrete dam was build in Nova Scotia using high-volume fly ash concrete (56% fly ash content). The decision to use this type of concrete was based on economical considerations for the option studied (15).

QUEBEC

As mentioned above for Quebec, SCMs are mostly used through blended hydraulic cements. These blended hydraulic cements were successfully used in many concrete applications, especially in infrastructure applications such as bridges, bridge decks, overpasses and pavements. Among these, are Viaduc Ville St-Laurent, overpass Edward Montpetit and many concrete pavements in Highways 20, 5 and 138 (16). Lac Robertson Dam (1994) is another example in which Roller Compacted Concrete was made by using 50% of fly ash to decrease the heat of hydration (17).

ONTARIO

In Ontario, many known concrete structures (Skydome, CN Tower, Crowne Plaza) have been made by using slag, silica fume or fly ash. One of the more often quoted projects from late 1980s is the Scotia Plaza Office Tower in Toronto. GGBFS was used along with silica fume in 14 different classes of concrete in this building. Up to 70 MPa concrete was used for the core and columns of this 68-storey office tower. Thirty-six thousand tonnes of GGBFS was consumed at a minimum 20% and as much as 30% of the total cementitious materials. Self-elevating jump forms and pumped concrete permitted a remarkable building rate of 2.5 days per floor on this project, with forms stripped after 11 hours (18, 19).

The lower Notch Dam in Northern Ontario has been build about 25 years ago using 20 to 30% fly ash in structural and massive elements of the structure to counteract potential deterioration related to the use of a local alkali-silica reactive aggregate. The structure is in perfect condition after 25 years service.

The computer studies centre at York University in Toronto is the most recent project made with high-volume fly ash (HVFA) concrete. This construction project was a part of the "Green Building Strategy". The specified strength of the concrete used was 30 MPa for columns, walls, and suspended slabs, and 25 MPa for the lower slab-on grade. Both concretes (related to the two mentioned strengths) contained 50% Type CI fly ash by mass of cementitious material from Northern Ontario PGS at 0.40 and 0.45 water to cementitious materials ratios, respectively. Both materials fully met and exceeded the specified strength development at both 7 and 28 days (20, 21).

THE PRAIRIES AND ALBERTA

The high percentage of ready-mixed concrete being made with fly ash (80 to over 90%) is a good indicator of general acceptance of fly ash in the concrete industry in the Prairies and Western Canada. The only areas where fly ash does not appear to be finding ready acceptance are in the infrastructure and concrete flatwork sectors, because of real or perceived technical barriers such as de-icing salt scaling resistance and finishability characteristics.

The major projects that have used SCMs in Alberta include Bankers Hall West Tower, Calgary, built in 1999 in which SCMs (fly ash and silica fume) content of up to 35% by mass of cement was used in structural concretes with specified strength as high as 80 MPa at 120 days. Oldman River Dam near Pincher Creek, Southern Alberta is another example in which 30 to 40% of fly ash was used in mass concrete and spillway to control heat of hydration and cracking. Similar concretes were used in the recent construction of the new spillway at the St. Mary's Dam, also near Pincher Creek (22).

The Cigar Lake Mine in Northern Saskatchewan used a very high-performance steel-fiber reinforced silica fume concrete for precast concrete tunnel liner segments (110 MPa at 28 days specified compressive strength). The Regina Legislature historic masonry building underpinning project used thousands of high performance pre-cast concrete piles, which contained silica fume (22).

BRITISH COLUMBIA

In British Columbia, although fly ash has been used in various concrete applications for the past few decades (6), the recent increased use of fly ash is to a significant degree due to the activities of EcoSmart which is a joint venture of the Greater Vancouver Regional District, Industry Canada, Environment Canada and Natural Resources Canada. There are now a number of successful projects with cement replacement by fly ash of up to 50% (11, 23). Local ready-mixed concrete suppliers have off-the-shelf mixture proportions at the 40% replacement level.

The Liu Centre for the Study of Global Issues, on the campus of the University of British Columbia in Vancouver, Canada, was designed using sustainable principles in order to reduce its demand on the environment and existing infrastructure. In accordance with those principles it was decided to use concrete with 50% fly ash in some elements of the building. The concrete had a water-to-cementing materials ratio of 0.33 and developed a 28-day compressive strength of 32 MPa (23).

Artists Live/Work Studios, located in downtown Vancouver and designed by a well-known Canadian architect, Arthur Erickson, is another successful project that has used concrete with 50% fly ash. This type of concrete was selected mainly for aesthetics considerations, because the use of this type of concrete in the Liu Centre project had indicated that the concrete was lighter in colour and had a high quality surface finish. The total amount of concrete placed was 1000 m^3 with a special compressive strength of 30 MPa at 28 days. Details on other projects using high volumes of fly ash can be found in the web site of EcoSmart (24).

EXCESS MATERIAL

Since the amount of SCMs produced in each region across Canada is generally larger than the amount currently being used in construction or other applications, a substantial proportion of the above material has to be disposed of, stored or is sold to clients outside of the regions. This amount of so-called "excess material" is given in Table 9.

QUANTITY IMPORTED FROM OTHER REGIONS OR COUNTRIES

Although there are excess amounts of SCMs in almost all regions across Canada, some regions still import significant volumes of these materials. This is done for a number of reasons. When the local production of a certain material is essentially controlled by one company, the other companies have to look for other sources of materials. In addition, the quality of the particular material and the associated economics (cost/benefits ratio, cost of transportation, etc.), can have an influence on the choice of the material to be used. Imports of SCMs from other regions or countries to the different regions of Canada are summarized in Table 10.

BENEFICIATION

The fly ashes produced in Atlantic Canada and in southern Ontario do not currently meet the CSA standard, mainly because of a high-carbon content (10 to 16%). Removal of unburned carbon is feasible through a number of beneficiation processes, well described in the literature and demonstrated, at least in pilot operations. These include carbon burnout, particle size control, electrostatic separation and wet separation. However, research is still underway to find beneficiation processes sufficiently low in cost to be considered for implementation.

In the Prairies and Alberta, the amount of fly ash used is so small compared to the amount produced and considered as suitable for use as an SCM that there is little need for beneficiation of fly ash. However, it is understood that some fly ashes need to be classified prior to be used as an SCM.

A type of slag is produced in Quebec at a rate of about 100,000 tonnes annually. The reactivity of the slag does not meet the CSA standards because the process of cooling is too slow. It seems that the technical knowledge to upgrade this material is still a challenge.

COST

The relative cost of SCMs to the cost of a Type 10 Portland cement in all the regions of Canada is given in Table 11. It should be noted that the cost of Type 10 Portland cement depends on the region and ranges from $105 to $175. Therefore, the figures listed below should not serve as a direct comparison between the cost in each region but rather within each region. However, the numbers show clearly that fly ash is everywhere less expensive than Type 10 Portland cement and even more so in the regions where it is produced. For silica fume, the numbers are misleading, it appears that silica fume is more expensive in Quebec (where it is produced) than in the other regions. However, the cost of silica fume is indeed relatively less expensive in Quebec than in other provinces, but since the cost of Type 10 cement is also cheaper in Quebec than in the other regions, the relative cost of the silica fume increases.

It should be noted that absolute material costs are only fraction of the total cost of implementing SCMs in a concrete mix. Transportation, storage, and mixing costs are also associated with SCM use. Nevertheless, in locations where fly ash is available (for example in some parts of Alberta), the economic benefits remain the main reason of using fly ash in concrete.

GUIDELINES AND SPECIFICATIONS

Guidelines and specifications for the use of SCMs in concrete are in general those specified by the Canadian Standards Association (CSA), or the often more stringent specifications produced by provincial or municipal authorities, or engineering firms. Table 12 presents the guidelines and specifications used in each region.

CANMET assisted Public Works and Government Services Canada (PWGSC) in developing guidelines on the use of SCMs in concrete for federal projects. PWGSC also proposed the following clause on the use of SCMs on all federal projects (25): “All concrete shall contain fly ash or ground, granulated blast-furnace slag as partial replacement for cement unless it can be shown that the incorporation of these materials is technically and/or economically not feasible. The amount of cement replacement by fly ash or ground, granulated blast-furnace slag will depend on the type of application. The concrete so provided shall meet the workability, strength, durability and other performance requirements as specified”.

