# Center for
# By By-Products
# Utilization

## THE ROLE OF FLOWABLE SLURRY IN SUSTAINABLE DEVELOPMENTS IN CIVIL ENGINEERING

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Report No. CBU-1999-01
REP-358
January 1999

For Presentation and Publication at the ASCE Conference on Materials and Construction - Exploring the Connection, May 10-12, 1999, Cincinnati, Ohio.

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**The Role of Flowable Slurry in Sustainable Developments in Civil Engineering**

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*Abstract*

**This project was conducted to evaluate the environmental impact of use of Controlled Low Strength Materials (CLSM) incorporating industrial by-products (coal fly ash, and used foundry sand). CLSM reference mixtures were proportioned for strength levels in the range of 0.3 to 0.7 MPa (50 to 100 psi), at 28 days, using two sources of ASTM Class F fly ashes. For each reference mixture, other mixtures were proportioned using various by-products (e.g., foundry sand as a replacement of fly ash in the range of 30 to 85 percent).**

**The ingredients of the CLSM mixtures were tested for their physical and chemical properties, and leachate characteristics. The leachate results of the materials made with and without foundry sand were below the Enforcement Standard of the Wisconsin Department of Natural Resources (WDNR) Groundwater Quality Standard. They also met practically all the parameters of the Drinking Water Standards (DWS). The use of coal fly ash and used foundry sand in flowable CLSM mixtures provided favorable environmental impact in terms of maintaining drinking water and ground water quality standards. Addition of the foundry sand caused substantial reduction in concentration of the elements that are considered hazardous in accordance with WDNR Groundwater Quality Standard. Therefore, the use of by-products would provide favorable environmental impact.**

*Introduction*

**U.S. foundries generate over 7 million tonnes (8 million tons) of by-products. Wisconsin alone produces nearly 1.1 million tonnes (1.25 million tons) of foundry by-products, including foundry sand and slag. Most of these by-products are landfilled. Landfilling is not a desirable option because it not only causes huge financial burden to foundries, but also makes them liable for future environmental costs, problems, and restrictions associated with landfilling. Furthermore, the cost of landfilling is escalating due to shrinking landfill space and stricter environmental regulations. One of the**

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**innovative solutions appears to be high-volume uses of foundry by-products in construction materials. This paper primarily deals with application of used foundry sand in manufacture of CLSM.**

**CLSM is defined as a "cementitious material that is in a flowable state at placement and has specified compressive strength of 8.3 MPa (1200 psi) or less at the age of 28 days (ACI 229 1994)." CLSM is primarily used for nonstructural applications such as a backfill material for utility trenches containing ducts and/or pipes, around manholes and other excavations in streets, around foundations, or as a fill for abandoned tunnels, sewers, storage tanks, etc.**

**Water permeation through CLSM can leach its water soluble constituents. If the leachate contains high concentrations of contaminants, it can have polluting influence on groundwater or surface water. Before commercial application of this material, it is essential to establish its environmental impact. Therefore, this research was primarily directed towards establishing the environmental impact of CLSM containing foundry sand.**

*Previous Work*

**Naik and his associates (Naik and Ramme 1994; Naik and Singh 1997; Naik et al. 1991) and others (Krell 1989; Larson 1990; Smith 1991) have made significant contributions in development of CLSM mixture proportions. Excavatable CLSM mixtures with strengths ranging between 0.3 and 0.7 MPa (50 to 100 psi) at the age of 28 days are generally used. However, there is a lack of information on properties of CLSM incorporating foundry sand (Naik and Singh 1994).**

**Ham et al. (Ham et al. 1981) evaluated leaching characteristics of used foundry sand. The results revealed that leaching potential was greatly influenced by the process temperature, and the greatest matter release was observed for the foundry sand not subjected to process temperature. Constituents of the leachates also depended upon type of foundry sand which reflected the differences in the binder material present in the waste material. Engroff (Engroff et al. 1989) evaluated leachate characteristics of foundry sands derived from nine common core binder systems using TCLP test method. The test data showed presence of a wide range of organic compounds, but their concentrations were low. Boyle (Boyle et al. 1981) determined leachate concentrations of cadmium, chromium, and lead for samples obtained from cupola dust or sludges of gray iron foundries. Their results showed that cupola dusts or sludges from 9 of 21 factories were EP toxic. Most likely, the processes that produced EP toxic cupola dust or sludges were electric arc furnaces and/or from baghouses which are more acidic nature than wastes from other processes tested. Traeger (Traeger 1987) investigated leaching potential of foundry waste material and on native soils from Wisconsin. In general, constituents leached from foundry sands were lower than the native soils compared to the Drinking Water Standards (DWS). The results further indicated that foundry sand was non-hazardous per Resource Conservation and Recovery Act (RCRA) criteria.**

