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SILICA FUME CONCRETE STUDIES— A PROGRESS REPORT

April 1985

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16. ABSTRACT

Research in the late 1960's showed that the use of silica fume (microsilica) as a partial replacement for cement in concrete mixes produced a dense concrete with properties superior to those of ordinary portland cement concrete. These properties indicated silica fume concrete would have a number of advantages when used for the repair of concrete structures.

Tests were performed on some 40 mixes made using silica fume as a replacement for cement in quantities of 15, 20, and 30 percent.

The results of this research program indicated that the following benefits might be achieved with silica fume portland cement concrete: increased strength, increased freezing and thawing resistance, improved mix consistency, reduced bleeding, and increased abrasion resistance.

Good concreting practices, especially during curing, must be maintained when using silica fume or the following may result: increased plastic shrinkage, increased long-term shrinkage, increased color variations, increased handling and finishing (workability) problems, increased placing costs, and lower strength.

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by

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Denver, Colorado

SI METRIC

April 1985

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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CONTENTS

TABLES

FIGURES

INTRODUCTION

In recent years, there has been considerable interest in improving the properties of concrete by incorporating various pozzolanic materials in the concrete mix. One of these materials, silica fume, has been receiving much attention because of its favorable contributions to portland cement concrete properties.

Silica fume is a byproduct from the production of ferrosilicon and silicon metal in an electric arc furnace. This byproduct is usually composed of more than 90 percent silicon dioxide and may contain traces of other oxides, depending on the furnace charge and the silicon metal being produced.

Initial investigations of the use of silica fume in concrete were conducted in the 1950's and 1960's, but most of the actual mix design work and the use of silica fume in concrete were not started until 1969. The Norwegians have been the most active in the development of silica fume concrete.

Silica fume particles are very small. Malhotra [1]* gives a fineness of 20 000 m^2/kg. Chatterji [2] points out: ''From the specific gravities and specific surfaces of silica fumes and portland cement, it can be shown that around each grain of portland cement there are about 100 000 grains of silica-fume.''

In much of the literature, test results of silica fume concrete have been compared as though silica fume is of uniform composition. However, producers of silica fume and reports on silica fume concrete state that the SiO_2 (silicon dioxide) content in silica fume varies from plant to plant (table 1). It is important to work with a material that has a consistent chemical composition, fineness, and reactivity because variations in compositions may cause problems that affect the mix design, production process, and control procedures. Composition variations also can affect the degree of compactibility, the amount of water required, the workability of the mix, and the color of the concrete.

How silica fume reacts in portland cement concrete is still being studied, and the chemistry of the reaction is still being debated. Nevertheless, it is safe to say that proper proportioning of silica fume, portland cement, HRWRA (high range water-reducing admixture), and concrete aggregate produces a concrete with excellent properties. Compressive strengths over 15 000 lb/in^2 (103 MPa) have been reported as well as excellent abrasion and freezing and thawing resistance.

* Numbers in brackets refer to the Bibliography.

Because of favorable reports on silica fume concrete, a study of its properties was started in July 1983. With the thought of using silica fume concrete as a repair material (overlays and patches), a mix design was developed using 3/4-in (19.0-mm) MSA (maximum size aggregate). Some 40 mixes were made to develop suitable proportioning of the various ingredients. The silica fume concrete mixes needed good workability and placement characteristics – near those of portland cement concrete mixes. Several silica fume contents were selected to develop a highly abrasion-resistant repair material.

SUMMARY AND CONCLUSIONS

1. The addition of silica fume to portland cement concrete mixes yields high compressive strengths, near 15 000 lb/in^2 (103 MPa); tensile strengths, over 600 lb/in^2 (4.14 MPa); and shear bond strengths, over 990 lb/in^2 (6.83 MPa).

2. Freezing and thawing resistance appears to be improved by the addition of silica fume, with a near zero mass loss after 1400 cycles. In the specimens tested, there were no significant differences in weight loss between air-entrained and non-air-entrained silica fume concrete.

3. Silica fume, when added to portland cement concrete, provides the following benefits when good concreting practices (especially during curing) are used:
   Increased strength
   Increased freezing and thawing resistance
   Increased abrasion resistance

4. If good concreting practices are not observed, the following may result:
   Increased drying shrinkage
   Increased color variations
   Increased handling (workability) problems
   Increased placing cost
   Lower strength gains

5. The use of an HRWRA is recommended to produce a workable mix and to control drying shrinkage.

MIX DESIGN DEVELOPMENT

An important factor in the production of high quality concrete is a low water to cementitious materials ratio. Concrete containing fairly large amounts of silica fume (15 to 30 percent by weight of cement) requires a relatively high proportion of water to maintain adequate workability and surface finishing characteristics, yet has a decided tendency to warp or crack from drying shrinkage if large amounts of water are added to the mix. It, therefore, appears essential to use an HRWRA to produce a high quality concrete having good workability and to control drying shrinkage. With an HRWRA, the water to cementitious materials ratio can be held to below 0.4.

A standard 3/4-in (19.0-mm) MSA portland cement concrete repair mix was used as a starting point. Silica fume was added to the concrete mix as a percent of the portland cement content. Because a mix containing silica fume requires more water to develop a workable mix, an HRWRA was added to reduce the water requirement. A small change in the ratio of HRWRA to cement in a silica fume mix has significant impact on the slump. Silica fume also reduces the setting time of the mix; therefore, a set-retarding admixture was used to increase the working time of the mix. Concrete mixes were made with and without an AEA (air-entraining agent). Concrete mixes with an AEA were designed to obtain the 6 percent entrained air which is recommended for freeze-thaw resistant conventional portland cement concrete with a 3/4-in MSA.