The above principle was reflected in the National Master Specifications (NMS) on the use of SCMs in concrete for federal projects. NMS is used not only by the federal government but also by the industry. The Guidelines have recently been revised (26). PWGSC and CANMET, in collaboration with other governments and the industry, are currently developing a best practice guide on the use of SCMs in concrete. NMS clauses are to be updated accordingly.

CSA A23.5 which is part of CSA Standards A3000 (Compendium Standards on Cementitious Materials) published in 1998 addresses the requirements for supplementary cementing materials added at the mixing plant to supplement the Portland cement in concrete. The requirements for concrete made with and without SCMs are covered by CSA A23.1.

Concerning the appropriate sections referring to cements and concrete, standards organizations such as the National Building Code of Canada 1995, National Housing Code of Canada 1998 and Ontario Building Code 1997, usually refer to the information given in CSA Standards CSA A5 and CSA A23.

It should be noted that CSA specifications dealing with concrete do not put any restrictions on the SCM content but rather on the 28-day compressive strength and the water-to-cementing materials ratio depending on the type of exposure the concrete is subjected to. CSA specifications dealing with blended hydraulic cements stipulate a maximum content of 70, 40 and 10% of GGBFS, fly ash and silica fume, respectively. The percentage is expressed by the total weight of cementitious materials.

The following are examples of specifications used in each region of Canada.

ATLANTIC CANADA

The widespread distribution of reactive aggregates in the Maritimes provinces of Canada has a definite impact on the specifications for concrete infrastructure in that part of the country. In New Brunswick, low-alkali blended hydraulic silica fume cements are specified routinely in high-performance concrete for use in NBDOT bridge projects (27). Similarly, the Department of Transportation and Public Works in Nova Scotia requires a minimum of 15% Class F fly ash in concrete for highway structures. It is also mandatory to use fly ash in all Nova Scotia Power Corporation projects (28).

PROVINCE OF QUEBEC

Ministry of Transportation of Quebec (MTQ)

- Silica fume blended hydraulic cements (T10E-SF) are required in HPC (high-performance concrete) and in shotcrete applications.
- Ternary blended hydraulic cements are required in self-levelling concrete, but the total mass of SCMs in ternary blended hydraulic cements must not be higher than 30% of the total mass of the cementitious materials.
- A mixture of minimum 70% Type 10 cement and up to 30% of silica fume blended hydraulic cement is permitted in conventional concrete.
- When reactive aggregates are used in concrete ¸ 35 MPa, silica fume blended hydraulic cement is required; in the case of concrete > 50MPa, ternary blended hydraulic cements are required.
- For concrete pavements, MTQ started using ternary blended hydraulic cements in 2000.

City of Montreal

- Silica fume blended hydraulic cement is required in roller compacted concrete (RCC) and high-performance concrete (HPC) with compressive strength of more than 50 MPa.

- It is permitted to use 70% of type 10 and 30% of silica fume blended hydraulic cement in sidewalks and curbs (35 MPa).

City of Quebec

- In general, the city of Quebec refers to the requirements of MTQ for infrastructure applications and to CSA standards for buildings structures. However, it does not allow the use of fly ash in sidewalks.

Hydro Quebec

- It is stated in the guidelines of Hydro Quebec SN-26.1-2000 that the use of SCMs is not permitted, except when it is specified by Hydro Quebec for a specific project.

PROVINCE OF ONTARIO

Both the Ministry of Transportation of Ontario (MTO) and Ontario Hydro used to have their own regulations; but as Ontario Provincial Standard Specifications (OPSS) were developed through the 1990's, the ministry and Ontario Hydro adopted the OPSS ones. The applicable specifications include:

OPSS 904	Concrete Structures
OPSS 1301	Cementing Materials
OPSS 1350	Materials Specifications for Concrete
OPSS 1352	Material Specifications for Pre-Cast Concrete Barriers
OPSS 350	Construction Specification for Concrete Pavement and Concrete Base

In OPSS 1350, under Cementing Materials (Clause 1350.05.01.01), the following restrictions related to the proportioning of SCMs by mass of the total cementing materials are given:

- Slag up to 25%
- Fly ash up to 10%
- A mixture of slag and fly ash up to 25% except that the amount of fly ash shall not exceed 10% by mass of the total cementing materials.

For high-performance concrete (HPC) – minimum specified 28-day strength 50 MPa - MTO enacted Special Provision No. HPC (May 1998), specifying mandatory use of silica fume. Other SCMs are allowed as well, and there is an additional requirement for chloride permeability at

28 days of 1000 Coulombs or less. Clause 1350.05.01.01 of OPSS 1350 concerning cementing materials is deleted and replaced by the following:

Cementing materials shall conform to OPSS 1301 and CAN/CSA A362. Type 10SF cement shall be used. A portion of it may be replaced by Type 10 cement, GGBFS or fly ash or a combination of these. Supplementary cementing materials shall be restricted to the following proportions by mass of the total cementing materials.

- Slag up to 25%
- Fly ash up to 10%
- A mixture of slag and fly ash up to 25%

For the Pre-Cast Concrete Barriers, OPSS 1352 and MTO requires the use of 28-day 30 MPa concrete, further specifying the cement to be used:

> *Cement shall be, Portland Cement, Portland Blast-Furnace Slag Cement (Type 10 or 10S) or Portland Pozzolan Cement (Type 10P) conforming to OPSS 1301. GGBFS, or fly ash may be used in conjunction with Normal Portland Cement (Type 10). GGBFS shall conform to OPSS 1301 and it shall constitute not more than 70% by the mass of total cementing material. Fly ash shall conform to OPSS 1301 and it shall constitute not more than 40% by the mass of total cementing material.*

Municipalities usually follow the OPSS, too. Poor experiences in the past or lack of knowledge and conservative approach of municipal engineers/specifiers, however, sometimes limits the acceptance of SCMs.

THE PRAIRIES

Manitoba Highways

- Median barriers, slabs, curbs, etc.: minimum 360 kg/m^3 Type 10 Portland cement for a 30 MPa strength at 28 days, 0.40 water/cement ratio concrete (effectively precludes use of fly ash).
- Overlay slabs, median barriers, shoulder barriers, abutments, etc.: silica fume blended hydraulic cement and shall not contain fly ash.

City of Winnipeg

- Bridge branch: for bridge decks, silica fume blended hydraulic cement and up to 10% fly ash by mass of cement is permitted.
- Public works department: for pavements:
- Fly ash concrete must produce 95% of the freeze-thaw durability of a control mixture without fly ash.
- Replacement of cement with fly ash limited to a maximum of 15% between May 2 and September 14, 10% between September 15 and October 1 and 0% between October 1 and May 1.

Engineering Firm in Winnipeg

- Silica fume concrete topping at airport: maximum fly ash content 10% by mass of cement.
- Parkade repair: maximum of 20% fly ash permitted, but minimum cement content specified at 380 kg/m^3 (no incentive to use fly ash in this concrete with a 0.40 maximum water/cementitious materials ratio and 35 MPa at 28 days specifications as requirements can easily be met with 380kg/m^3 type 10 Portland cement as the only cementing material).

Engineering Firm in Regina

- Concrete pavement: the use of fly ash will not be permitted.
- General concrete construction:
- Not more than 20% by mass of the total cement material content may be replaced with fly ash.
- After September 15, no portion of the total cement material content may be replaced with fly ash.

Prairie Farm Rehabilitation Administration (Saskatchewan)

- In southern Saskatchewan, recent specifications for concrete to be used for structures associated with small to medium earthen dams was requesting controlling the total alkali content in concrete and use of low-alkali Alberta fly ash at 25-30% by mass of the total cementitious material (29).

ALBERTA

Alberta Transportation

- Specifications for bridge construction permit the use of up to 35% fly ash by mass of cement in bridge pipe piles and spread footing, but does not allow the use of fly ash in bridge decks, curbs, median barriers, approach slabs and deck overlay concrete. Instead, it prescribes the use of 7.5% silica fume by mass of cement in such elements.

- Specifications for highway construction state: unless otherwise approved by the department, the use of fly ash is not permitted. The specification does, however, prescribe the use of silica fume in certain bridge components as described above.

Alberta Infrastructure

- Specifications allow the use of fly ash in piles/footings (30%), walls/columns (25%), slabs (20%) and topping (15%), but prohibits its use in precast or prestressed products. This specification also makes the following statement: *fly ash should not be used in concrete subjected to freeze-thaw cycles, or de-icing salts*. The specification also places such a high limit on the minimum cement content in the mixture (335 kg/m^3) for weather exposed concrete that it would likely make it unnecessary for the concrete producer to use fly ash in order to meet the specified maximum allowable water/cementing materials ratio and minimum 28-day compressive strength requirements. This effectively negates the use of fly ash in such concretes.