**Leachate test results on fly ash and cement samples (Pflughoeft-Hassett et al. 1993) have shown all elements below RCRA limits and many of them even below primary DWS. American Engineering Testing, Inc (American 1992) evaluated leachate characteristics of fly ash, spray dryer material, and bottom ash/slag. The TCLP leach data, except for barium, showed elemental concentration at or below their corresponding DWS. Both ASTM and TCLP leach data exhibited similar results for most elements. The TCLP data showed high concentration of barium and lower concentration of boron compared to the ASTM leach data.**

*Materials*

**Both clean (unused) and used foundry sands were incorporated in this investigation. The used foundry sand was obtained from a steel foundry. Physical properties of foundry sands were determined using appropriate ASTM standards.**

**Two ASTM Class F fly ashes (designated as F1 and F2), obtained from two different sources in Wisconsin, were used in this work. All the physical properties of the fly ashes, except the Strength Activity Index at 7 days for fly ash F1 and LOI for fly ash F2, satisfied the ASTM C 618 requirements for Class F fly ash. Type I cement meeting ASTM C 150 requirements was secured from one source and was used throughout this investigation.**

*Mixture Proportions for Flowable Slurry Materials*

**In this work, two reference CLSM mixtures (one for each type of fly ash) were used. The reference mixture with fly ash F1 was designed for flow of 400 ± 25 mm (16 ± 1 in.) and the second mixture with fly ash F2 for flow of 280 ± 50 mm (11 ± 2 in.). For each reference mixture, additional mixtures were proportioned with foundry sand as a partial replacement of fly ash. All mixtures were proportioned to have the 28-day compressive strength in the range of 0.3 to 0.7 MPa (50 to 100 psi). A total of 18 different CLSM mixtures (Table 1) were proportioned and produced at the UWM Center for By-Products Utilization (UWM-CBU) Cement and Concrete Research Laboratory. Of these, two were the control mixtures without foundry sand, and the remaining sixteen had four different replacement levels of fly ash on a mass basis (30, 50, 70, and 85%) with two types of foundry sand (clean and used).**

*Preparation and Testing of Specimens*

**For each CLSM mixture, 150 mm dia. x 300 mm cylinders (6" dia. x 12") were made for compressive strength in accordance with ASTM D 4832. Leach tests were conducted on fly ash, clean and used foundry sand, and CLSM mixtures in accordance with ASTM D 3987. This method was selected to determine mobility (leaching) of substances due to permeation of water through these material when used in actual construction work.**

*Test Results and Discussion*

**The compressive strength increased with age. The compressive strength values for all slurry mixtures ranged from 0.27 to 0.55 MPa (40 to 80 psi) for the fly ash F1 mixtures and 0.3 to 0.6 MPa (45 to 90 psi) for the fly ash F2 mixtures at 28 days. Generally, compressive strength increased with increasing amount of foundry sand up to a certain limit, and then decreased. The strength data revealed that excavatable flowable slurry with up to 85% fly ash replacement with clean or used foundry sand can be manufactured without significantly affecting the strengths of the reference mixtures.**

**The permeability of the CLSM slurry mixtures varied from 4 $\times 10^{-6}$ cm/s to 72 $\times 10^{-6}$ cm/s which are comparable to granular fill materials. The permeability for both reference mixtures were not greatly affected by increasing foundry sand content for up to 70% fly ash replacement at the age of 30 days. However, a rapid increase in permeability was observed for the fly ash replacement with foundry sand beyond 70%. This probably occurred because of increases in size of voids produced by the increase in the amount of foundry sand, and decrease in the amount of finer fly ash particles in the mixture. For lower foundry sand mixtures, i.e. higher fly ash mixtures, a decrease in permeability also occurred due to the densification of the material microstructure resulting from pozzolanic reaction of the fly ash. The effects of source of fly ash and foundry sand on permeability were negligible.**

**The bulk chemical analysis was carried out to determine total elemental concentrations of fly ash, clean foundry sand, and used foundry sand. This analysis determines the presence and concentration of chemical elements in these materials, but not their mobility. However, the bulk analysis is of interest in determining the type of constituent materials present, and maximum possible leachate concentration.**