The following materials were used:

silica fume	Reynolds Metal
portland cement	Type II (laboratory blend)
HRWRA	W. R. Grace, D-19
water-reducing set-retarding admixture	Sika Plastiment, type D
AEA	5 percent vinsol resin
aggregate	local natural aggregate (Clear Creek)

Because saving time means saving money, efforts were made to minimize the mixing time. Several mixes were made to develop a mixing sequence that would produce a workable mix with the desired properties. The mix procedure developed is as follows:

1. Add set retardant and HRWRA to the mix water.

2. Add mix water containing set retarding admixture and HRWRA to the mixer.

3. Add prebatched aggregate, cement, and silica fume. Silica fume should be added early in the mixing process to ensure proper wetting and good dispersion through the mix.

4. Mix for 3 minutes.

5. Wait 2 minutes to avoid false set and to ensure good wetting of aggregate, cement, and silica fume.

6. Add AEA if desired.

7. Mix for 2 minutes.

Three-quarter-inch (19.0-mm, table 3) MSA was used for mixes containing 15, 20, and 30 percent silica fume, with and without AEA. These mixes are shown in table 2. Six percent air in the 30-percent silica fume mix was not achieved, and additional development work is planned using AEA to see if this mix can be made. The use of AEA increases the workability and slump; thus, water requirements may be reduced. Using AEA in conjunction with an HRWRA increases slump. This can be seen when comparing the slumps measured for the mixes in table 2. Reducing the water lowers the *W/C* (water-cement ratio), thus increasing the compressive strength. However, increasing the air content reduces the compressive strength [3]; therefore, air entrainment of the concrete results in a tradeoff.

In proportioning silica fume concrete mixes, the following points should be considered:

1. It may be desirable to increase the ratio of coarse aggregate to fine sand, depending on the amount of silica fume used in the mix.

2. Silica fume reduces the workability of the mix. To achieve normal workability the slump should be increased by 3/4 to 1-1/4 in (19 to 30 mm).

3. The use of silica fume increases the water requirement, and the use of an HRWRA is beneficial.

Unless good concreting practices are used, the following detrimental effects may result when silica fume is used.

1. Increased drying shrinkage which may lead to cracking problems.

2. Color variations

3. Handling and finishing problems

4. Increased placement cost

PROPERTIES

When properly designed and placed, silica fume produces a high quality concrete. Silica fume concrete is of interest as it has a high early strength development, high ultimate strength, good abrasion resistance and good resistance to freeze-thaw action. In laboratory studies, 28-day compressive strengths over 14 000 lb/in^2 (97 MPa) were easily obtained using silica fume with normal amounts of portland cement (table 4).

A variety of tests were performed to evaluate silica fume concrete as a construction and repair material. Data from these tests are shown in tables 4, 5, 6, 7, and 8.

Compressive Strength Testing, Modulus of Elasticity, and Poisson's Ratio

Silica fume concrete shows good compressive strength properties. Specimens had compressive strengths ranging from 10 000 to over 14 000 lb/in^2 (70 to 98 MPa) (table 4). Compressive strength testing was performed in accordance with ASTM C 39-81, and elastic properties were determined according to ASTM C 469-81.

Silica fume mix of 30 percent. – Six percent air content was not achieved in the 30-percent silica fume air-entrained mix; only 2.8 percent air content was attained. Seven-day compressive strengths of 3- by 6-in (75- by 150-mm) cylinders were 10 080 lb/in^2 (69.5 MPa) for the non-air-entrained specimens and 8570 lb/in^2 (59.0 MPa) for the air-entrained specimens. The 28-day compressive strengths of the 6- by 12-in (150- by 300-mm) cylinders (both the air-entrained and the non-air-entrained specimens) exceeded the capacity of the 400 000-lb (1800-kN) testing machine. The static modulus of elasticity was about 5×10^6 lb/in^2 (34.5 GPa) for both the air-entrained and the non-air-entrained 6- by 12-in specimens.

Silica fume mixes of 20 and 15 percent. – Air-entraining was successful with both the 20- and the 15-percent silica fume mixes. The 7-day compressive strength of a 15-percent silica fume, 3- by 6-in non-air-entrained specimen was 7940 lb/in^2 (54.7 MPa). No 7-day compressive strengths were measured for 20 percent air-entrained or non-air-entrained, or 15 percent air-entrained specimens. The 28-day compressive strength for the 20-percent silica fume, 6- by 12-in, non-air-entrained specimen exceeded the capacity of the 400 000-lb (1800-kN) testing machine. The 28-day compressive strength of the 15-percent silica fume, non-air-entrained specimen was 13 880 lb/in^2 (95.7 MPa). The 28-day compressive strengths for air-entrained specimens were 11 250 lb/in^2 (77.5 MPa) and 10 570 lb/in^2 (72.8 MPa) for the 15 and 20 percent specimens, respectively. The static moduli of elasticity for the 15 and the 20 percent silica fume specimens (air-entrained and non-air-entrained) were all about 5 x 10^6 lb/in^2 (34.5 GPa).

A complete summary of 28-day compressive tests is shown in table 4. Figure 1 shows a typical compressive stress-strain curve for a non-air-entrained, 20-percent, 6- by 12-in specimen. Poisson's ratio, the ratio of lateral to axial strain, is about 0.20 for this curve and was about this value for each silica fume concrete mix tested.