Alberta Environment

- As part of its mitigation strategy against ASR in a large number of small water management structures in remote areas throughout Alberta, specifications call for a maximum alkali content in the concrete and provide for optional addition of fly ash at 20-25% by mass of total cementitious material (29).

City of Edmonton

- Specifications for concrete for general purpose use state that the ratio of SCMs-to-total cementitious materials shall not exceed 0.20. For concrete exposed to freeze-thaw conditions, however, a minimum cement content of 335 kg/m^3 should be used. The city allows the use of a maximum 10% fly ash content.
- Specifications for concrete for roadways state that for Class A, B and C concrete, no more than 10% of the specified minimum cement content may be replaced with fly ash. Even further restrictions are placed on the use of fly ash on a seasonal basis, permitting it to be used only during the period of May 16 to September 30.

City of Calgary

- The city requires a minimum cement content precluding the use of fly ash in concrete sidewalks, curbs and gutters.

BRITISH COLUMBIA

A typical recent specification for SCMs developed by Levelton and Associates (engineering firm) for a large water reservoir project specified a minimum of 50% fly ash replacement in some elements. A similar approach is being advocated by EcoSmart who has the policy (for those wishing to use EcoSmart concrete) that “...the maximum replacement of cement with fly ash consistent with constructibility restraints, should be used”. Owners of “green” buildings are now asking for the use of SCMs (fly ash). However, many construction managers adopt the position that “...use as much fly ash as you want as long as it does not impact on budget and schedule”.

BARRIERS AND PROPOSED SOLUTIONS

POLICY BARRIERS

Based on the aforementioned guidelines and specifications, it can be easily concluded that existing policies at various government levels (municipal to provincial) often represent serious barriers to the increased use of SCMs in the construction market. Such barriers are sometimes based on perception, lack of technical information or knowledge on the properties of SCMs or on bad experiences due, so often, to lack of knowledge.

In Alberta and the Prairies, for example, a complaint from ready-mixed concrete producers was that engineers from outside of Western Canada, not familiar with the good quality of Western Canadian fly ashes and history of successful use of fly ash in concrete in those regions, were placing blanket bans on the use of fly ash in most concretes. These engineers typically resided outside of the province and worked for large internationally owned engineering companies, which tend to use generic concrete specifications and have been influenced by negative experiences with fly ash in other parts of North America. Such bans could actually be detrimental to the long-term durability of concrete in Alberta for reasons of AAR among others.

In Atlantic Canada, the “every day” writer of specifications for concrete and the corporate employers of the individual writers still perceive fly ash as an “experimental” and little understood product. Thus, adding a clause in the specifications allowing the use of fly ash cannot be made without the specification writer making considerable efforts and the corporate employers taking on a perceived liability for the change.

In Quebec, the MTQ specification is a widely used document and is given as a reference by consulting engineering firms and municipal engineers. It was, only two years ago, that the MTQ started using ternary blended hydraulic cements with slag and / or fly ash, i.e. when such combinations became available as blended hydraulic cements. For most owners of infrastructure, the use of SCMs depends on the speed at which research is being performed and most of all on the speed at which knowledge on the benefits of the use of SCMs is transmitted.

In Ontario, the ready-mixed concrete community and cement companies as well as other engineers and specifiers have pointed out discrepancies in codes and specifications regarding the quantity of SCMs to be used in concrete for each application.

It is believed that clearer, stronger and simpler specifications and national guidelines giving the upper limits of cement replacement by SCMs agreed upon by all interested parties and issued under the CSA auspices are required; such a document could include a comprehensive table showing the limits for the particular application and particular SCMs, for summer and winter applications.

A preliminary document including the above information has already been prepared by CANMET with the financial support of PWGSC, and will be included in the next edition of the National Master Specifications that is used for the federal government projects and by the industry at large. EcoSmart with the help of the cement industry, cement and concrete experts and the financial support of Action Plan 2000 is currently developing documents and recommendations on the use of SCMs for consideration in the CSA standards. EcoSmart is also developing recommendations for the content of four guidelines for fly ash producers, designers and specifiers, Ready-mixed concrete operators, and contractors.

TECHNICAL BARRIERS

The slower set/strength development of concrete containing SCMs (especially, fly ash and slag) under cold weather conditions is a technical barrier that was mentioned by almost all the consultants.

The quality of fly ash was mentioned as a technical barrier in Atlantic Canada and in southern Ontario. Quality ash means fly ash with less than 4% free carbon. The Class F fly ashes generated in southern Ontario and in Atlantic Canada contains up to 12-16% of free carbon making it unusable in their current form as SCMs in cement and concrete. These ashes also have high-alkali contents, which make their use problematic in combination with reactive aggregates.

In Alberta and the Prairies, there is a general perception amongst specifying authorities that the use of fly ash should be either severely restricted, or even prohibited in concrete structures or elements exposed to freezing and thawing and/or de-icing chemicals. There are, however, inconsistencies between various provincial and municipal authorities and engineering companies in applying such restrictions. This has caused confusion and complaints from concrete suppliers. There would appear to be a strong need for forums on this issue in the above regions, such that a more rational and consistent approach to the use of fly ash and other SCMs under such exposure conditions could be developed.

Fairly severe restrictions have also been placed on the use of fly ash by some users in the concrete flatwork industry. It was reported that the incorporation of fly ash in the mixture creates finishing problems such as delays in the finishing operations, difficulties in establishing the proper timing for finishing operations (because of difference of bleeding characteristics) and problems in achieving specified floor flatness and levelness requirements. However, it is the view of the concrete suppliers interviewed that this restriction on fly ash use is ill-conceived. A forum to review and discuss this issue with concrete specifiers and placing and finishing contractors would appear to be warranted.

In Alberta, a number of the fly ash suppliers and ready-mixed concrete producers expressed concerns regarding the recent push for high-volume fly ash concrete in construction. The concern is that if too high a percentage of fly ash replacement for Portland cement is used, then problems of concrete durability may arise particularly for concrete exposed to freeze-thaw cycles and/or de-icing chemicals. This has apparently previously occurred in Alberta with negative consequences for fly ash usage. Also, concerns were expressed with respect to constructability issues (e.g. time to finish flatwork, forms removal, time to perform post-tensioning, etc.). The generally voiced concern was that if high-volume fly ash concrete usage led to constructability or durability problems, it could lead to blanket bans against the use of even moderate volumes of fly ash in concrete. Therefore, the proposed use of high-volume fly ash concrete should only proceed with great caution and with longer term field demonstrations of durability in the Alberta climate before a more widely based adoption of such technology occurs.

It was also mentioned in British Columbia that a more sophisticated concrete mixture proportioning procedure and increased quality control for the use of HVFA mixtues are required. Some suppliers are simply substituting fly ash for cement on a kg-for-kg basis and not doing anything further. There is a major risk that this could result in substandard HVFA concrete.

EcoSmart has also established a list of technical issues related to the use of high volume fly ash in concrete and has tested the validity and importance of these issues through consultations with concrete users and through cases study (www.ecosmart.ca). The EcoSmart team is currently developing a study on these issues that will identify the current state of the knowledge in relevant scientific and technical literature, including technical data for case studies. The results of this report will serve as a reference for amending the Standards and later on for the content of the guidelines.

With regard to the new fumed smelter slag now being used in Alberta, extensive laboratory testing and field evaluation and testing showing favorable performance have already been completed and it has been commercially produced and used in ready-mixed concrete in Alberta since 2001. Additional testing is currently underway to assess compliance of the product with the recommendations of the new CSA A3001-03 Specification. More specifically, the product is being evaluated for conformance to the Specification in accordance with the recommendations in Appendix D "Guide for the Evaluation of Alternative Supplementary Cementing Materials in Concrete". Completion of this testing should provide full characterization of the behaviour of this fumed smelter slag in a range of different types of concretes.

For silica fume, it was mentioned that caution is required when it is used in flatwork due to the generally low bleeding and high plastic shrinkage of concrete made with silica fume.

ECONOMIC BARRIERS

With fly ash selling at around 38 - 80% the price of Portland cement, the economic incentive is for ready-mixed concrete companies and other producers to use fly ash wherever technically feasible or permitted. The only real economic barriers relate to costs of transportation and silos for storage. Some of the smaller producers in rural and remote areas do not find it economical to transport fly ash long distances. Also, smaller producers only have one silo for cement and are reluctant to invest in the cost of a second silo for fly ash.

