Two Decades of Ready-Mixed High Performance Silica Fume Concrete … A US Project Review

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Introduction / A Silica Fume Perspective:

Concrete production exists around the globe and is one of the leading construction materials, essentially man-made stone that has become a most versatile and universally recognized tool to build with. The bulk of the materials, or 80% of all ingredients in concrete, are naturally abundant aggregate, while the other fifth (20%) constitutes a binder, or glue, primarily composed of cement and supplementary cementitious materials (SCM) in combination with water. Hydraulic cement, globally the primary binder material utilized, is in approximate production of two billion tons per annum, used to produce about 2.5 tons of concrete per person on the planet.

In the United States following amounts of dry binder materials are estimated to be currently utilized on a yearly basis: Cement 150 million tons (136×10^6 mt), Fly Ash 30 million tons (27×10^6 mt), Slag 10 million tons (9×10^6 mt) and Silica Fume 100,000 tons (0.9×10^6 mt). Unlike other SCM, silica fume is not viewed as a cement replacement and customarily calculated as a cement addition. A comparatively small amount of silica fume (average of 5-10% by the weight of cement) has great impact in changing concrete performance due to its dominant chemical characteristic of a relatively high $SiO2$ content. A unique physical characteristic of this natural pozzolan derived from metallurgical furnaces is its microscopic size being about 100 times finer than Portland cement.

While silica fume has multiple applications, a significant portion of its annual production is utilized in concrete at an average quantity of 50 lbs/yd^3 supplementing an estimated one million cubic yards of high performance concrete (HPC) in the United States each year, supplied by the ready-mix industry. Silica fume inclusion to the concrete design is primarily dictated by project performance specifications aiming to minimize corrosion concerns and maximizing concrete strength performance, abrasion-, impact- or chemical resistance, while some uses are non-project specific addressing improvement to other occasional shortcomings in concrete technology such as limiting aggressive alkali activity, reduction of heat of hydration generation, optimizing viscosity modifying properties and limiting drying shrinkage potentials.

Types of projects that have utilized silica fume as a mineral additive for high performance concrete in its relatively brief market existence since the mid-1980s will be discussed from here on forward, with actual concrete mix design prescriptions presented in the appendix. Projects presented include high-rise construction, industrial floor applications, transportation and marine structures, and others with accompanying information of silica fume's contribution to the construction challenges, concrete performance and solutions achieved, not only from an engineering perspective but also from the point of view of the producers and contractors involved.

Silica Fume Applications

Some of the lesser known applications of silica fume to the ready-mix industry are a good starting point to better grasp the versatility of silica fume before elaborating on the more well-known applications such as in use for high strength concrete design and corrosion protection. Though silica fume has been available since the mid-1900's, its fine particle size and thus high water demand had not been advantageously manageable in concrete production until the advent of modern day high range water reducer technology arrived, which became a dominant presence in ready-mixed HPC from the 1980's forward.

Kinzua Dam, Pennsylvania

The Kinzua dam in Pennsylvania was one of the first major projects in the US to receive silica fume concrete to repair a stilling basin worn by falling water which caused severe abrasion erosion. Investigations showed that very high strength concrete with an altered pore structure created by the micro-packing properties of silica fume and combination of a very low water-cementitious ratio (W/C) were better suited than choosing a stronger aggregate grade to obtain maximum concrete abrasion resistance. Essentially the binder portion of concrete is always the weakest link and strengthening that will increase performance. As such, high strength concrete performance of 12,500 psi was specified by the authorities to address the need for a long-term durable solution. This application has been in place since 1983 and has stood the test of time very well. There are plans to core this concrete and examine in-place performance for a 25 year update.

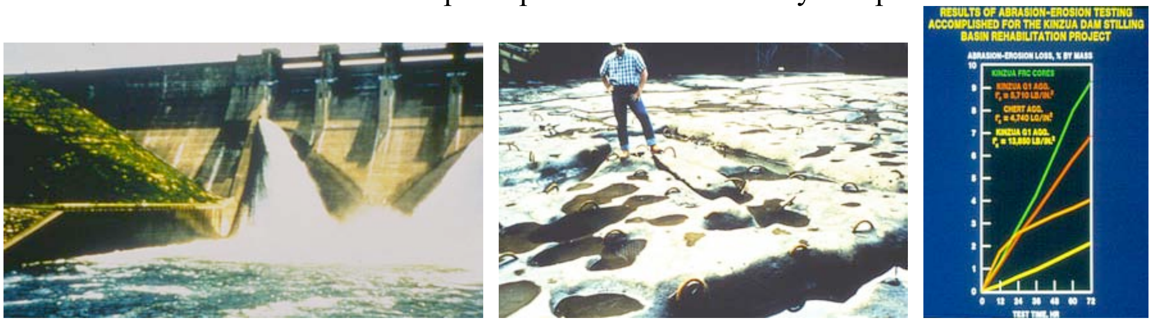

Fig.1-3 Kinzua Dam and de-watered stilling basin with severe erosion; Comparison of abrasion testing

Shotcrete & Underground Construction

Shotcrete is one concreting method not typically thought of as a ready-mixed supplied material. Large projects have their own on-site plants and use alternate means of transporting concrete to location, such as by rail or long-distance pumping, but more recently quite a few projects are receiving silica fume concrete from the ready mix industry. This may be related to the more applied use of the Austrian Tunneling Method (ATM) which is not only utilized in hard geology now in the US, but more recently in soft ground as well. The ATM is significant in that it eliminates traditional formwork and re-shoring through steel structures for tunnel support replacing it with sacrificial steel fiber reinforced shotcrete walls. Silica fume is a natural for use in shotcrete because it greatly increases the build-up thickness of freshly shot concrete and at the same time decreases rebound significantly. Both these attributes afforded by silica fume make for an extreme advance in constructability speed and decrease of material waste.