Tensile Strength Tests

Tensile strength testing was performed on 3- by 6-in (75- by 150-mm) cylinders by both the splitting tensile strength method (ASTM C 496-79) and the direct tensile strength method. Table 5 shows that the splitting tensile strengths were higher than the direct tensile strengths for all silica fume contents tested, with little difference between the tensile strengths for the various silica fume contents. Generally, the non-air-entrained specimens showed slightly higher strengths than the air-entrained specimens. The static moduli of elasticity from the direct tensile tests were about the same for all silica fume contents and about the same as the compressive static moduli of elasticity. The Poisson's ratios varied considerably because the stresses were very low, and the lateral strain does not show a smooth relationship to the stress in the low ranges. Figure 2 shows a typical direct tensile stress-strain to failure curve for an air-entrained, 30-percent silica fume specimen.

Shear Bond Tests

Shear bond tests were made on 2-in (50-mm) diameter cores drilled from 1-ft (300-mm) square concrete slabs, which were overlaid with 15 percent silica fume, non-air-entrained concrete. A cement slurry was used for a bond coat. Specimens were tested at 56 days, and the average shear bond strength was 990 lb/in^2 (6.83 MPa) (table 6).

Thermal Tests

Coefficient of thermal expansion tests were performed on 2- by 4-in (50- by 100-mm) cylinders made from 15 percent silica fume, non-air-entrained concrete. These tests (table 7) showed the coefficient of thermal expansion to be 4.73 $\times$ 10^{-6} in/in per °F (8.51 $\times$ 10^{-6} m/m per °C). This is near the average value for portland cement concrete, which varies from 3.80 to 5.50 $\times$ 10^{-6} in/in per °F (6.84 to 9.90 $\times$ 10^{-6} m/m per °C).

Abrasion Tests

Silica fume concrete showed excellent abrasion resistance. Tests were performed using apparatus and procedures similar to those of the Corps of Engineers, WES (Waterways Experiment Station) [4]. The control mix shown in table 8 was used for comparison. The mixes that were non-air-entrained showed better abrasion resistance than the air-entrained mixes, and all of the mixes showed much better abrasion resistance than the control concrete. Complete abrasion-resistance data are shown in table 9. Figure 3 shows the 30-percent silica fume, non-air-entrained specimen after 72 hours of testing in the WES equipment. The wear pattern shown was typical for all specimens.

Shrinkage

Silica fume concrete shows more drying shrinkage than conventional portland cement concrete [5]. Tests were conducted using the DuPont shrinkage gauge for curing shrinkage of cementitious materials [6]. Figure 4 shows the shrinkage of a 30-percent silica fume mix that was cured in a laboratory at 73 °F (22.8 °C) and varying humidity. Figure 5 shows the shrinkage for a mix with a curing compound to reduce drying shrinkage. These results show the importance of good curing.

Durability Tests

The durability tests for freezing and thawing were conducted according to USBR 4666-84 "Procedure for Resistance of Concrete to Rapid Freezing and Thawing." Data are not yet available on the sulfate resistance testing. In the freezing and thawing tests, silica mixes with and without AEA showed excellent durability (table 10).

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Table 1. – Silica fume composition.

SiO_2 in U.S. Silica Fume [1]	
Producer	*Percent SiO_2*
Ohio Fern Alloys	93
Interlake, Inc.	
Selma, Alabama Plant	96
Beverly, Ohio Plant	86 - 92
Hanna Mining	93
SKW Alloys	85 - 90
Reynolds Metals	98

Silica Fume Composition for Various Countries [5]

Components	*Australia*	*U.S. and Canada*	*Norway*
	percent	*percent*	*percent*
SiO_2	88.60	63.30 – 98.00	86 – 98
Al_2O_3	2.44	0.10 – 5.40	0.1 – 0.6
Fe_2O_3	2.56	0.10 – 12.20	0.02 – 1.0
C	3.00	1.75 – 10.00	0.8 – 3.0

[1] Based on unpublished data, Corps of Engineers.

Table 2. – Silica fume concrete mix design.

15 Percent Silica Fume – No AEA [1]

Quantities per 1 yd³ (0.76 m³)

	Air	*HRWRA*	*Water*	*Cement*	*Silica fume*	*Sand*	*Gravel*	*Total*
Wt (lb)	1%	32.4	195	608	91	1352	1871	4149
Vol. (ft^3)	0.27	0.43	3.12	3.09	0.66	8.24	11.19	27.00
Wt (kg)	1%	14.7	88.5	276	41.3	613	849	1882
Vol. (m^3)	0.01	0.01	0.09	0.09	0.01	0.23	0.32	0.76

$W/(C + S.F.) = 0.33$

Measured values

Unit weight 154.2 lb/ft³ (2467 kg/m³)
Air 0.3%
Slump 0.5 in (13 mm)

15 Percent Silica Fume – With AEA

Quantities per 1 yd³ (0.76 m³)

	Air	HRWRA	Water	Cement	Silica fume	Sand	Gravel	Total
Wt (lb)	6%	30.7	185	575	86	1297	1767	3940
Vol. (ft^3)	1.62	0.41	2.96	2.92	0.62	7.90	10.57	27.00
Wt (kg)	6%	13.9	83.9	261	39.0	588	801	1787
Vol. (m^3)	0.05	0.01	0.08	0.08	0.01	0.22	0.30	0.76

$W/(C + S.F.) = 0.33$

Measured values

Unit weight 147.7 lb/ft³ (2363 kg/m³)
Air 6%
Slump 6 in (150 mm)

20 Percent Silica Fume – No AEA

Quantities per 1 yd³ (0.76 m³)

	Air	HRWRA	Water	Cement	Silica fume	Sand	Gravel	Total
Wt (lb)	1%	27.2	202	598	120	1351	1840	4154
Vol. (ft^3)	0.27	0.36	3.24	3.04	0.86	8.23	11.00	27.00
Wt (kg)	1%	12.3	91.6	271	54	613	855	1884
Vol. (m^3)	0.01	0.01	0.09	0.09	0.01	0.23	0.31	0.76

$W/(C + S.F.) = 0.32$

Measured values

Unit weight not measured
Air 0.5%
Slump 0.5 in (13 mm)

Table 2. – Silica fume concrete mix design – Continued.