The transportation cost was also mentioned as an economic barrier for the use of slag and fly ash in Quebec.

It was mentioned in the “Lafarge Sustainable Report” that the competitive range for road deliveries from a cement work is said to be up to roughly 200 km. In the case of SCMs, Table 10 shows that these materials were imported from a distance ranging from 300 to 900 km using rail or truck as a mode of transportation. This probably means that the transportation costs of fly ash or slag do not represent an economic barrier for a distance of up to 900 km. It should also be noted as an example that the transportation cost of fly ash from Saskatchewan to Quebec was, in one case, estimated to be roughly $50-60/tonne, which was not economically viable.

With the cost of silica fume ranging from 340 to 480% that of the cement Type 10, the price of silica fume was mentioned by almost all the consultants as the real barrier to the increased use of silica fume. However, most of the silica fume produced in Canada and in the USA is used in concrete construction. Silica fume is basically a specialty product that is mainly being used in high-performance and high-strength products, applications for which additional cost is acceptable because of the desired long service life.

OTHER BARRIERS

One barrier to the increased use of SCMs is the "relatively" new position of the ready-mixed concrete industry in which they wish to produce concrete as a "manufactured product" (like steel). On this basis, they control the proportioning internally and the amount of SCMs, if any, is unknown. The question then arises whether there is any incentive on their part to expand the use. It is understood that when the use of SCMs in concrete reduces costs, the ready-mixed concrete industry will optimize the use of these materials. However, when for some applications, the use of SCMs appears not to be cost effective (especially for the initial cost), even if it is specified in the contract, there is no incentive for the ready-mixed concrete industry to use these materials.

MARKET ANALYSIS

Based on the information dealing with the quantities of SCMs used in cement and concrete applications, the estimated breakdown of SCMs utilization in Canada in 2001 is given in Table 18.

The numbers in Table 18 show that the quantity of silica fume used is significantly higher than what is produced in Canada, and that almost all the GGBFS produced is used. Fly ash is the only material that is underused and presents a potential for an increased use in the construction sector. Only 20% of the fly ash potentially useable as SCMs is used as a replacement for cement, which represents only 10% of the quantity produced. The big challenge for the increased use of fly ash remains the transportation and beneficiation costs. The large market for the cement and concrete industry is in Eastern Canada where there is a lack of quality ash; on the other hand, quality ash is abundant in Western Canada where the concrete industry represents only 25% of that of Canada.

Figure 4 shows in percentage the ratio of the quantity of SCMs to that of cement used in each region across the country. It can be seen that the regions that are blessed with a good quality of fly ash or with GGBFS are the top users of SCMs (~17%). Quebec ranks last due to the unavailability of fly ash and GGBFS in its region.

A number of suggestions for overcoming the real and perceived barriers to the increased utilization of SCMs in concrete were already discussed in the previous section and are included in Tables 13-17. The following is a summary of those propositions:

SUGGESTIONS TO OVERCOME POLICY BARRIERS

- Clear, stronger and simpler specifications and national guidelines giving the upper limits of cement replacement by SCMs as a function of exposure classes agreed upon by all interested parties and issued under the CSA auspices are required.

- Organize workshops in different cities of Canada with a major effort being made to get all the major specifying authorities, concrete suppliers, users and engineering inspection and testing companies of each city to attend. The prime objective of the workshops would be to develop a uniform set of guidelines for use of SCMs for adoption in the provinces.

SUGGESTIONS TO OVERCOME TECHNICAL BARRIERS

- Organize forums to discuss ways to resolve technical issues, including developing a more rational and consistent approach to the use of fly ash and other SCMs under different exposure conditions.
- For the concrete flatwork sector, a forum to review and discuss this issue with concrete specifiers, suppliers and placing/finishing contractors would appear to be warranted.
- Support R&D programs in resolving technical barriers such as the de-icing salt scalinf resistance.

SUGGESTIONS TO OVERCOME ECONOMIC BARRIERS

- Government could subsidize the costs of transporting SCMs. However, it was mentioned by some parties that this solution is unlikely to happen, since it gives advantage to one construction material over the others (for example steel).

POTENTIAL SOURCES

Four materials were identified as potential sources for SCMs. These are disposed fly ash, non-ferrous slag, metakaolin and natural pozzolans. Table 19 presents the potential sources of SCMs in each region.

DISPOSED FLY ASH

The unexploited, ever growing volumes of fly ash disposed in pounds or landfills across Canada represent a major potential application opportunity in the future. Changing economic and environmental situations, at least partially dictated by ratification of the Kyoto protocol by Canada, with resulting impact on both the power-generating and cement / concrete industries, could be the drivers. The fly ash beneficiation technologies already exist, albeit at a cost penalty. The changing economic and environmental conditions could make the increased costs justifiable.

NON-FERROUS SLAG

Teck Cominco produces about 150,000 tonnes of fumed smelter slag per year from their Trail, BC production smelter. Eighty thousand tonnes/year are used as raw feed for Portland cement production and the rest disposed of as waste product.

Recently Teck Cominco in cooperation with Cementec of Calgary, constructed a grinding plant to improve the slag's reactivity. The Calgary plant has a capacity of 30,000 tonnes/year; in 2001 production was 8,000 tonnes and 10,000 tonnes is expected to be used in Alberta in 2002. The processed slag is now marketed as GS-Cem and as a "cement economy" rather than an SCM. It is used in conjunction with Cementec's Econoset admixture, which both accelerates the mixture's setting time and performs as a HRWRA (High Range Water Reducer Admixture). GSCem is recommended by Cementec as a direct replacement of cement in the 15 - 20% range. It is also compatible with up to 30% fly ash as a binary SCM system. Ready-mixed concrete industry representatives in Alberta indicated that they had limited experience with GSCem.

It was also mentioned that 100,000 tonnes per year of slag is produced in Quebec. However, the technical knowledge to upgrade this slag to meet the CSA Standards does not exist yet.

METAKAOLIN

There is a potential for the production of metakaolin from the waste sludge of oil sands processing in Fort McMurray, Alberta. A recent study by EcoSmart indicated that production and transportation costs to supply the lower mainland of British Columbia might be in the $300/tonne range if total demand is in the 25,000 tonnes/year range. Such material could eventually compete with silica fume in its properties and potential applications.

There are two other sources of kaolin in Nova Scotia, namely Kemptville (Black Bull Sources) in Western Nova Scotia and Shubenacadie (Kaoclay) in Central Nova Scotia, and one source in Quebec that are not exploited at the present time but may have some future application.

NATURAL POZZOLANS

There are in excess of 100 sources of diatomaceous earth in Nova Scotia. CANMET performed a preliminary characterization of several of these sources in the late 1980's. The study concluded that diatomaceous earth was a good pozzolan, however, the material has not been promoted for use in concrete.

British Columbia has deposits of natural shales (Quesnel area), diatomaceous earth (Quesnel and Southern Okanagan areas) and pumice (Pemberton area), which are known to be pozzolanic. Attempts were made to bring these to commercial viability in the late 1970's and through the 1980's but with limited success. Restraints were transportation costs, low reactivity and lack of uniformity of the material. All of these products were tested by Levelton at various times in their development. One Quesnel pozzolan from red shale was known to produce a rose hue to otherwise grey concrete and received some market acceptance in architectural concrete.

CONCLUSIONS AND RECOMMENDATIONS

The data gathered on the current situation of SCMs in Canada have shown that about 524,000, 347,000, and 37,000 tonnes of fly ash, Ground Granulated Blast Furnace Slag (GGBFS) and silica fume were used in cement and concrete applications in 2001, which represent 11, 90, and 185% of the quantity produced, respectively. For GGBFS, the remaining 10% of the quantity produced was used in the USA, and for silica fume, 17,000 tonnes were imported from the USA and Norway to meet market demand. Fly ash appears to be the only material that is underused and that represents a potential for increased use of SCMs in Canada. For the GGBFS, the quantity used can be increased if the demand increases.

However, this investigation has shown that there are policy, technical and economic barriers to the increased use of SCMs in Canada. Policy barriers: although these materials have been in the Canadian market for 20 to 30 years, and many projects, including high profile projects such as Hibernia and the Confederation Bridge, have successfully used high volumes of fly ash and slag, there are still municipalities and provincial agencies that ban or limit the use of fly ash and slag to a certain percentage of replacement for some applications.