Fig.4-6 Robotic shotcrete application; inside and frontal view of sacrificial shotcrete walls support ATM

Shotcrete is not exclusively used for underground applications as shown in the Little Rock Dam, California project which received a retrofit overlay to provide for adequate seismic stability. This ±3” (75 mm) slump shotcrete mix design employed for binder materials 682 lb/yd^3 (405 kg/m^3) of Type I Portland cement, 69 lb/yd^3 (41 kg/m^3) of silica fume, 101 lb/yd^3 (60 kg/m^3) of steel fiber and water, not to exceed a 0.45 W/C. The average shotcrete thickness was 4.7” (120 mm) with compressive strength cores averaging 7200 psi (50 MPa) at 28 days of age. Many other above-ground applications exist for shotcrete not only for retrofit or repair, but also for new construction such as water containment, retaining walls and similar structures.

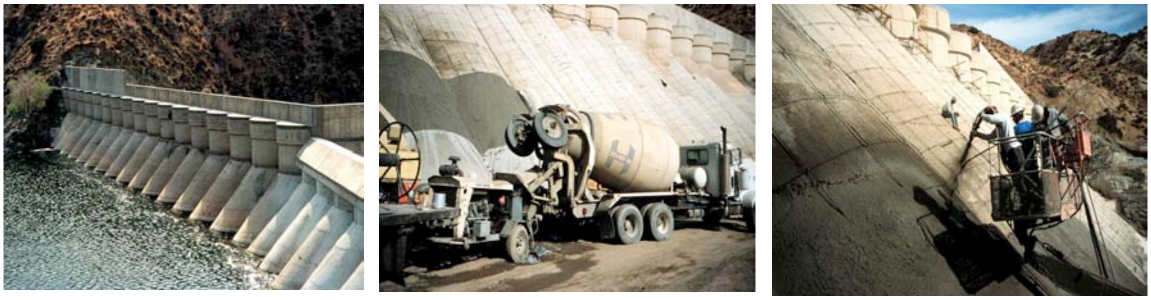

Fig.7-9 Little Rock Dam receives a seismic retrofit upgrade through ready-mixed delivered shotcrete

Canister Storage Facility Hanford Washington

At the construction of the canister storage building at the Hanford nuclear site in the State of Washington a variety of criteria made mix design selection unusual business. Requiring high strength of 7,500 psi (51.5 MPa) and limiting the maximum temperature in place to 100ºF (38ºC) to control thermal cracking are two contradicting characteristics when designing concrete. The solution was limiting the concrete placing temperature to 70ºF (21ºC) through addition of ice and utilizing a low total cementitious content of 601 lb/yd^3 (357 kg/m^3) which included a 40% pozzolanic content, fly ash @ 28% replacement and silica fume @ 11% addition rates. Silica fume provides a lot of strength gain for a relatively small powder volume, and one that does not generate heat immediately like Portland cement would. In addition, as can be seen from the dense reinforcement pictures, this had to be a highly workable mixture for ease of placement, which again was a feature to accomplish with a maximum W/C of 0.37 coupled with a low cementitious content and the necessary ice further depleting the actual free water addition.

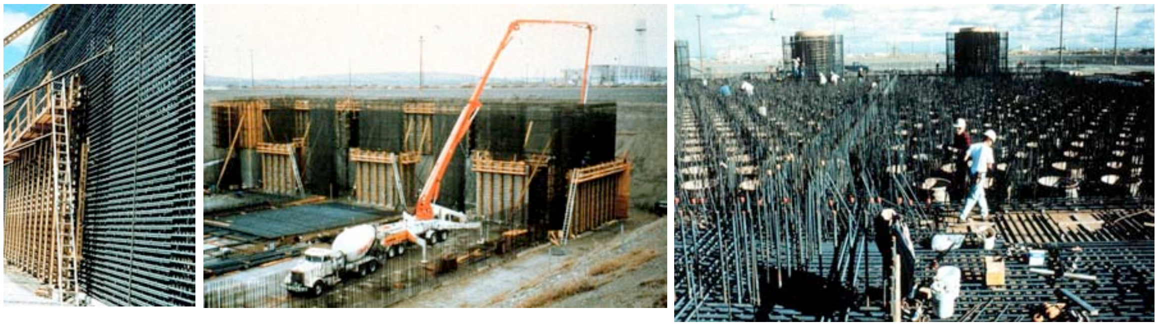

Fig.10-12 Massive structures receive low heat of hydration concrete at the Hanford Nuclear Site in WA

The Great Stupa of Dharmakaya Fort Collins Colorado

A most interesting project which has just been completed after fifteen plus years under construction was placed painstakingly by volunteer labor with not much prior experience in concreting altogether, yet achieving a beautiful structure in a remote location. Prior to construction, the owner's desire to make this a 1000 year structure was spread through the industry. The resultant concrete design incorporated various materials known to maximize longevity of the structure and as such silica fume was an obvious choice to achieve long term durability through high strength, corrosion and abrasion resistance.