20 Percent Silica Fume With AEA

	Quantities per 1 yd³ (0.76 m³)							
	Air	HRWRA	Water	Cement	Silica fume	Sand	Gravel	Total
Wt (lb)	6%	30.9	193	566	113	1276	1740	3919
Vol. (ft^3)	1.62	0.41	3.09	2.88	0.82	778	10.40	27.00
Wt (kg)	6%	14.0	87	256	51	579	789	1777
Vol. (m^3)	0.05	0.01	0.09	0.08	0.01	22.0	0.29	0.76

W/(C + S.F.) = 0.33

Measured values

Unit weight 145.0 lb/ft³ (2320 kg/m³)
Air 6.2%
Slump 9 in (230 mm)

30 Percent Silica Fume – No AEA

	Quantities Per 1 yd³ (0.76 m³)							
	Air	HRWRA	Water	Cement	Silica fume	Sand	Gravel	Total
Wt (lb)	1%	30.8	209	580	174	1310	1803	4107
Vol. (ft^3)	0.27	0.41	3.35	2.95	1.26	7.98	10.78	27.00
Wt (kg)	1%	14.0	95	263	79	594	818	1862
Vol. (m^3)	0.01	0.01	0.09	0.08	0.03	0.23	0.31	0.76

W/(C + S.F.) = 0.32

Measured values

Unit weight 154.8 lb/ft³ (2477 kg/m³)
Air 0.9%
Slump 0.75 in (19 mm)

30 Percent Silica Fume With AEA

	Quantities Per 1 yd³ (0.76 m³)							
	Air	HRWRA	Water	Cement	Silica fume	Sand	Gravel	Total
Wt (lb)	6.0%	29.3	199	552	166	1249	1702	3897
Vol. (ft^3)	1.62	0.39	3.19	2.81	1.20	7.61	10.18	27.00
Wt (kg)	6.0%	13.2	90	250	75	566	772	1766
Vol. (m^3)	0.04	0.01	0.09	0.07	0.03	0.22	0.28	0.76

W/(C + S.F.) = 0.32

Measured values

Unit weight 147.0 lb/ft³ (2352 kg/m³)
Air 2.8%
Slump 7.5 in (190 mm)

[1] Air was estimated at 1.0% for non-air-entrained mix design. HRWRA (high range water-reducing admixture) contains 41% solids. Sand contains 1% water and gravel contains 0.1% water. AEA is air-entraining admixture. Each mix also contained a water-reducing set-retarding admixture which was added in in increments corresponding to 697 cm³ 1 yd³.

Table 3. – Aggregate gradation

Sieve designations		% by weight
3/8 to 3/4 inch	9.5 to 19 mm	32.0
No. 4 to 3/8 inch	4.75 to 9.5 mm	26.0
No. 8 to No. 4	2.36 to 4.75 mm	6.3
No. 16 to No. 8	1.18 to 2.36 mm	6.3
No. 30 to No. 16	600µm to 1.18 mm	10.5
No. 50 to No. 30	300 to 500 µm	10.5
No. 100 to No. 50	150 to 300 µm	2.1

Table 4. – Compressive strength, modulus of elasticity, and Poisson's ratio.

Mix	Compressive strength (28-day)		Modulus of elasticity		Poisson's ratio
	lb/in²	MPa	lb/in² × 10⁶	GPa	
15 percent silica fume					
No AEA	13 880	95.70	5.21	35.9	0.20
w/AEA	11 250	77.57	4.75	32.8	0.19
20 percent silica fume					
No AEA	*14 330	98.80	5.38	37.1	0.20
w/AEA	10 570	72.88	4.92	34.0	0.20
30 percent silica fume					
No AEA	*14 330	92.80	5.00	34.5	0.19
w/AEA	*14 330	98.80	5.43	37.4	0.20

* Strength of specimen exceeded maximum capacity of the testing machine. Specimen did not fail.

Test results are for single, 6- by 12-in (150- by 300-mm) cylindrical specimens at 28 days' age.

Table 5. – Tensile strength tests.

Mix	Tensile Strength				Modulus of elasticity		Poisson's ratio
	Splitting		Direct				
	lb/in²	MPa	lb/in²	MPa	lb/in² × 10⁶	GPa	
15 percent silica fume							
No AEA	625	4.31	535	3.69	5.25	36.2	0.16
w/AEA	541	3.73	452	3.12	5.53	38.1	0.25
20 percent silica fume							
No AEA	634	4.37	503	3.47	5.47	37.7	0.12
w/AEA	628	4.33	617	4.25	5.20	35.8	0.22
30 percent silica fume							
No AEA	623	4.30	519	3.58	4.68	32.3	0.10
w/AEA	632	4.38	494	3.41	4.72	32.5	0.11

All tests performed on 3- by 6-in (75- by 150-mm) cylindrical specimens at 28 days' age. Splitting strength results are average of three specimens; direct strength results are for single specimens.

Table 6. – Shear bond tests on 15 percent silica fume, non-air-entrained concrete.