Technical barriers: the slower setting times and strength development of concrete incorporating fly ash and slag are limiting the use of these materials in applications that need fast form-work removal. The reduced resistance of these concrete mixtures to the freezing and thawing cycles in the presence of de-icing chemicals is also considered a hurdle. The quality of the fly ash, which is related to the type of coal used for the production of electricity in the thermal power plants, is a concern in the Eastern part of the country.

The economic barriers are not related to the costs of the materials, except for the silica fume, but rather to the costs of transportation and silos. Concrete producers in locations that are far from the sources of SCMs need extra silos for storing these materials.

The following are some solutions that were proposed to overcome the above barriers. They can be considered as the basis of a strategic plan for Action Plan 2000 to increase the use of SCMs in the construction market in order to decrease the CO_2 emissions related to the use of Portland cement:

- Develop clear specifications and national guidelines for the use of SCMs in cement and concrete. The guidelines must be stronger and simpler than those currently in use, must be agreed upon by all interested parties and must be issued under the auspices of the Canadian Standards Association (CSA).
- Organise workshops in different cities of Canada with a major effort being made to get all the significant specifying authorities, concrete suppliers, users and engineering inspection and testing companies of each city to attend. The prime objective of the workshops would be to adopt the above, developed guidelines in the provinces (with modifications if necessary).
- Organise forums to discuss ways to resolve technical issues, including developing a more rational and consistent approach to the use of SCMs under different exposure conditions.
- Support R&D programs in resolving technical issues.

It was also mentioned that the cement industry should be encouraged to produce more blended hydraulic cements (as is the case in the province of Quebec) to overcome the technical issue related quality control of fly ash, and also to overcome the economic barriers related to the costs of transportation and silos.

ACKNOWLEDGEMENT

This investigation was funded by the Government of Canada Action Plan 2000 on Climate Change, CANMET, CIRCA, and CSPA. Grateful acknowledgement is made to the consultants involved in the regional studies, i.e. W.S. Langley, P. Lamothe, G.J. Venta, D.R. Morgan and P.T. Seabrook. Special thanks are also made to the members of the advisory committee of Action Plan 2000 SCMs program, and to L. Wilson, V. Sivasundaram, P-C. Nkinamubanzi and A. Bilodeau from CANMET for helpful discussions during the progress of the investigation.

REFERENCES

1. W.S. Langley, "Current Situation of Supplementary Cementing Materials in Atlantic Canada", Report for Natural Resources Canada, ICON/CANMET, September 2002.

2. P. Lamothe, "Current Situation of Supplementary Cementing Materials in Quebec", Report for Natural Resources Canada, ICON/CANMET, September 2002.

3. G.J. Venta, "Current Situation of Supplementary Cementing Materials in Ontario", Report for Natural Resources Canada, ICON/CANMET, September 2002 (Confidential).

4. D.R. Morgan, "Current Situation of Supplementary Cementing Materials in Saskatchewan and Manitoba", Report for Natural Resources Canada, ICON/CANMET, September 2002.

5. D.R. Morgan, "Current Situation of Supplementary Cementing Materials in Alberta", Report for Natural Resources Canada, ICON/CANMET, September 2002.

6. P. T. Seabrook, "Current Situation of Supplementary Cementing Materials in British Columbia", Report for Natural Resources Canada, ICON/CANMET, September 2002.

7. V.M. Malhotra and P.K. Mehta, "Pozzolanic and Cementitious Materials", Advances in Concrete Technology Volume 1, Gordon and Breach Publishers, 1996.

8. R. McCaffrey, "Climate Change and the Cement Industry", Global Cement Technology, October 2001.

9. B. Mitchell and G. Floe, "Metakaolin Pre-Feasibility Study", NLK Project EA2860 prepared for Ecosmart Concrete Project, September, 2002. (Can be found in www.ecosmart.ca)

10. W.G. Hime, “Delayed Ettringite Formation - a concern for Pre-cast Concrete”, PCI Journal, July-August, 1996, pp. 26-30.

11. V.M. Malhotra and P.K. Mehta, “High-Performance High-Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties, Construction Practice, and Case Histories”, Marquardt Printing Ltd., Ottawa, Canada, August 2002.

12. G.C. Hoff and R. Elimov, “Concrete Production for the Hibernia Platform”, Supplementary papers, CANMET/ACI International Symposium on Advances in Concrete Technology, pp. 11-14, June 1995.

13. G. Tadros, J. Combault, D.W. Bilderbeek, and G. Fotinos, “The Design and Construction of the Northumberland Strait Crossing Fixed Link in Canada” 15th Congress of IABSE, pp. 16-20, June 1996.

14. W.S. Langley, G. Forbes and E. Tromposch, “Some Durability Considerations in the Design of the Confederation Bridge”, Fourth CANMET/ACI/JCI International Symposium on Advances in Concrete Technology, SP-179, 1998, pp. 1-22.

15. W.S. Langley, “Practical uses for High-Volume Fly Ash Concrete utilizing a Low Calcium Fly Ash”, presented at Technology Transfer Seminar Series on Durability and Sustainability of Concrete Through the use of Fly Ash, Silica Fume and Superplasticizers, Dallas, Feb. 2001.

16. Personal communications, D. Vezina from MTQ, Quebec (418-644-0181 Ext. 234).

17. F. Robitaille and J. Beaulieu, “First Dam made with RCC in Canada: Lac Robertson, Field Quality Control of Air-entrained RCC”, ACI-Proceeding, Progress in Concrete, Montreal, Nov. 1995.

18. “Developments in Building Products: Opportunities for Industrial Minerals,” IRC/NRC & Matex Consultants Industrial Mineral Background paper 13, Ministry of Northern Development and Mines, 1990.

19. “Success Stories - Scotia Plaza, Toronto, Ontario,” www.slag.com/stories.

20. M.D.A. Thomas et al., “The Use of High-Volume Fly Ash in Concrete,” Proceedings, 7th International Gypsum and Fly Ash Science and Technology Conference, Toronto, June 2-4, 2002.

21. “Use of EcoSmart™ Concrete In York University Computer Science Building, Toronto, Ontario,” Report by Busby + Associates Architects, April 2001. *(downloaded from the EcoSmart™ website)*

22. Personal communications, D.R. Morgan, AMEC, BC, Canada.

23. Bilodeau and P. T. Seabrook, "Recent Applications of High-Volume Fly Ash Concrete in Canada" MTL/CANMET internal report, July 2001.

24. www.ecosmart.ca.

25. M. Cheung and S. Foo, "Use of Fly Ash or Slag in Concrete: Proposed PWGSC Guidelines", Two-day CANMET/ACI International Symposium on Concrete Technology for Sustainable Development, Vancouver, BC, April 1999.

26. A. Bilodeau, "Guidelines for the use of Fly Ash and Slag in Concrete", CANMET Report MTL , Natural Resources Canada, Ottawa, March 2003.

27. D.P. DeMerchant, B. Fournier, and F. Strang, "Alkali-Aggregate Research in New Brunswick", Canadian Journal of Civil Engineering, Vol. 27, No. 2, April 2000, pp. 212-225.

28. W.S. Langley, "Alkali-Aggregate Reactivity in Nova Scotia", Canadian Journal of Civil Engineering, Vol. 27, No. 2, April 2000, pp. 204-211.

29. S.T.R. Roy and J.A. Morrison, "Experience with Alkali-Aggregate Reaction in the Canadian Prairie Region", Canadian Journal of Civil Engineering, Vol. 27, No. 2, April 2000, pp. 261-276.

Table 1 - SCMs currently being used in construction in Canada.