Fig.13-15 A 1000 year concrete design for the Great Stupa of Dharmakaya in Fort Collins, Colorado

Corrosion Protection

Corrosion protection of steel-reinforced concrete is the single largest market for ready-mixed silica fume concrete. Not only can silica fume generate sufficient concrete impermeability to dramatically delay the onset of corrosion, but once corrosion is initiated, it is severely limited in the progress of deteriorating concrete thanks to the low electrical conductivity afforded by the silica fume concrete, as steel reinforcement corrosion is basically an electrical process. One main area of corrosion concern exists in transportation structures where artificially deposited chlorides (de-icing salts used during the winter months) promote corrosion. Natural chloride attack in the vicinity of ocean water, spray or mist is specifically aggressive on marine structures and others nearby. 5 to 10% silica fume addition by the weight of total cementitious along with a W/C below 0.45 has become a standard formula to equip concrete with the means to protect its vital reinforcing steel, which if corroding can expand up to seven times its original volume and create internal forces much stronger than the concrete itself, cracking and spalling it.

Roosevelt Bridge Stuart Florida

Florida has more than its fair share of corrosion concerns, not only due to being surrounded by ocean water, but also by the constantly warm climate where concrete experiences more drying / wetting cycles enabling a higher chloride absorption rate, thus intensifying the corrosion process. The Florida D.O.T. specifies an 8 to 9% silica fume addition rate for all concrete under salt water or in its splash zone. Amongst other concrete performance criteria, a maximum of 1,000 coulombs @ 28 days has to be achieved, as evaluated by the AASHTO T-277 Rapid Chloride Permeability test. In 1993 the Roosevelt Bridge in Stuart started construction in southeast Florida along US Hwy.1

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Fig.16-20 Mass concrete barged to location to Florida D.O.T. project at ocean inlet for new US 1 bridge

Seaport Calhoun County Texas

Seaports are right at the oceanfront exposed to constant chloride ingress where conventional concrete would not experience a lifespan longer than a couple of decades. Add to that abrasion forces from the ocean wake and possible impact situations from vessels and it is only prudent for the designing engineer to select not only high performance concrete, but also one with corrosion protection built in, as it was the case for the port authorities supervising the Calhoun County Seaport construction in Texas.

Fig.21-25 Texas' Calhoun County navigational district builds corrosion-resistant with silica fume concrete

Airport Parking Garage Memphis Tennessee

Parking garages experience the greatest potential chloride exposure when automobiles enter during the winter months saturated with de-icing salts collected from the roadways, dripping off onto the floors and creating run-off onto the rest of the structure. Repairs are possible, but at a great expense, downtime and inconvenience to customers. The often privately operated income-generating structures are very keen at keeping future operating expenses under control, specifying very low permeability concrete, at ≤ 1000 coulombs.

Fig.26-28 Memphis Airport; fogging concrete surface retains moisture, small sections to control cracking

Bridge Deck Overlay Beverly Ohio

Ohio's geography is well centered in the so-called "rust belt", where concrete is truly put to the test not only because of the corrosion concerns due to man-applied chlorides to the road ways but furthermore by the high amount of freezing and thawing cycles per year. More freeze-thaw cycles means also more expansion and contraction of the concrete, making it susceptible to more cracking potential which would ultimately provide additional avenues for chloride to travel into the concrete and promote corrosion at the steel reinforcement level. In such an environment silica fume's role of limiting electrical conductivity is paramount to combat corrosion and keep it at bay once initiated. Ohio D.O.T. specifies a high air content for its concrete of 8 ± 2% to also provide the concrete with the best freeze-thaw durability. High strength, very low W/C and a very low permeability requirement are all parts of Ohio's concrete design for bridge deck overlays which can relatively quickly rehabilitate deteriorated structures. Below we have a step by step pictorial review of the typical seamless and continuous constructability of silica fume concrete utilized in a rehabilitation overlay project.

Fig.29-31 "medium" slump range ≤ 8"; bonding slurry application and concrete deposit close to location

Fig.32-33 bridge deck machine takes over the leveling and screeding process; concrete deposits continue

Fig.34-36 automatic float and burlap drag; final rake texturing; the critical curing via moist burlap cover

High Strength Concrete

Embassy Suites & Trump Palace New York City

These two projects were amongst the earliest large volume bulk silica fume concrete applications for high-rise structures. For New York City it was a first application of f'c = 9,800 psi (67.5 Mpa) concrete and highest specified compressive strength ever at this time in 1989. The building code purposely did not identify such concrete as 10,000 psi (68.9 Mpa) for that would have required an additional inspector on site.

High strength failures had become commonplace in New York City and these projects could not accommodate repairs, which often translated into increasing column size after-the-fact and reducing useable square footage, thus silica fume concrete was viewed as providing an insurance in strength overdesign and as well elevate high performance concrete in New York City to a new level to accommodate future design possibilities.

At Embassy Suites, which was constructed over a landmark historic theatre without touching it, literally a steel bridge was filled with this new 9,800 psi (67.5 MPa) concrete design to support the rising superstructure above. Simultaneously, a few miles north, much of the vertical concrete at the Trump Palace, with a high modulus of elasticity requirement, also utilized the same concrete design. Both projects consumed an estimated 25,000 cubic yards (19,100 m^3) of high strength silica fume concrete, which was transported from outside Manhattan Island, from Queens, thus often delayed in traffic arriving at the site close to the specified 90 minute expiration time.