Specimen No.	Strength lb/in²	Strength MPa	Age days
052584-15-1	826	5.70	56
052584-15-2	1148	7.92	56
052584-15-3	998	6.88	56
Mean	991	6.83	

Table 7. – Thermal tests on 15 percent silica fume, non-air-entrained concrete.

Specimen No.	Temperature range		Coefficient of thermal expansion	
	°F	°C	in/in per °F	m/m per °C
2 x 4C-15	35 to 90	2 to 32	4.73×10^{-6}	8.51×10^{-6}

Table 8. – Concrete mix design, for conventional concrete abrasion test specimen.

	Quantities per 1 yd³ (0.76 m³)					
	Air	Water	Cement	Sand	Gravel	Total
Wt (lb)	6.5%	270	611	1236	1688	3805
Vol. (ft³)	1.76	4.33	3.08	7.49	10.34	27.00
Wt (kg)	6.5%	122	277	560	765	1726
Vol. (m³)	0.05	0.12	0.09	0.21	0.29	0.76

Table 9. – Abrasion tests (percent weight loss). [1]

		15 percent silica fume		20 percent silica fume		30 percent silica fume	
Time h	Conventional concrete mix	no AEA mix	w/AEA mix	no AEA mix	w/AEA mix	no AEA mix	w/AEA mix
12	2.81	[2]	[2]	[2]	[2]	[2]	[2]
24	5.58	0.84	1.33	0.79	1.52	0.53	0.79
36	7.37	– –	– –	– –	– –	– –	– –
48	9.07	1.35	2.55	1.57	3.04	1.15	1.52
60	[3]	– –	– –	– –	– –	– –	– –
72		2.04	3.68	2.10	4.27	1.64	2.25

[1] The abrasion is performed in accordance with CRD-C 63-80, Corps of Engineers, and is percent weight loss.
[2] Losses were so small for 12-hour intervals that specimens were tested for 24-hour intervals.
[3] Test stopped after 48 hours.

Table 10. – Freezing and thawing tests.

Specimen identification	Cycles	Percent weight change
15 percent silica fume		
No AEA	1400	−0.10
w/AEA	1400	−0.32
20 percent silica fume		
No AEA	1400	−0.01
w/AEA	1400	−0.10
30 percent silica fume		
No AEA	1400	−0.11
w/AEA	1400	+0.05

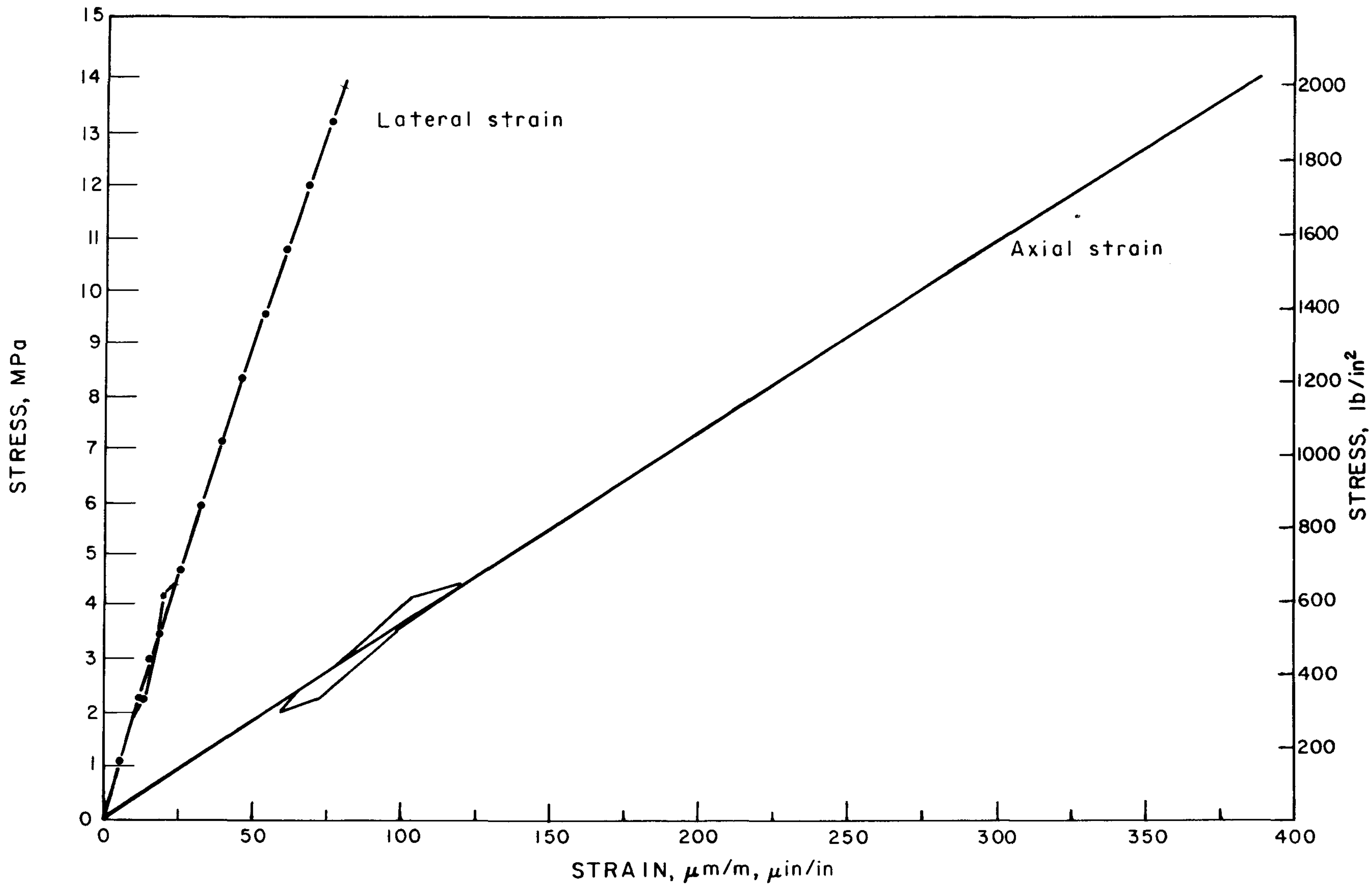

Figure 1. – Typical compressive stress-strain curve for a 20-percent silica fume, non-air-entrained specimen.

