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Silica Fume Concrete: Industrial Applications

Keywords: chemical resistance, abrasion resistance, impact resistance, self-consolidating concrete, sustainability.

Introduction

Prolonged Durability

Silica Fume inclusion in concrete design as a mineral admixture provides higher strength and lower permeability, when added at an average rate of 5-10% by the weight of cementitious materials. Hardened concrete performance has also demonstrated significant increases in abrasion- and impact-resistance, which appear to be in direct relation to increased compressive and flexural strength behavior. Research and field performance have shown that high percentage (15-25%) silica fume concrete can be used to effectively mitigate chemical attack depending on specific exposure conditions (i.e. types of chemicals and concentration, pH levels, ambient conditions and number of wet/dry cycles). In the 1980's a variety of evaluations were conducted around the world testing loss of mass and decrease in modulus of elasticity of concrete exposed to magnesium-, calcium- and sodium chlorides, ammonium- and calcium nitrate, acetic-, formic-, nitric-, sulfuric-, lactic and hydrochloric acids and others. In general and, high percentage silica fume concrete can increase aggressive chemical resistance by a factor of two to five times that of ordinary Portland cement concrete.

Background

Primary Mechanisms

Fig. 1 Expansion

Silica Fume can minimize two self-destructive reactions within the concrete medium, dissolution and expansion. Dissolution occurs when salts and chemicals entering the concrete medium react with the abundant calcium hydroxide (a.k.a. free lime) present as a by-product of cement hydration. Up to 30% silica fume addition can virtually eliminate all calcium hydroxide by chemical interaction and form more strength/density producing CSH gel within the concrete medium. Expansion in concrete by internal volume change due to reaction between aggressive salts or a variety of chemicals and the many different concrete ingredients can be minimized by decreasing the porosity, or permeability, of the entire concrete medium. The Cement and Concrete Research Institute (CCRI) in Trondheim, Norway has conducted testing rendering 20% silica fume treated concrete at very low W/C (≤0.30), for all practical purposes, practically water impermeable. Extremely low permeability concrete dramatically restricts the water transport potential of aggressive chemicals into the concrete medium.

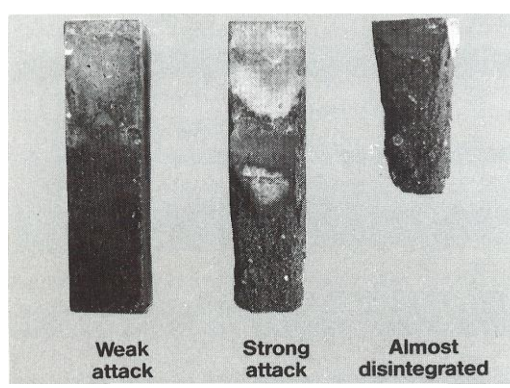

Fig. 2 Dissolution

Industrial Application Examples

At a south-eastern US paper plant silica fume content concrete was selected for a new five story tall structure by the engineering team with the desire to obtain highest possible concrete density with extremely low permeability characteristics to withstand a generally very corrosive environment. High compressive strength performance, in this case not a necessity but a desirable side effect, would be assured by a combination of high percentage silica fume content coupled with a very low water-to-total cementitious ratio. Moreover, high modulus of elasticity, elevated abrasion and impact resistance and conservatively low shrinkage potentials were attractive to the design team. Maximum dosages of Type F high range water reducer provided the high workability to this very cohesive concrete mixture in the range of 10" (255mm) of slump which facilitated proper consolidation, specifically in the heavily reinforced wall sections. Hot weather concreting effe ncrete also required air-entrainment 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 excellent results very close to a ≤100 coulomb result, considered negligible in the AASHTO T-277 permeability rating.