Fig.37-39 Embassy Suites Tower & Hotel; flowing silica fume concrete and adapted placemen procedure

Very high slump of ±10" (255 mm) was intra-designed and a slump below 8" (200 mm) became basis for rejection unless properly retempered with superplasticizer on the site until corrective measures were implemented at the concrete production plant. When slump criteria were met, concrete temperatures of 100°F (38ºC) and up to 2 hours time from batching were acceptable, allowing concrete to perform as anticipated, i.e. flow into difficult placement situations in a self-leveling manner. High slump and optimized mix design finess modulus afforded by fine particle size silica fume allowed for easy pumpability and placement procedures, and prevented segregation. As seen in pictures, often a sheet of wood or wooden chute were utilized to deflect and guide the concrete to its final destination, also necessitating minimum consolidation by mechanical means.

Fig 40-43 Trump Palace; high performance concrete placement; finished high strength column

9,800 psi (67.5 MPa) silica fume HPC became the standard in New York City during the 1990's, resulting in 100's of thousand of cubic yards applied in many world class high-rise structures, furhtermore maintaining concrete as the primary and preferred building material and propelling engineered ingenuity and architectural adventurism.

Society (Key Corp.) Tower Cleveland Ohio

In the early 1990's Cleveland's tallest building to be was designed with column concrete attaining a modulus of elasticity of 6.8 million psi (46.9 GPa) and a compressive strength of 12,000 psi (67.5 MPa). To achieve an optimized mix design with a reasonable amount of total cementitous quantity to limit shrinkage and creep potentials, an 8% silica fume addition played an integral part along with a 30% replacement value of slag cement, combined with a very low W/C of 0.24.

A single stage pump delivered this high performance concrete from the ground level to the floors above into column forms which were filled from the bottom up. Since there was no access to consolidate via mechanical vibration and vibrating forms were impractical, high concrete fluidity was required and specified as a minimum slump requirement of 10" (255 mm). A combination of a large dose of plant-added high range water reducer coupled with set balancing additives provided this negative water slump mix design the necessary workability. Spread, or slump flow as coined a decade later with the advent of self-consolidating concrete (SCC) was measured and expected to exceed 20" (510 mm) to assure proper in-place consolidation.

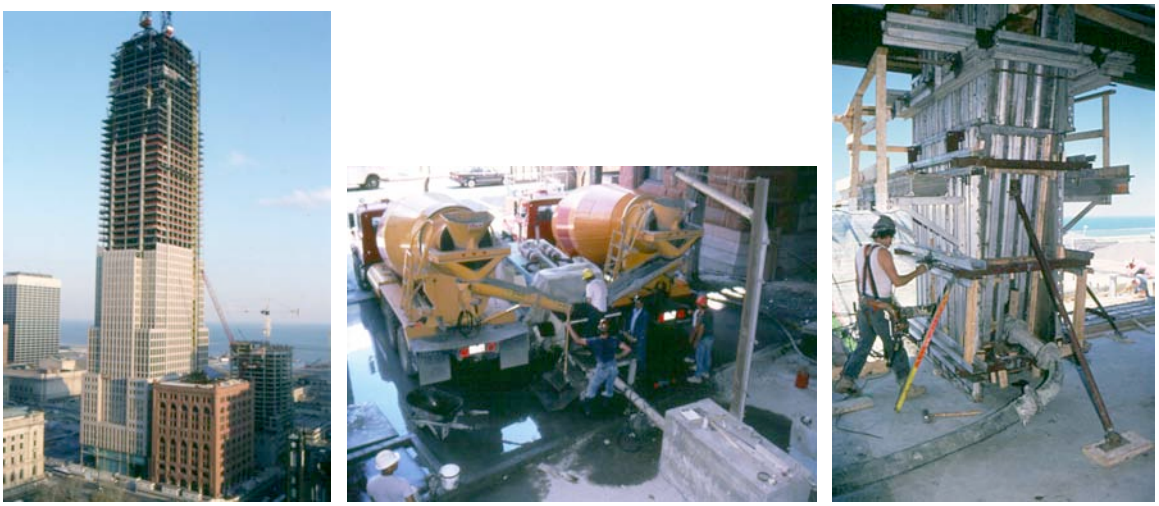


Fig 44-46 Society Tower; full height single stage concrete pumping and filling column from the bottom up

The average compressive strength achieved was in excess of 15,000 psi (103 MPa), well above specified performance, basically as a side effect to the more difficult performance of modulus of elasticity which in this case reached 7 million psi (48.3 GPa). Silica fume not only was instrumental in achieving the high modulus of elasticity requirement, but also to provide control in concrete viscosity, assuring a non-segregating SCC, well workable and long-distance pumpable high performance concrete.

Orange County Court House   Orlando   Florida

In the mid-1990's Florida released the highest to-date compressive strength specification of f'c =12,000 psi (83 MPa) applied to any cast-in-place concrete within the state at the time. With the standard over-design as per code, nearly 15,000 psi (103 MPa) compressive strength of concrete performance was required. This requirement was not brought about by the typical application for an ultra-tall skyscraper, but rather a moderate height legal building designed with large courtrooms of unobstructed views, requiring large open spans and therefore ultra-high strength beams and columns.

Fig 47-50   15,000 psi concrete for vertical applications at the Orange County Court House in Orlando

Research with locally available materials carefully evaluated for performance versus cost efficiency, resulted in an elevated total cementitious content with a minimal fly ash replacement quantity of 7% and a very low W/C of 0.25 which were further optimized through silica fume addition of 6% to push the envelope of concrete performance to the required specification parameters. A high concentration of superplasticizer enabled a high workability level to ensure ease of placement and appropriate consolidation, specifically in the summer months with concrete temperatures nearing 100ºF (38ºC). Columns and beams were placed with workability approaching SCC consistency.