Regions	SCMs	Information (source, type...)	Period of Time in the Market/Promotional Activities
Atlantic	Fly Ash	Class F (Lingan, Point Tupper or Trenton from Nova Scotia up to 2001, and presently, Sunbury from New York)	Fly ash has been used in Atlantic Canada since 1985
	Silica Fume	From admixtures suppliers	Silica fume (for which there is no local source) has been used in Atlantic Canada since 1985
Quebec	Fly Ash	Class F (Nanticoke, ON, Trenton, NS, Pennsylvania, USA)	Nanticoke used for more than 10 years, Trenton >5 years and Pennsylvania >20 years
		Class CI (Ontario)	more than 20 years
	Slag	GGBFS (Ontario)	~ 20 years
	Silica Fume	Quebec and USA	Quebec: more than 20 years, USA >10 years
Ontario	Fly Ash	Class F (Ontario Power Generation and imports)	Regularly used since about 1982/83
		Class C (Ontario Power Generation and imports)	Regularly used since about 1982/83
	Slag	GGBFS (Ontario steel industry in conjunction with cement industry)	Regularly used since about 1976
	Silica Fume	Quebec, USA	Since 1990 in bags, and since 1995 as Type 10SF cement
Prairies	Fly Ash	Class F, Boundary Dam plant in Saskatchewan	N.A
	Slag	GGBFS (imported from Ontario to be used in a blended hydraulic cement with 20% slag)	N.A
	Silica Fume	Quebec, USA and Norway	N.A
Alberta	Fly ash	Class F (Forestburg and Genesee)	First supply of Forestburg: 1972 First supply of Genesee: 1992
		Class CI (Sheerness and Sundance)	First supply of Sundance: 1973 For Sheerness: NA
	Slag	Fumed smelter slag from BC ground with a special chemical admixture in Alberta to produce a SCM called GSCem*	Introduced to the market in 2001
	Silica Fume	Quebec, USA and Norway	Was first used by the concrete industry in the mid-1980's
British Columbia	Fly Ash	Class F (Genesee from Alberta)	Since 1997
		Class CI (Sheerness and Sundance from Alberta and Centralia from Washington, USA)	Sheerness: less than 5 years Sundance: since ~1987 Centralia: since ~1977
	Silica Fume	Quebec, Eastern USA, Norway and Australia	~ 1987
	Metakaolin	USA	~ 1997 but small amount for architectural or special concretes

*According to CSA Standards, this material is not considered as an SCM, but some testing is currently underway to assess compliance of the product with the recommendations of the new CSA A3001-03 as an alternate SCM.

Table 2 - SCMs production in Canada (tonnes).

SCMs	Type/Class	Production Level 2001	Potentially Useable as SCMs
Fly Ash	All classes (F, Cl, CH)	~ 4,800,000[1]	~ 2,200,000
Slag	BFS[2]	1,438,000[3]	380,000[3] (GGBFS)
	Non- ferrous slag	4,100,000[4]	8,000 (GSCem[5])
Silica Fume	SF	20,000	20,000

1. The same quantity of fly ash was also mentioned in NRCan publications.
2. Blast furnace slag
3. The quantity that is not used for the production of GGBFS is mainly used for the production of lightweight aggregate or exported to USA. However the whole quantity of BFS can be considered as potentially useable as SCM. The quantity of GGBFS can be increased if the market demand increases.
4. It was mentioned in a paper published in 1987 (E. Douglas and V.M. Malhotra, ACI-SP 86-8E, 1987) that in Canada 4.1 Mt of non-ferrous slags are produced annually, with only small amounts used as railroad ballast or engineering fill.
5. Fumed smelter slag from BC ground with a special chemical admixture in Alberta – estimate.

Table 3 - Concrete utilization in Canada (m^3).

Applications	2000	2001	2002 (expected)
Cast in Place	20,713,000	21,157,000	21,270,000
Concrete Products (block, pipe, brick, paving blocks, other manufactured products)	1,873,000	1,910,500	1,899,000
Precast (exterior panels, T-shaped beams or hollow decks)	1,452,000	1,450,500	1,440,500

Table 4 - Concrete Applications in Canada.

Applications	%	Quantity of Concrete Used in 2001 (m^3)
Residential	32.1	7,865,000
Commercial/Industrial/Institutional	49.7	12,182,500
Infrastructure	7.6	1,863,000
Special	1.1	269,500
Other	9.5	2,338,000

Table 5 - SCMs used as a Separate Ingredient in Concrete Applications Across Canada.

Applications	Type of SCMs	Reasons for Use	2000*		2001		2002*	
			Quantity, Tonnes	% replace	Quantity, Tonnes	% replace	Quantity, Tonnes	% replace
Residential	Fly Ash	Cost, performance	165,100	10-25	165,700	10-25	167,000	10-25
	Slag	Cost, performance	36,000	15-40	36,000	15-40	36,000	15-40
Commercial/ Industrial/ Institutional	Fly Ash	Cost, performance	238,700	up to 20	236,000	up to 20	228,000	up to 20
	Slag	Cost, performance	144,000	15-40	144,000	15-40	144,000	15-40
Infrastructure	Fly Ash	Durability	46,300	10-25	46,500	10-25	47,600	10-25
	Slag	Cost, performance	36,000	15-40	36,000	15-40	36,000	15-40
	Silica Fume	Durability	3,100	5-12	3,100	5-12	3,100	5-12
Special	Fly Ash	Performance (workability)	1,100	10-20	1,150	10-20	1,210	10-20
	Silica Fume	Performance	250	7-12	250	7-12	250	7-12
Total	Fly Ash		451,200		449,350		443,810	
	Slag		216,000		216,000		216,000	
	Silica Fume		3,350		3,350		3,350	

*Some consultants gave the quantities of SCMs used in 2001 and assumed that similar quantities would have been used in 2000 and 2002.

Table 6 - Blended hydraulic cements production in Canada.

Regions	Type of Blended Hydraulic Cement	2000	2001	2002
Atlantic	LASF (8% SF)	4,000	4,000	4,000
Quebec	10E-SF (~8% SF)	105,000	110,000	117,000
	20E-F\SF (20% FA, 5% SF)	10,000	20,000	30,000
	10E-S\SF (20% Slag, 5% SF)	20,000	50,000	80,000
Ontario	10E-SF (~8% SF)	85,510	88,990	93,550
	20% Slag	-	6,000	-
Manitoba	20-25% FA	-	7,000	-
Alberta	fly ash blended hydraulic cement (%	13,000	19,000	-
Total of SCMs Used in Blended Hydraulic Cements	Fly Ash	~5,250	~10,150	6,000
	Blast Furnace Slag	4,000	11,200	16,000
	Silica Fume	16,910	19,390	22,114

LASF: Low-alkali silice fume blended hydraulic cement.
10E-SF: Silica fume blended hydraulic cement having equivalent performance to that of a Type 10 Portland cement.
20E-F\SF: Ternary blended hydraulic cement having equivalent performance to that of a Type 20 Portland cement with fly ash being the predominant SCM and silica fume the secondary SCM.
10E-S\SF: Ternary blended hydraulic cement having equivalent performance to that of a Type 10 Portland cement with slag being the predominant SCM and silica fume the secondary SCM.

Table 7 - Blended hydraulic cements applications.

Applications	Type of Blended Hydraulic Cements	Reasons for Use	Quantity, Tonnes 2001	Quantity, Tonnes 2002
HPC (bridge elements, bridge decks, parking garages, marine concrete, high-rise)	SF	Enhanced durability (low permeability, resistance to AAR), high-strength, better pumpability.	130,000	138,500
Shotcrete and RCC	SF	Enhanced durability (resistance to abrasion and freeze/thaw), adherence, shootability, high-strength.	42,000	43,500
Other (precast, cement board, sidewalks)	SF	Faster early strength development, better resistance to AAR and de-icing salt scaling	14,000	34,500
HPC, Highway Pavements	Ternary	Enhanced durability (low-permeability, resistance to AAR), better pumpability, less heat-of-hydration	40,000	60,000
Mining Industry, Rural Areas	Fly Ash and GGBFS	Cost	32,000	-
	Ternary (slag)	Cost	25,000	25,000

Table 8 – Other SCMs applications.

Applications	**Type of SCM**	**Reasons for Use**	**Quantities, Tonnes**	
			2001	**2002**
Grouts, Mortars, Repair Products	Fly Ash	Performance (enhanced workability and adhesive/cohesive characteristics)	1,200	1,220
	Slag		25	25
	Silica Fume		150	120
Mining	Fly Ash	Cost and performance (Filling and shootability)	60,000	60,000
	Slag		120,000	120,000
	Silica Fume		2,500	2,500
Oil well Cement	Fly Ash	-	2,900	2,900
	Silica Fume		12,000	12,000
Total	Fly Ash	-	64,100	64,100
	Slag		120,025	120,025
	Silica Fume		14,650	14,650

Table 9 - Excess material (tonnes).

Regions	SCM	Type	Excess Amount, Tonnes	% Disposed (method)	% Stored (method)	% Sold
Atlantic	Fly Ash	F	200,000	92% (landfills or lagoon)	0.1% (for use in concrete)	3%
Quebec	Silica Fume	SF	> 7,000	0	70% holding cells and 30%	100%
Ontario	Fly Ash	F	915,000	Part of this is exported as cement kiln feed to the USA	Landfilled	-
		C	43,000	-	Landfilled	10,000 to
	Slag	GGBFS	~76,000	-	-	100% sold to the adjoining provinces and states
Prairies	Fly Ash	F	~300,000	Lagoon	-	-
Alberta	Fly Ash	-	1,540,000	Lagoon, backfilled	-	60,000 to BC

*This number does not include the quantity of fly ash produced and not considered as potentially useable as an SCM.