Mix Design Materials :	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	
High Range Water Reducer	2.1-2.5 gal/ yd^3	8 - 10 ltr / m^3
Other chemical 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 @ 42 days	115 coulombs	

Table 1 Paper plant concrete design and performance

Table 1 Concrete mix design & performance for paper plant

Concrete structures in ammonium nitrate processing facilities also experience significant and rapid deterioration and have thus have investigated and utilized various repair and construction materials over the years. Over two decades ago silica fume has first been used in such facilities and it has performed well, outlasting conventional concrete many times over before repair or replacement was necessary. Expansion plans at a mid-western US facility including new concrete structures were to be constructed of high percentage silica fume concrete. Two concrete mix designs for varying degrees of chemical exposure were utilized, designed at 16% and 23% silica fume addition by weight of cement, with water-to-total cementitious ratios of 0.35 and 0.32, respectively. This specific project had several phases and contractors as it lasted from spring through fall. Ambient conditions during this time fluctuated from freezing temperatures to the near triple digits, from wet to arid, and put the demand on the concrete to remain fine-tuned and be adjusted through the seasons. Maintaining a uniform average of 6% air-entrainment and properly and effectively protecting and curing this concrete under these extreme ambient conditions tested the ingenuity of producers and contractors, but ultimately paid off in successful completion of the project.

Fig. 3 Chemical Storage Building

Fig. 4 Chemical Storage & Containment Areas

Garbage transfer stations experience very short life cycles of their dump floors that are in operation practically 24/7. Impact from garbage trucks unloading waste and abrasion from heavy equipment moving the trash shortens life expectancy of specialty floors to an average of only two to three years. To the Solid Waste Authority minimizing downtime of any plant and the logistics of diverting constantly accumulating trash is top priority. The downtime to repair such floors with specialty toppings averages two months before it goes back into operation, at an average expense (at the time of this project in the mid 1990's) of approximately $ 17 per square foot ($ 183/m^2). High percentage silica fume concrete's positive track record in the chemical industry intrigued a south-eastern US Solid Waste Authority to specify a similar concrete mix design on an initial application for a 6"-8" deep floor resurfacing. Performance exceeded expectations by tripling service life beyond 7 years, at half the accustomed plant downtime during construction. 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 experienced in the past.

Mix Design Materials :	yd^3	kg / m^3
Cement, Type IP / Type I	705	418
Silica Fume (20% addition)	141	84
# 89 Limestone & Natural Sand	S / A = 0.35	
Water / Cementitious Ratio	0.31	
High Range Water Reducer	2.25 gal/ yd^3	11.2 ltr / m^3
Other chemical admixtures	Type D retarder & AEA	
1 day compressive strength	4,500 psi	31 MPa
28 day "	10,000 psi	69 MPa
NBS Abrasion Resistance .356 mm @ ½ hr & .584 mm @ 1 hr		
RCP Permeability @ 42 days	335 coulombs	

Table 2 Ultra-durable waste transfer floor concrete design

Fig. 5 Waste Transfer Station durable floors

A titanium producing facility in the south-western US has production floors occasionally subjected to temporary, but extreme temperature exposure in addition to heavy traffic, impact and chemical run-off. During the construction, high ambient temperature conditions coupled with very low humidity would be a liability to successful concrete production and placement execution. The solution to maintaining excellent concrete workability under these conditions was achieved by inclusion of a hydration control admixture used at a low dosage range of one to three oz/cwt (65-260 ml/100kg). The usually preferred methods of finishing and curing this type of high performance concrete demands, were prescribed per specification: Application of evaporation retardant or water fogging to immediately follow the placing and screeding procedure until shortly thereafter the final float and desired texture is applied to the floor surface, then followed by 7 continuous days of moist curing.

Fig. 6 Titanium plant retrofit

Mix Design Materials :	yd^3	kg / m^3
Cement, Type V	700	415
Silica Fume (20% addition)	140	83
# 67 Stone & Manuf. Sand	S / A = 0.40	
Water / Cementitious Ratio	0.35	
High Range Water Reducer	1.5-2.0 gal/ yd^3	7.5-10 ltr / m^3
Other chemical admixtures:	Hydration Control Admixture	

Table 3 Refined metals industrial floor concrete design

Summary

The resistance of high percentage silica fume concrete to the deteriorating effects of chemicals, impact and abrasion can considerably extend the service life of concrete structures. Such concrete mix designs also lend themselves for easy conversion to self-consolidating workability levels, facilitating larger and speedier concrete placements and thus minimizing operational plant downtimes. Silica Fume, an EPA designated recovered mineral component, will positively address sustainability efforts, specifically by extending service life.

Fig. 7 Self-Consolidating High Percentage Silica Fume Concrete

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