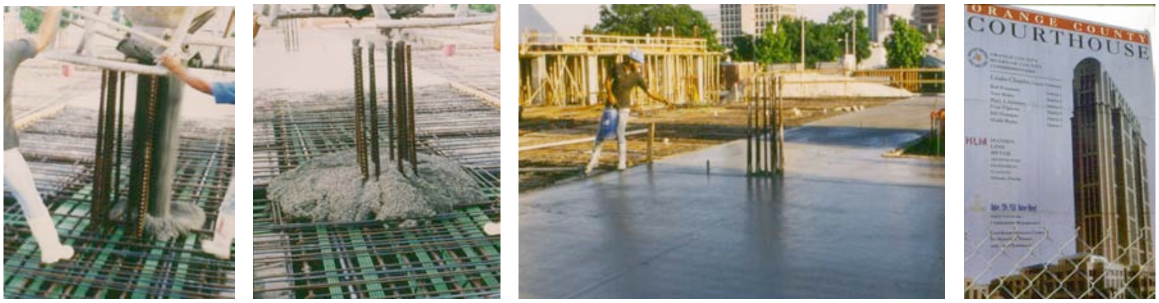


Fig 51-54 HPC concrete "puddling" for transfer of high strength concrete from columns through slab

Portions of the conventional strength slabs included the same high performance concrete in sections where the footprint of any high strength column was located. The high performance silica fume concrete placed there ("mushrooming / puddling") just prior to arrival of the conventional slab concrete was designed for a lower slump range from 6 to 8 inches (150 - 200 mm) to prevent the HPC from flowing out into the slab beams from the desired concentration of the column footprint, or potentially mix up with the slab concrete. Contractor placing finesse was key to successfully merge the two different concrete types through the finishing process and timing, as well as curing procedures.

Four Seasons Hotel & Tower Miami Florida

A ready-mixed, cast-in-place, silica fume SCC application, utilizing the silica fume to boost modulus of elasticity performance with local limestone and achieve high strength concrete versus a mix design with imported granite aggregate. At 750 feet height (230m) this building became the tallest structure in the USA south of Atlanta. In Florida to-date, this is one of the leanest mass-produced high strength concrete designed around desirable engineering characteristics of minimum creep and shrinkage by employing optimized alternate cementitious materials.

With extremely dense reinforcement and a high modulus of elasticity requirement this building was designed to withstand high category hurricane-force wind loads. Placing concrete in the dense reinforcement environment, particularly the core or elevator shaft portion of the building, required high concrete flowability of 20 to 25 inches (510 - 635 mm) spread. Such plastic concrete characteristics were applied on this project in the year 2000 before SCC became a household name in the US. Furthermore the high strength silica fume concrete design employed 10-15% less total cementitious quantity than similar high performance concrete produced locally, benefitting the desirable engineering characteristics through minimized total cementitious contents.

Fig 55-59 Extremely dense reinforcement necessitated self consolidating high performance concrete

Often impractical to consolidate by conventional means due to extreme rebar density it was critical to provide SCC characteristics and maintaining such workability with concrete temperatures close to 100° F (38ºC) and for up to 2 hours from time from batching. Silica fume's viscocity modifying properties enhanced the SCC consistency in controlling segregation even under free-fall situations of heights up to 20 feet (6.5 m). Concrete was pumped through a 5 -inch (12.7 cm) diameter line the entire building height with a single-stage pump. The various concrete mix designs employed an approximate 6% silica fume addition rate across the board to a 50/50 blend of slag and Portland cements.

Fig 60-61 Cast-in-place silica fume SCC for elevator shaft (internal view) and 36th level transfer floor

Approximately 20,000 cubic yards (15,000 m^3) of HPC with a 5 to 6 million psi (34.5 – 41.4 Gpa) modulus of elasticity requirement and an 8,000-10,000 psi (55 - 69 Mpa) compressive stgrength specification utilized imported granite. 15,000 cubic yards with a 4 to 5 million psi (27.6 - 34.5 Gpa) modulus of elasticity requirement and also an 8,000-10,000 psi (55 - 69 Mpa) compressive strength specification could forgo the imported granite aggregate through the use of silica fume in conjunction with local Florida limestone pearock and an HPC savings of approximately $ 150,000.00. Historically Florida limestone capacity to reach higher modulus of elasticity values fizzles out at approximately ±4 million psi (27.6 Gpa)

Fig 62-65 HPC column placement; external view of elevator shaft; nearly finished building in 2002

Heavy Industrial Applications

Facilities in the food production, waste management, chemical storage and generally raw material processing have become accustomed to constantly repair as an ongoing process. Material handling at these kind of industries takes a heavy toll on any concrete, particularly floors where all kinds of chemistry has opportunity to ingress into concrete, rapidly disintegrating it. Reaction of many chemicals with concrete constituents can quickly cause internal volume changes destroying concrete much faster than chloride initiating steel corrosion causing concrete destruction. Additionally heavy machinery often exerts serious abrasion and impact on already compromised concrete, making matters worse. Most of these types of facilities are constantly exploring new repair products or new methods for new construction to take longevity of structures beyond the usual couple of years, employing full-time engineering staff and construction crews to minimize plant downtime. Repairs here are typically made on a small scale and are expensive and time-consuming. It has long been a dream to provide ultra-durable concrete that can be delivered and applied on larger scale and high silica fume concrete provided in ready mixed quantities has filled a need, if not only for larger repair possibilities, but also much superior economy and excellent results in durability.