Table 10 - SCMs Imported in 2001.

Regions	SCMs	Type	Quantity Imported (Tonnes)	Imported from **	Mode and Distance of Transportation (km)
Atlantic	Fly Ash	F	15,000*	NY, Sunbury	Rail, 900 km
	Silica Fume	SF	400	Quebec	Truck, 900 km
Quebec	Fly Ash	F	21,000	Trenton, NS and USA (Pennsylvania)	Truck, Rail
		CI	10,000	Ontario	Truck, Rail
	Slag	S	46,000	Ontario	Truck, Rail
	Silica Fume	SF	4,000*	Kentucky, USA	Truck, Rail
Ontario	Fly Ash	F & C	180,000 to 225,000	MI, WI, small volumes from OH, NY	Truck or ship, 300 to 500 km
	Silica Fume	-	6,000 to 7,300	Quebec, small volumes from WV, NY	Truck, 500 to 750 km
Manitoba	Fly Ash	-	40,000	Sask, ON, Al and North Dakota	-
Saskatchewan	Fly Ash	-	5,000	Alberta	-
Alberta	Silica Fume	-	15,500	Quebec, USA, Norway	-
	Fumed smelter Slag	-	8,000 - 10,000	Alberta	-
British Columbia	Fly Ash	F	70,000	Washington	Rail & Truck
		CI	60,000	Alberta	Rail
	Silica Fume	SF	2,000	Quebec, USA, Norway	Truck
	Metakaolin	SF	Negligible	Alabama	Rail then Truck

*Estimate of 2002

**NY: New York, MI: Michigan, WI: Wisconsin, OH: Ohio, WV: West Virginia, NS: Nova Scotia, Al: Alberta

Table 11 - SCMs average cost relative to cost of a Type 10 Portland Cement.

SCM Type	**Average Cost Relative to Cost of a Type 10 Portland Cement**						
	Atlantic	Quebec	Ontario	Saskatchewan	Manitoba	Alberta	British Columbia
Fly Ash	40-45%	75-80%	50-60%	38-43%	43-45%	50-60%	56-70%
Slag	-	85%	80%	-	-	80-85%	-
Silica Fume	360-400%	480%	300-430%	350-430%	350-430%	390-450%	480%
Metakaolin	-	-	-	-	-	-	480%

Table 12 - Guidelines and specifications.

Regions	**CSA**	**Provincial & Municipal by-laws**	**Other**
Atlantic	CSA A23.5	None	Engineering Firms
Quebec	CSA A23.1, A23.5	MTQ (Ministry of Transportation of Quebec) City of Montreal Hydro-Quebec	-
Ontario	CSA A23.5	OPSS (Ontario Provincial Standard Specifications)	ACI, ASTM
Prairies	CSA A23.1, A438	Manitoba Highways City of Winnipeg	Engineering Firms in Winnipeg and Regina
Alberta	CSA A23.1, A438	Alberta Transportation Alberta Infrastructure City of Edmonton City of Calgary	Engineering Firms
British Columbia	CSA A23.1, A23.5	None	Engineering Firms

Table 13 - Atlantic provinces.

SCM	Policy Barriers		Technical Barriers		Economic Barriers		Other Barriers	
	Remarks	Sector	Remarks	Sector	Remarks	Sector	Remarks	Sector
Fly Ash	Not permitted for use in concrete	Federal (Department of National Defence DND)	Unfamiliarity with its properties	Architects Consultants	Long haul distances	Ready mix plants	Competition with Portland cement	Cement interests
	Not included in specifications	Specification writers	Non-uniformity	Utilities & distributors	Silos & handling equipment	Ready mix plants	Insufficient information provided for imported fly ash	Consultants and end users
	CSA does not adequately address the use of large quantities	Committee chairs and members						
Silica Fume			Not readily available	Ready-mix plants	Cost	Owner		

Barriers	Suggestions to overcome barriers
Political	Technology transfer at a senior level and more active participation by the department of Environment on the virtues of recycling. Federal projects should be “green” structures and a showcase for the maximisation of SCMs.
Technical	Technology transfer is required to educate specification writers and consultants in order to have the use of SCMs incorporated in specifications. Sustainability in the construction process must be emphasized.
Economic	Higher percentage of usage would reduce the costs of transportation.
Others	The quality problem can be overcome through a beneficiation process.

Table 14 – Quebec

SCM	Policy Barriers		Technical Barriers		Economic Barriers		Other Barriers	
	Remarks	Sector	Remarks	Sector	Remarks	Sector	Remarks	Sector
Fly Ash	Limited use in specification	Specification writers	Not all the producers are familiar with the use of fly ash. Background and research	Producer Owner	Transport	Supplier Owner	Insufficient silos. Not available in all regions	Producer
Slag	Limited use in specification	Specification writers	Not all the producers are familiar with the use of slag. Background and research	Producer Owner	Transport	Supplier Owner	-	-
Silica Fume	-	-	Background and research	Producer Owner	-	-	-	-

Barriers	Suggestions to overcome barriers
Political	Promote the use of environmentally friendly concrete (Kyoto)
Technical	Continue the research and show the benefits of SCMs use, and their limits of use in function with the conditions of exposure (proportions, water-to-cement ratio and cement content) via seminars and test results. Target projects for the use of cement with SCMs and follow their evolution with time.
Economic	Subsidize transportation costs of SCMs. Demonstrate long term performance if the cost is higher.
Others	Allow enough time to all concerned to familiarize themselves with the use of SCMs.

Table 15 – Ontario

SCM	Policy Barriers	Technical Barriers	Economic Barriers	Other Barriers
Fly Ash	$ Decision by Canadian and U.S. regulators on the classification of fly ash, whether as "nonhazardous" or "recyclable" material.	$ Fly ash quality (carbon content). $ Slow concrete set and strength development especially in cold conditions. $ Poor de-icing salt scaling resistance for high percentage utilisation. $ Fly ash quality in the future (NOx, SOx, CO_2 and Hg).	$ Cost of transportation. $ Cost of potential fly ash beneficiation.	$ Prescriptive codes as opposed to the use of performance specifications. $ Lack of specific application standards and guidelines. $ Lack of statistics regarding the current usage.
Silica Fume			Cost	

Barriers	Suggestions to overcome barriers
Others	• Clear, stronger and simpler specifications and national guidelines giving the upper limits of cement replacement by fly ash and other SCMs agreed upon by all interested parties and issued under the CSA auspices are required (a comprehensive table showing the limits for the particular application, particular SCM, for summer and winter) (strongly suggested by RMCAO). • Need for further education concerning the performance, especially long-term durability. • More information released from Canadian Industries Recycling Coal Ash (CIRCA), from SCMs producers, from the cement industry. While American Coal Ash Association (ACAA) regularly publishes data concerning the production and use of Coal Combustion Products (CCPs), CIRCA, admittedly a younger organization, at this stage does not. More information showing the growth in the use of fly ash, and volumes available and the different applications using fly ash, would help to build the confidence of the fly ash users. • Education, both of future engineers and construction technologists still at the higher education institutions, as well as those already in the practice, is essential. Today there is only one school in all of North America where future civil engineers are exposed to any knowledge of SCMs in more than just a passing manner.

Table 16 - Prairies (Saskatchewan & Manitoba) & Alberta.

SCM	Policy Barriers	Technical Barriers	Economic Barriers
Fly Ash	$ Restrictions placed on its use by certain provincial and municipal authorities and certain engineering firms. These restrictions mainly apply to concrete exposed to freeze-thaw cycles and/or application of de-icing chemicals, or concrete constructed outside of the summer months.	$ Fly ash concrete exposed to freeze-thaw cycles and/or application of de-icing chemicals. $ Restrictions in concrete flatwork sector: 1. Delay of finishing operations, 2. Difficulties of establishing the proper timing for finishing operations, 3. Problems in achieving specified floor flatness and levelness requirements. $ For Alberta only, the push for high volume use has resulted in concerns that if such use leads to durability or constructability problems, it could lead to blanket bans against the use of even moderate volume fly ash use as has already happened in the infrastructure sector in Alberta.	$ Cost of transportation in remote areas. $ Cost of silo for small companies.
Silica Fume			$ Cost of the material.
Fumed smelter Slag		$ GSCem, additional testing is currently underway to assess compliance of the product with the recommendations of the new CSA A3001-03 Specification	$ BFS, cost of transportation (except perhaps eastern Manitoba).