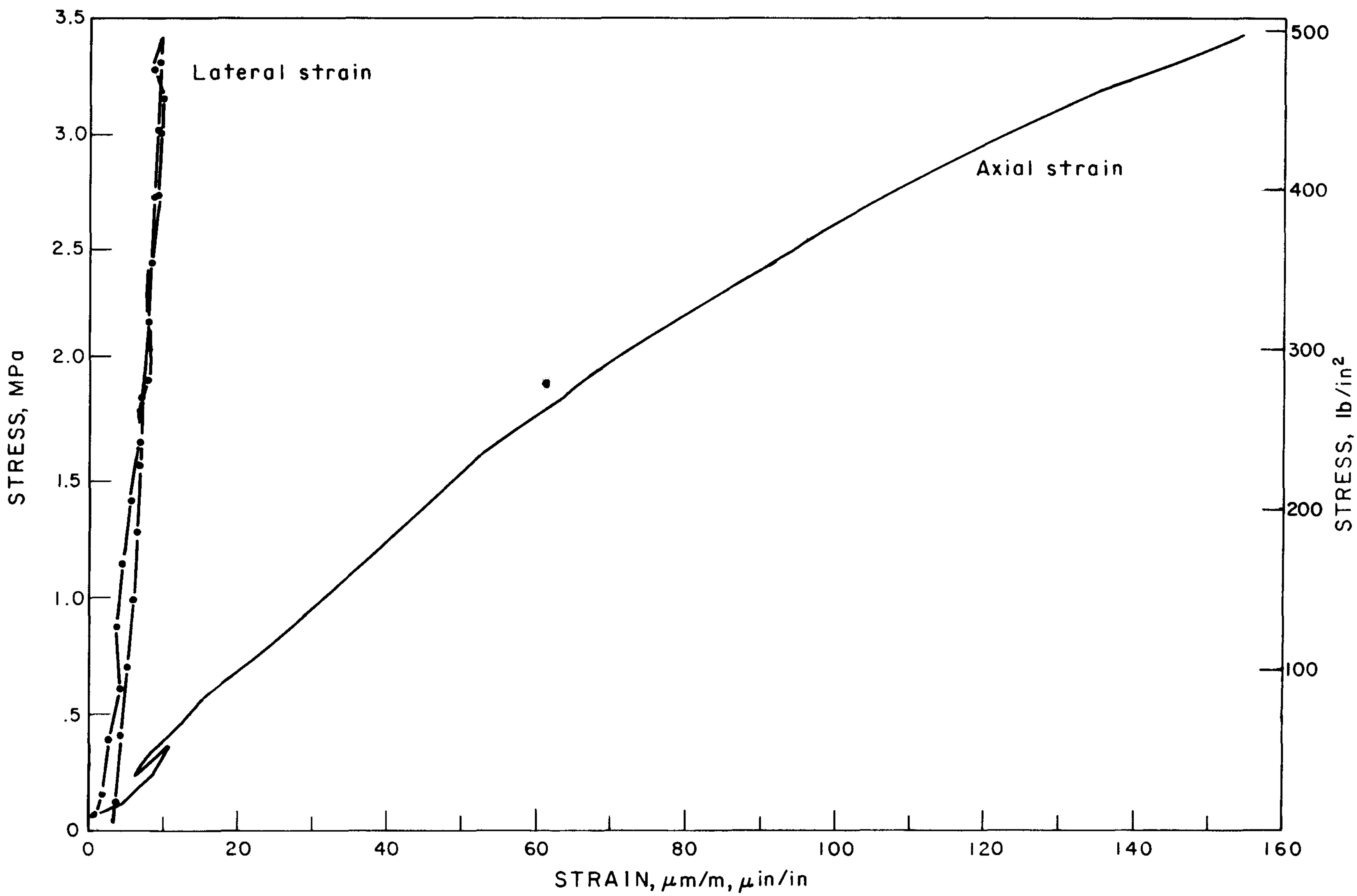

Figure 2. – Typical direct tensile stress-strain curve for a 30-percent silica fume, air-entrained specimen.