Chemical Storage Facility Savannah Georgia

Much of this heavy industry is in need of a variety of chemicals that continuously are delivered, transfered and stored at these production facilities. Hazardous materials storage areas are required to have spill containment areas to protect the environment. These areas are primarily functional for accident prevention to contain a chemical spill, but also necessary to collect wash-down water as these areas are routinely cleaned, if only to collect very small quantities of chemicals that may have leaked during material transfer or aging hardware. Very similar concrete mix design parameters that are utilized for corrosion protection are applicable for such construction and subsequent concrete protection, with the low W/C ≤ 0.45 specified, coupled with a ≈ 10% silica fume addition as part of the high performance specification.

Fig 66-68 Chemical storage containment areas entirely constructed with a 10% silica fume concrete

Paper Plant Wilmington North Carolina

Paper production operations have an abundance of fairly hazardous chemicals on their properties. When it came time to expand Federal Paper Co., plant engineers designed for a massive, five-story high building to house chemical additives and they were researching for the most durable concrete possible to apply to their new structure. A very high silica fume content was recommended to obtain highest possible concrete density with extremely low permeability. Desirable high compressive strength performance would be assured by a very low W/C, in this case set at 0.31; in fact over 11,000 psi (75 Mpa) were attained at the age of 28 days, a novelty in this rural area of North Carolina. Large quantities, nearly triple a conventional dosage of a Type F (normal set) high range water reducer provided the high workability of this very cohesive concrete mixture in the range of 10” (255mm) of slump and allowed for proper consolidation, specifically in the heavily reinforced wall sections. Hot weather concreting was overcome with a retarding admixture for set balancing. This concrete was air-entrained as well, as it would be subject to occasional freeze-thaw conditions in this geography. Rapid chloride permeability evaluation as per AASHTO T-277 were performed just for curiosity and yielded the excellent result of 115 coulombs. This is very close to a ≤100 coulomb result, considered negligible in the AASHTO T-277 permeability rating, and this author’s lowest permeability value ever observed in field production concrete over the past thirty years. The concrete was produced by a local ready mix company who had no prior experience with HPC nor silica fume, of which the high quantity (165 lbs/yd^3 – 98 kg/m^3) was handloaded from bags.

Fig 69-71 5-story chemical processing building entirely constructed with 22% silica fume HPC

Solid Waste Authority Palm Beach Gardens Florida

Garbage transfer stations experience very short life cycles of their dump floors that are in operation practically 24/7. Impact from garbage trucks unloading and abrasion from heavy equipment moving the trash shortens the average floor life to only two to three years, and that is on specialty floors made with iron aggregate toppings or similar exotic construction materials. To the Solid Waste Authority the downtime of any plant and the logistics of diverting constantly accumulating trash are bigger problems than the expense of repairing their facilities. The downtime to repair such floors with specialty toppings averages two months before it goes back into operation; the average expense at the time of this project was approximately \$ 17 per square foot (\$ 183/m^2).

Silica fume's positive track record in the chemical industry with high addition rates intrigued the Solid Waste Authority to try out such a concrete on one of their upcoming projects in 1993. The concrete recipe is quite similar to the paper plant project discussed above and has become a widely utilized HPC design for heavy industrial applications. The trial project was a complete success, as the plant closing time was cut in half – only one month construction time from start of demolition to reopening of the facility. The total construction cost approached \$ 9 per square foot (\$ 97/m^3) for a topping twice as thick, or twice the volume as with the conventional specialty repair materials. After seven years this floor was still in use.

Fig 72-73 Compost transfer facility; pouring self-leveling concrete, followed by immediate final finish

Fig 74-75 Two hours after bay 1 completion concrete can support manpower applying burlap for wet cure

From that point on the Solid Waste Authority, as well as others, first in Florida and then in other states, adopted this sort of system. The pictures presented here are from Palm Beach County's second Solid Waste Authority installation, a new compost facility where with simple equipment and a pre-construction meeting a contractor who had no prior experience with such high caliber concrete, was able to do a successful job. Two long joint-free bays were continuously poured, adjacent to each other, with the usual SCC - approaching workability this concrete prefers (demands). Instead of the more labor-intensive fogging, monomolecular evaporation retarder is applied onto the concrete to maintain surface moisture until finishing can completed, visible in the fluorescent green sheen on top of the screeded concrete. A bull float finish is usually sufficient for these types of floors. It is possible to machine-trowel finish high silica fume content concrete, yet rarely essential, and only a very experienced finishing crew should attempt to perform such as timing and understanding of the concrete intricacies would be a pre-requisite. The final touch, as usual, is to provide moisture protection, here done with burlap which will shall be continuously kept moist for at least seven days to provide this silica fume HPC the proper hydration mechanism and prevent plastic and drying shrinkage potentials, particularly in the warmer climates exposed to sun radiation and wind.