**The clean foundry sand primarily showed concentration of Si in excess of 500 ppm. The used foundry sand exhibited concentrations of Cr, Hf, Ti, Si, Zr, Fe, Na and Al above 500 ppm concentration. The used foundry sand exhibited the presence of higher concentrations of several elements, including, Dy, Nd, Ce, U, Cr, Hf, Ti, Mg, Cu, Zr, Ni, Fe, Co, Na, Al, Mn, Ca, V, etc., compared to the clean foundry sand and lower amount of Si. The additional amounts of these elements entered into the used foundry sand during the mold making and metal casting processes. Other elements in the foundry sands ranged from below their respective detection limits (BDLs) to maximum concentration less than 500 ppm.**

The analysis of fly ash samples exhibited concentration of various elements such as Ce, Ba, Ti, Mg, Al, Sr, Rb, Fe, Na, K, La, and Ca above 500 ppm. Numerous other elements present in the fly ash were either at very low concentrations or BDL, to maximum concentrations of less than 500 ppm.

In this investigation, the Groundwater Quality Standards (GWQS) of the Wisconsin Department of Natural Resources (WDNR), especially health-related, were used as a frame of reference for determining environmental impact of the materials. However, leachate data were also compared with the Drinking Water Standards (DWS) for comparing leachate quality. The ASTM leach tests were performed on the clean foundry sand, the used foundry sand, fly ash F2, and CLSM mixtures made with both foundry sands. Leachate derived from each material was analyzed for inorganic constituents in accordance with WDNR requirements.

The clean foundry sand met both the Preventive Action Limit (PAL) and the Enforcement Standard (ES) of the public health-related GWQS. The used foundry sand met all parameters of the ES, but it exceeded the PAL for lead and chromium. However, the concentration of iron in used foundry sand was higher than the public welfare-related ES of the GWQS. The increased iron in the used foundry sand was probably due to the introduction of iron during the metal casting processes. Both foundry sands met all the requirements for the DWS. The fly ash sample (F2), except for arsenic, met all parameters of the ES of the GWQS concerning public health. It exceeded the PAL for arsenic, chromium, lead, and selenium. With the exception of selenium, this fly ash also met all parameters of the DWS. The fly ash met all parameters of the GWQS related to public welfare for iron.

The leachate test results revealed that the reference mixture containing only fly ash F1 met all the requirements of the ES and most of the PAL of the GWQS. It also met all the parameters of the DWS. With fly ash F1, addition of clean foundry sand caused slight reduction in selenium concentration of the CLSM mixture containing up to 70% clean foundry sand. Since the clean foundry sand showed absence of selenium, the detected selenium contribution in the CLSM is due to contributions from both fly ash and cement. All the CLSM mixtures met the ES and PAL parameters for public welfare-related GWQS.

The CLSM mixture containing fly ash F2 without foundry sand met all requirements of the ES of the GWQS. However, selenium concentration was above the PAL for the mixtures containing up to 70% foundry sand. Except for selenium, these mixtures satisfied the drinking water standards (DWS). The amounts of selenium in the CLSM mixtures were contributed by fly ash F2 and the cement. Generally, addition of both clean and used foundry sand caused reduction in the selenium concentration of the CLSM mixture. Therefore, addition of foundry sand appears to provide favorable environmental impact for the CLSM mixtures.

American Engineering Testing (1992) reported leachate concentrations of coal combustion by-product materials in the same range as that observed for portland cement and virgin soil. The same was found to be true for slurry ingredients and slurry

**mixtures tested in this work. Based on the results obtained, it was concluded that CLSM containing fly ash and foundry sand are environmentally friendly materials.**

*Conclusions*

**Although the used foundry sand did not pass all ASTM C33 specifications for fine aggregate for use in concrete, it was found suitable for use in CLSM. The results demonstrated that excavatable flowable slurry incorporating fly ash and foundry sand as a replacement of fly ash up to 85% can be produced.**

**The water permeability of the fly ash CLSM mixtures was relatively unaffected by inclusion of either clean or used foundry sand for fly ash replacement up to 70%. The permeability values of the CLSM mixtures in this investigation was comparable to those observed for typical sand backfill materials. The permeability values ranged from 4 x $10^{-6}$ to 74 x $10^{-6}$ cm/s. The effect of type and source of fly ash as well as foundry sand was insignificant on compressive strength and permeability.**