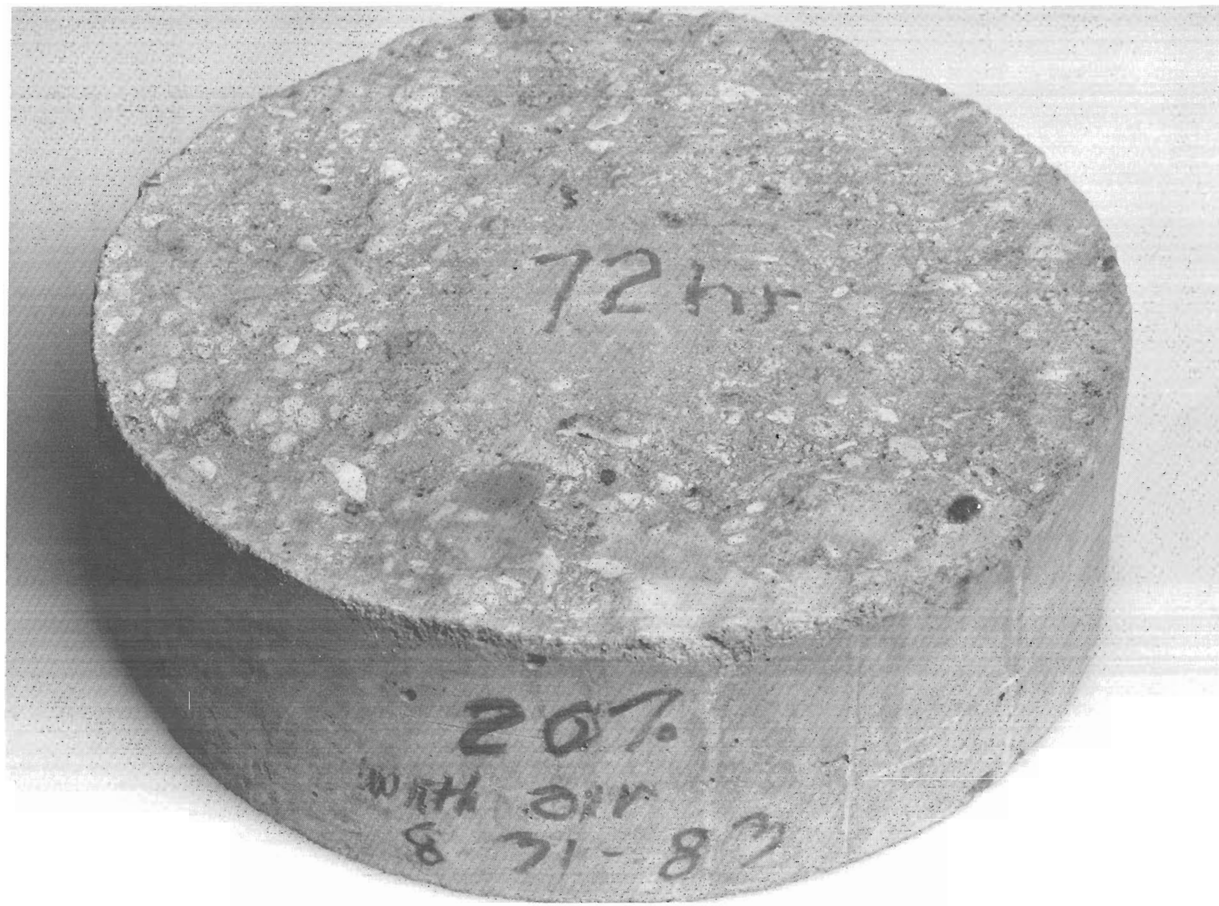

Figure 3. – The 20-percent silica fume, non-air-entrained specimen after 72 hours in the Waterways Experiment Station abrasion-erosion equipment.