Fig 76-78 Two hours after bay 1 completion concrete can support manpower applying burlap for wet cure

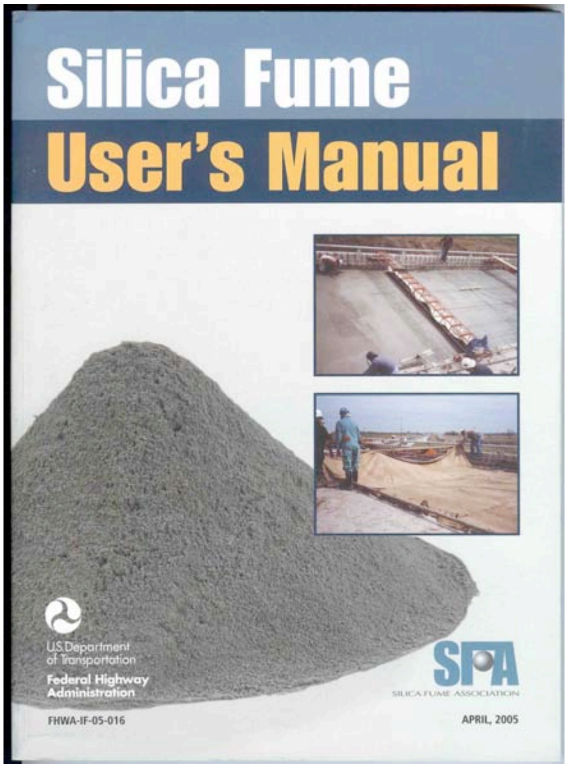
Titanium Plant Retrofit Henderson Nevada

This project had similar requirements for chemical exposure, impact and abrasion resistivity concerns that its concrete floors would be constantly exposed to during titanium production. As freshly produced titanium exits the production facility in just post-melted status, the concrete floor could also be occasionally subjected to extreme heat. The constructability environment for HPC applied here would provide an additional challenge with the very high concrete temperatures that Nevada can expect, particularly during the summer months. Ice replacing water would not be practical as the expected very low W/C would barely provide enough free water to efficiently mix this very cohesive concrete mixture and liquid nitrogen not deemed economical for smaller volume pours spread over a period of approximately half a year during this retrofit construction. Not only high heat, but also very low humidity would be a liability to successfull concrete production and execution. The solution was provided by a hydration control admixture used at a low dosage of 1 to 4 oz/cwt (65-260 ml/100kg) of the total cementitious value. This dosage was varied according to weather of the day and reports back from the project during pours about workability consistency; it allowed for normal setting characteristics of the HPC while not sacrificing workability at any time.

Fig 79-82 Titanium plant in Nevada undergoes retrofit with ultradurable high content silica fume concrete

Prologue

The projects and information contained in this ready-mixed silica fume concrete project review are only a few of the highlights of many more silica fume projects that have occurred in the US, and are based on information primarily obtained by the author's personal field experience and involvement. Individuals interested in obtaining more detailed information about silica fume's mechanical properties, storage, handling, available industry documents supporting the material, proportioning, designing and recommendations on producing and working with silica fume concrete, may find the Silica Fume's User Manual, published by the Silica Fume Association and the Federal Highway Administration very resourceful. The full manual is available also in PDF format for free download at www.silicafume.org



Silica Fume
User's Manual

U.S. Department of Transportation
Federal Highway Administration

SFA
SILICA FUME ASSOCIATION

FHWA-IF-05-016

APRIL, 2005

Appendix, Mix Design Proportioning & Performance Information of Projects Discussed

Kinzua Dam, PA -1983

US Army Corps of Engineers	Specifications:	
Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	650 - 700	385 - 415
Water / Cementitious Ratio	≤ 0.30	
Slump	7” – 10”	175 – 255 mm
7 day compressive strength	≥ 10,000 psi	29 MPa
28 day “	≥ 12,500 psi	54 MPa

Canister Storage Facility, Hanford, WA -1998

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	391	232
Fly Ash, Class F (28% replacement)	150	89
Silica Fume (11% addition)	60	36
Aggregates	to yield;	non - air-entrained
Water / Cementitious Ratio	0.37	0.37
High Range Water Reducer	1.7 gal / yd^3	8.1 ltr / m^3
28 day compressive strength	6,300 psi	43 MPa
90 day “	7,500 psi	52 MPa
Max.Concrete Temp. delivered	70° F	21° C
Max.Concrete Temp. in place	100° F	38° C

The Great Stupa of Dharmakaya, CO -1990 until 2005

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I / II	730	433
Fly Ash, Class C (11 % replacement)	94	56
Silica Fume (9 % addition)	76	45
Aggregates	to yield;	5 % air-entrained
High Range Water Reducer	1.3 - 1.5 gal / yd^3	4 - 5 ltr / m^3
Water / Cementitious Ratio	0.35	0.35
7 day compressive strength	6,900 psi	48 MPa
28 day “	8,700 psi	60 MPa

Calhoun County Seaport, Point Comfort, TX 1990

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	611	363
Silica Fume (8% addition)	50	30
Aggregates	to yield;	4 % air-entrained
Water / Cementitious Ratio	0.40	0.40
High Range Water Reducer	0.8- 1.1 gal / yd^3	3 – 4 ltr / m^3
28 day compressive strength	8,600 psi	59 MPa

Roosevelt Bridge, Stuart, FL -1993

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	451	267
Fly Ash (36 % replacement)	257	152
Silica Fume (8 % addition)	57	34
# 67 Limestone	1778	1054
Natural Sand	966	573
Water / Cementitious Ratio	0.35	0.35
Basic admixtures	Type D retarder	& AEA
High Range Water Reducer	1 gal / yd^3	4.6 ltr / m^3
28 day compressive strength	8,300 psi	57 MPa
56 day compressive strength	9,100 psi	63 MPa
Specification Requirement: very low permeability, i.e.<1,000 coulombs		