**The clean foundry sand showed only one element whose concentration exceeded 500 ppm. Whereas, the used foundry sand showed concentrations of elements Cr, Hf, Ti, Si, Zr, Fe, Na, and Ar above 500 ppm. The used foundry sand showed the presence of several elements, including Dy, Nd, Ce, U, Hf, Ti, Mg, Cu, Zr, Ni, Co, Na, Al, Mn, Ca, etc., higher than the clean sand. The fly ash F1 exhibited concentrations of various elements, such as, Ce, Ba, Ti, Mg, Al, Sr, Rb, Fe, Na, K, La, and Ca above 500 ppm. Fly ash F2 met all parameters with exception for arsenic of the ES of the GWQS and DWS. Both clean and used foundry met the ES of the GWQS. They also satisfied the requirements for the DWS. All CLSM slurry mixtures made with fly ash F1 met all the requirements of the ES. All slurry mixtures made with fly ash F2 met all the requirements of the GWQS.**

**In general, inclusion of both clean and used foundry sand caused reduction in concentration of certain contaminants. The use of foundry sand in CLSM slurry, therefore, provided a favorable environmental performance. All fly ash slurry materials made with and without foundry sand are environmentally friendly materials.**

*Acknowledgement*

**The authors express deep sense of gratitude to the UWS Solid Waste Research Council, Madison, WI; Badger Mining Corp., Berlin, WI; Fall River Foundry Company, Fall River, WI; Maynard Steel Casting Corporation, Milwaukee, WI; Pelton Casteel, Inc., Milwaukee, WI; Stainless Foundry & Engineering, Inc., Milwaukee, WI; Wisconsin Aluminum Foundry Company, Manitowoc, WI; and, Wisconsin Electric Power Company, Milwaukee, WI for their financial support for this investigation. Special thanks are expressed to Oluwole B. Adebayo for his help in experimental planning, testing, and data collection used in this work.**

**The Center was established by a generous grant from the Dairyland Power Cooperative, La Crosse, WI; Madison Gas and Electric Company, Madison, WI;**

**National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire, WI; Wisconsin Electric Power Company, Milwaukee, WI; Wisconsin Power and Light Company, Madison, WI; and, Wisconsin Public Service Corporation, Green Bay, WI. Manitowoc Public Utility is also providing a grant to continue the work of the Center. Their financial support, along with the financial support of the Manitowoc Public Utilities, continuing help and encouragement, and active, continuing interest, is gratefully acknowledged.**

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**TABLE 1: CLSM Mixture Proportions**

| Mixture No. | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
|---|---|---|---|---|---|---|---|---|---|
| Foundry Sand,* % | 0 | 30(FS1) | 50(FS1) | 70(FS1) | 85(FS1) | 30(FS2) | 50(FS2) | 70(FS2) | 85(FS2) |
| Cement, kg/m$^3$ | 36 | 44 | 37 | 35 | 46 | 44 | 37 | 36 | 46 |
| Fly Ash F1, kg/m$^3$ | 1044 | 899 | 737 | 482 | 244 | 899 | 737 | 490 | 248 |
| Foundry Sand, kg/m$^3$ | 0 | 398 | 756 | 1149 | 1274 | 405 | 757 | 1104 | 1434 |
| Water, kg/m$^3$ | 540 | 450 | 406 | 363 | 363 | 450 | 405 | 368 | 369 |
| (W / (C+FA)) | 0.50 | 0.48 | 0.52 | 0.70 | 1.25 | 0.48 | 0.52 | 0.70 | 1.25 |
| Flow/Spread, mm | 413 | 406 | 400 | 406 | 406 | 406 | 406 | 400 | 413 |

| Mixture No. | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 |
|---|---|---|---|---|---|---|---|---|---|
| Foundry Sand,* % | 0 | 30(FS1) | 50(FS1) | 70(FS1) | 85(FS1) | 30(FS2) | 50(FS2) | 70(FS2) | 85(FS2) |
| Cement, kg/m$^3$ | 47 | 46 | 44 | 47 | 44 | 47 | 46 | 47 | 45 |
| Fly Ash F2, kg/m$^3$ | 834 | 795 | 634 | 451 | 242 | 812 | 666 | 478 | 249 |
| Foundry Sand, kg/m$^3$ | 0 | 356 | 633 | 1105 | 1461 | 549 | 710 | 1166 | 1503 |
| Water, kg/m$^3$ | 685 | 561 | 507 | 297 | 322 | 361 | 467 | 351 | 311 |
| (W / (C+FA)) | 0.78 | 0.67 | 0.75 | 0.60 | 1.12 | 0.42 | 0.66 | 0.67 | 1.05 |
| Flow/Spread, mm | 298 | 292 | 305 | 305 | 330 | 305 | 311 | 337 | 318 |

***FS1 = Clean Foundry Sand; FS2 = Used Foundry Sand.**

**Keywords**

**chemical analysis, CLSM, compressive strength, controlled low strength materials, environmental performance, flowable fill, flowable slurry, fly ash, foundry sand, leachate, permeability.**