Barriers	Suggestions to overcome barriers
Policy	$ It was suggested that Dr. Michael Thomas in conjunction with ICON/CANMET, CIRCA, local chapters of ACI and Provincial Ready-mixed concrete Associations, organize a workshop with a major effort being made to get all the major specifying authorities, concrete suppliers, users and engineering inspection and testing companies to attend. The prime objective of the workshop would be to develop a uniform set of guidelines for use of fly ash, for adoption in the provinces.
Technical	$ A strong need for forums on the first barrier identified above, such that a more rational and consistent approach to the use of fly ash and other SCMs under such exposure conditions could be developed. ICON/CANMET or local American Concrete Institute (ACI) chapter could take a lead in such forums. $ For concrete flatwork sector, a forum to review and discuss this issue with concrete specifiers, suppliers and placing and finishing contractors would appear to be warranted. The SRMCA and MRMCA could take a lead in such forums. $ For Alberta only, use of high-volume fly ash should only proceed with great caution and longer term field demonstrations of durability in Alberta climate. $ For Alberta only, systematic testing, over a period of time, of various Type 10 cements and fly ashes available in Alberta to evaluate their ability to provide sulphate resistance for adoption as an alternative to Type 50 cements. $ For Alberta only, for GSCem, more standardized testing of concretes would appear to be needed to better define how such slag modifed concretes perform. Such testing should include the full suite of standard CSA and ASTM durability tests.

Table 17 - British Columbia

SCM	Policy Barriers	Technical Barriers	Economic Barriers	Other Barriers
Fly Ash	$ None	$ Constructibility (lower early strength and setting time) particularly in cold weather. $ Simple substitution of cement with fly ash on a kg for kg basis can result in substandard HVFA concrete which will then have an impact on the credibility of the system.	$ None at current price.	$ The relatively new position of the ready-mixed concrete industry in which they wish to produce concrete as a "manufactured product" (like steel). On this basis, they control the proportioning internally and the amount of SCM, if any, is unknown. The question then arises whether there is any incentive on their part to expand the use of SCMs.
Silica Fume	$ None	$ Caution required when used in flatwork.	$ Cost of the material.	$ Not strongly represented technically in BC.
Metakaolin	$ None	$ None	$ Historically too costly but now may become competitive with silica fume.	$ Not being marketed.

Barriers	Suggestion to overcome barriers
General	$ The utilization of SCMs is being effectively and successfully developed by EcoSmart and further promotion of SCMs is not recommended. The industry's (perceived) restraints are also addressed by EcoSmart. In fact, the approach used by EcoSmart (forums/seminars/demoprojects/publications) could be a model for promotion of SCMs elsewhere.

Table 18 – Total amount of SCMs produced and used across Canada.

	Fly Ash	GGBFS	Fumed smelter slag	Silica Fume
Production	4,800,000	380,000	150,000	20,000
Potentially Useable as SCM	2,200,000	380,000*	8,000	20,000
Currently Used in Concrete Applications as separate ingredient	449,350	216,000	-	3,350
Currently Used in Blended hydraulic cements	10,150	12,00	-	19,390
Currently Used in Other Applications	64,100	120,025	-	14,650
Total Amount of SCMs Used	523,600	347,225	8,000	37,390

* The whole quantity of BFS (1,438,000 tonnes) can be considered as potentially useable as SCM. The quantity of GGBFS can be increased if the market demand increases

Table 19 - Potential Sources.

Regions	Potential Sources of Unexploited SCMs	Possible Applications	Quantity, Tonnes	Expected Time of Availability of Technology
Atlantic	Landfilled fly ash, Diatomaceous earth and metakaolin			
Quebec	Slag	Blended hydraulic cement	100000	5 to 10 years
	Metakaolin (cost too high to process)	Blended hydraulic cement	-	> 10 years
Ontario	unused fly ash	concrete, blended hydraulic cement, kiln feed	15 to 20 million + 750,000 annually	Beneficiation technology is there, but is too expensive. Meeting the Kyoto protocol could change the situation
		flowable fill and self-compacting concrete		Technology already exists and has been demonstrated but not accepted by engineers, specifiers and the marketplace to any substantial degree
Prairies	No other potential sources. Even if alternative sources were identified, they would likely find it difficult to find a market, given the large excess of good quality fly ash available in the region, which is currently not being used.			
Alberta	Metakaolin (from FortMcMurray)			The EcoSmart Concrete study should, hopefully, provide more clarity regarding the potential commercial viability of this proposed SCM
Britich Columbia	Natural pozzolans (natural shales, diatomaceous earth and pumice)			Attempts were made to bring these to commercial viability in the late 1970's and through the 1980's with limited success. Restraints were: transportation cost, low reactivity and lack of uniformity.
	Slag	GSCem “cement economy”	30000	

Fig. 1 - Location of the potentially useable SCMs in Canada.

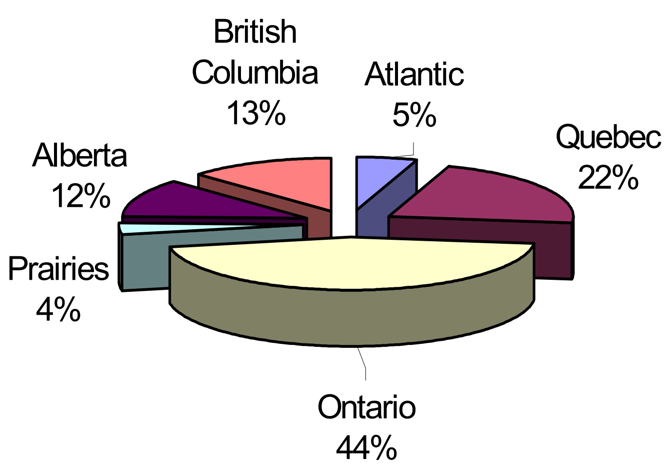

Fig. 2 - Percentage of concrete produced in each region (2001).

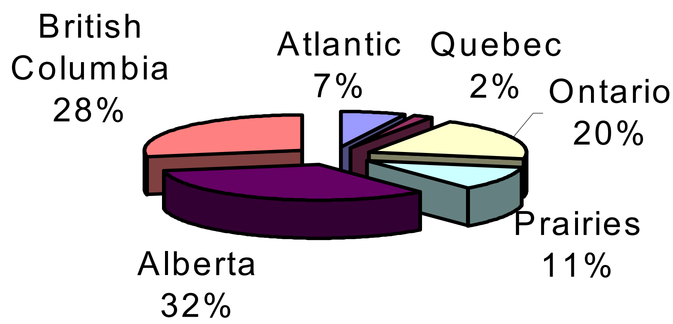

Fig. 3 - Percentage of fly ash used in concrete applications in each region.

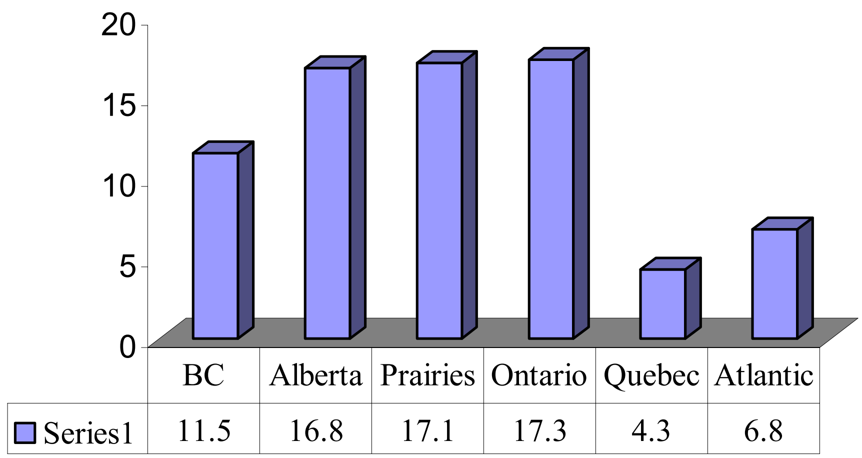

Fig. 4 - Percentage of SCMs to the quantity of cement used in each region (2001).