Airport Parking Garage, Memphis, TN -1991

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	600	356
Silica Fume (8% addition)	48	29
Aggregates	to yield;	5 ± 1 % air-entrained
Water / Cementitious Ratio	0.37	0.37
High Range Water Reducer	0.8 gal / yd^3	3 ltr / m^3
2 day compressive strength	3,000 psi	21 MPa
28 day “	7,000 psi	48 MPa
RCP Permeability	750 coulombs	

Bridge Deck Overlay, Beverly, OH -1990

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	700	415
Silica Fume (10% addition)	70	42
Aggregates	to yield;	8 ± 2 % air-entrained
Water / Cementitious Ratio	0.36	0.36
High Range Water Reducer	1.2 gal / yd^3	5 ltr / m^3
28 day compressive strength	8,000 psi	55 MPa
RCP Permeability	600 coulombs	

Embassy Suites / Trump Palace, New York City -1989

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I / II	799	474
Silica Fume	88	52
Aggregates	natural sand and traprock to yield;	non-air-entrained
High Range Water Reducer	2.1- 2.4 gal / yd^3	7 – 9 ltr / m^3
Water / Cementitious Ratio	0.32	0.32
3 day compressive strength	7,900 psi	54 MPa
7 day “	10,400 psi	72 MPa
28 day “	12,600 psi	87 MPa
56 day “	13,600 psi	94 MPa
56 day modulus of elasticity	7.4 x 10^6 psi	51 GPa

Society (Key Corp.) Tower, Cleveland, OH -1992

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	685	406
Slag Cement (G.G.B.F.S. 30%)	285	169
Silica Fume (8 % addition)	80	47
Aggregates	natural sand and traprock to yield;	non-air-entrained
Water / Cementitious Ratio	0.24	0.24
High Range Water Reducer	2.3-3.5 gal / yd^3	9 - 12 ltr / m^3
3 day compressive strength	9,300 psi	64 MPa
7 day “	12,600 psi	87 MPa
28 day “	14,200 psi	98 MPa
56 day “	15,100 psi	104 MPa
56 day modulus of elasticity	7.0 x 10^6 psi	48 GPa

Orange County Courthouse, Orlando, FL -1995

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	900	534
Fly Ash, Class F	72	43
Silica Fume	62	37
# 8 Granite	1840	1091
Natural Sand	924	548
Water / Cementitious Ratio	0.25	0.25
Basic admixtures	Type D retarder	& AEA
High Range Water Reducer	2 gal / yd^3	10 ltr / m^3
56 day compressive	15,000 psi	103 MPa
56 day modulus of elasticity	6.0 x 10^6 psi	41 GPa

Four Seasons, Miami, FL -2000

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	450	267
Slag Cement	450	267
Silica Fume	50	30
# 89 Limestone	1652	980
Natural Sand	960	570
Water / Cementitious Ratio	0.29	0.29
High Range Water Reducer	1.1 gal / yd^3	5.5 ltr / m^3
28 day compressive	11,700 psi	81 MPa
28 day modulus of elasticity	5.5 x 10^6 psi	38 GPa

Chemical Storage Facility, Savannah, GA -1990

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	564	335
Silica Fume (10% addition)	56	34
Aggregates	to yield;	5-6 % air-entrained
Water / Cementitious Ratio	0.44	0.44
High Range Water Reducer	0.9 gal / yd^3	3 ltr / m^3
7 day compressive strength	4,200 psi	29 MPa
28 day “	7,800 psi	54 MPa

Paper Plant, Wilmington, NC -1991

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	750	445
Silica Fume (22% addition)	165	98
Aggregates	to yield;	5 ± 2 % air-entrained
Water / Cementitious Ratio	0.31	0.31
High Range Water Reducer	2.1 - 2.5 gal / yd^3	8 - 10 ltr / m^3
Basic admixtures	Type D retarder	& AEA
1 day compressive strength	4,500 psi	31 MPa
7 day “	8,300 psi	57 MPa
28 day “	11,200 psi	77 MPa
RCP Permeability	115 coulombs	

Solid Waste Authority, Palm Beach Gardens, FL -1994

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type I	705	418
Silica Fume (20 % addition)	141	84
# 89 Limestone	705	418
Natural Sand	705	418
Water / Cementitious Ratio	0.24	0.24
Basic admixtures	Type D retarder	& AEA
High Range Water Reducer	2.25 gal / yd^3	11.2 ltr / m^3
1 day compressive strength	4,500 psi	31 MPa
7 day compressive strength	6,500 psi	45 MPa
28 day compressive strength	10,000 psi	69 MPa
Rapid Chloride Permeability	Aashto T-277	335 coulombs
NBS Abrasion Resistance	.356 mm @ ½ hr	.584 mm @ 1 hr

Titanium Plant Retrofit, Las Vegas, NV -2006

Mix Design Materials :	lbs / yd^3	kg / m^3
Cement, Type V	700	415
Silica Fume (20 % addition)	140	83
# 67 stone	1680	996
manufactured Sand	1120	665
High Range Water Reducer	1.5- 2.0 gal / yd^3	7.5 – 10 ltr / m^3
Hydration Control Admixture	5 - 40 ozs / yd^3	25 – 250 ml / m^3
Water / Cementitious Ratio	0.35	0.35
56 day compressive strength	≥ 10,000 psi	≥ 70 MPa