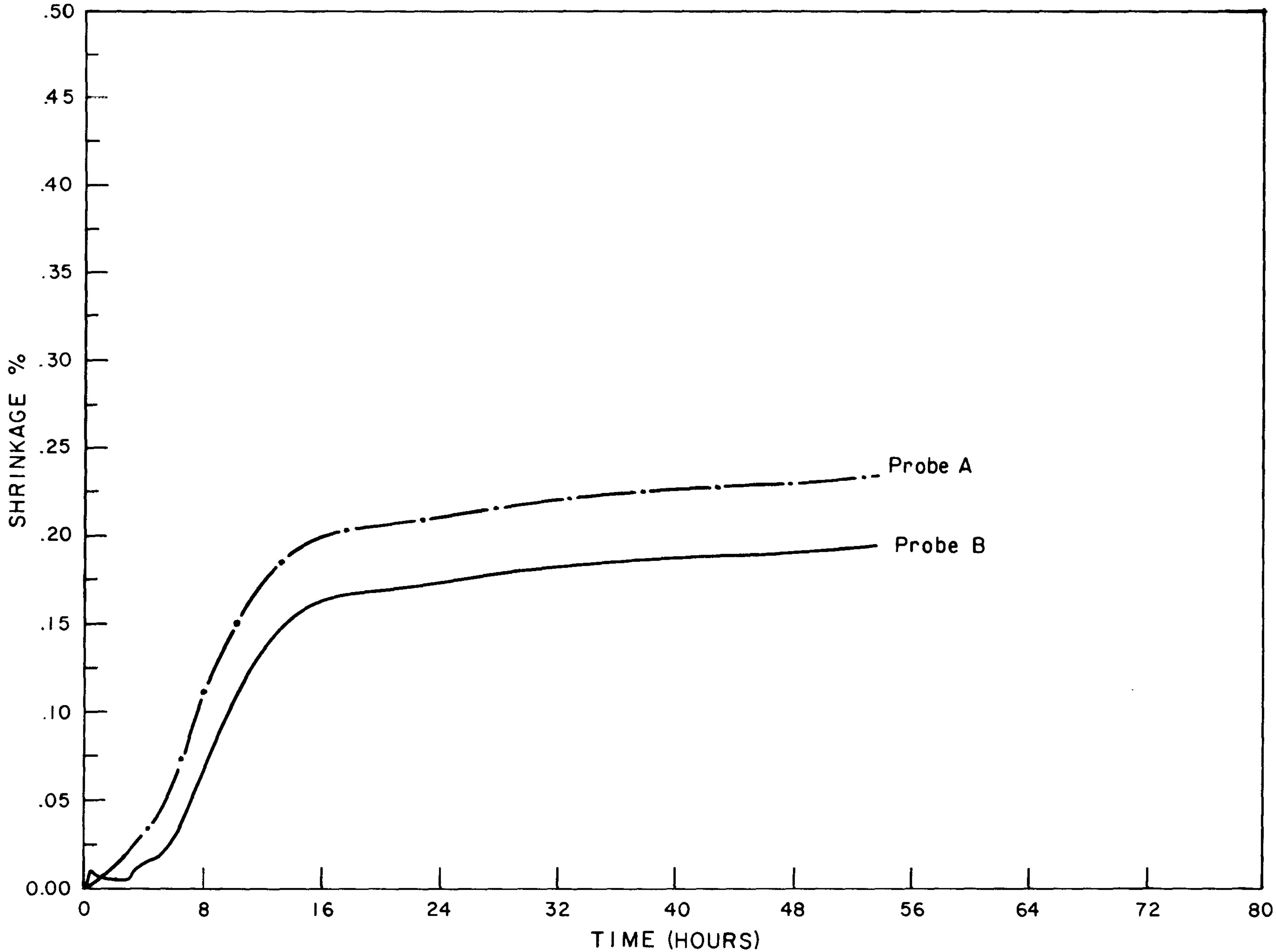

Figure 4. – Cure shrinkage for a 30-percent silica fume mix.

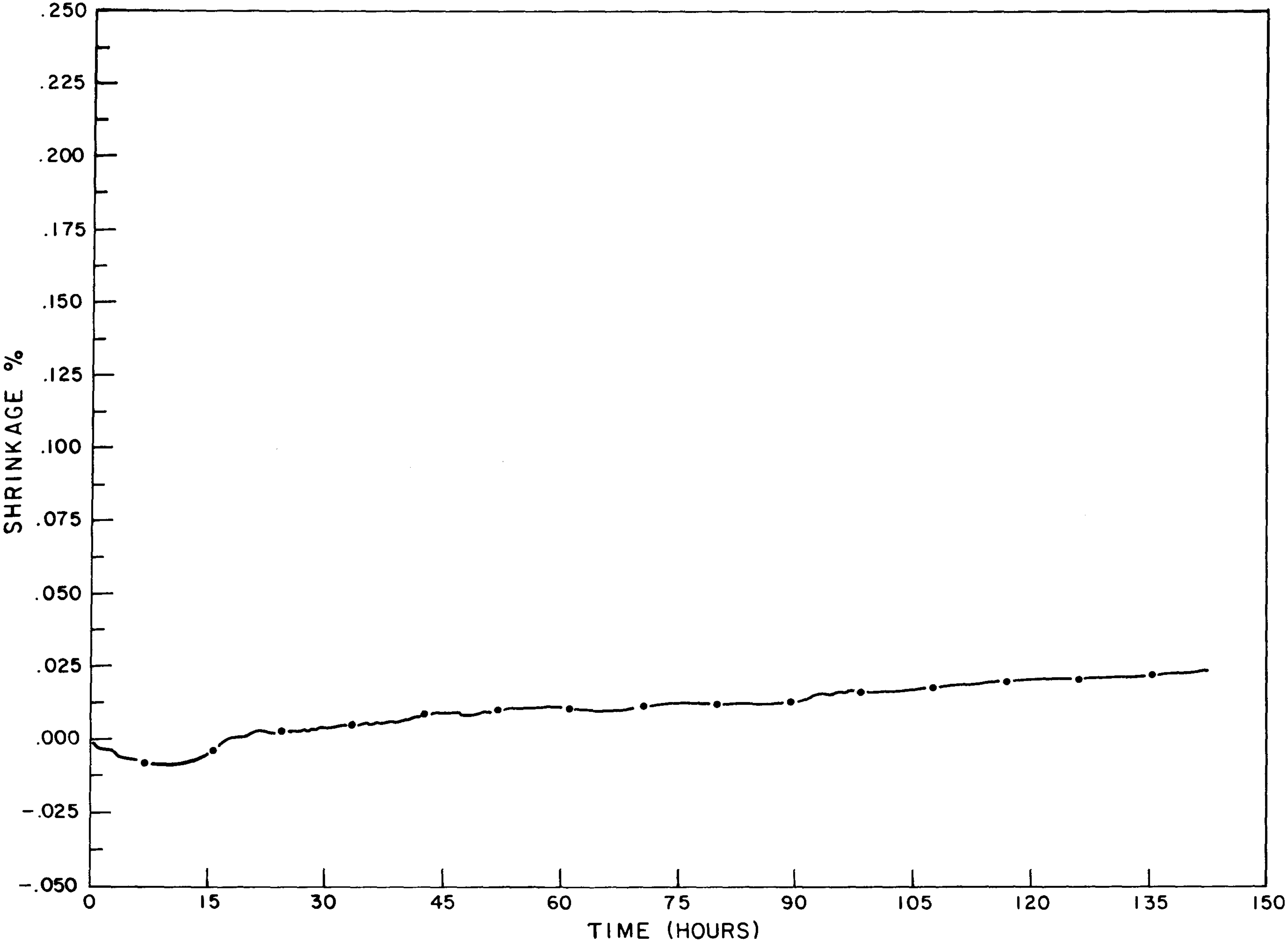

Figure 5. – Cure shrinkage for a 30-percent silica fume mix with curing compound.

GPO 846-716

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.