SILICA WASTE UTILIZATION PHASE II

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KEYWORDS

silica, direct use, utilization, silica waste, bricks, Cerro Prieto, Imperial Valley

PROJECT BACKGROUND AND STATUS

The Geo-Heat Center has been investigating the utilization of waste silica from the Cerro Prieto geothermal field for several years (Lund, et al., 1994; 1995a; 1995b, and 1996). The impetus behind this project was the large quantities of silica being produced from waste brines at the power plants in the Imperial Valley of Mexico and California, and a cooperative agreement between the U.S. Department of Energy (USDOE) and Comision Federal de Electricidad (CFE) of Mexico. The Cerro Prieto geothermal field in Mexico, has an installed capacity of 620 MW, and in the process, generates 6,400 tonnes/hr of brine consisting of about 6 tonnes/hr of silica. Since geothermal fields of that area extend into the Imperial Valley of California where waste silica is produced from an additional 420 MW of geothermal power generation, it is hoped that this research would also be applicable to the U.S. side of the border.

The conclusions from the original research (Lund, et al., 1994 and 1995) were that (1) the silica-lime mixtures had low strength and weather resistance, but high insulating properties; (2) additions of fibers to the silica-lime mixtures increased the strength; (3) silica-cement mixtures had high strength and weather resistance, but lower insulating values and appear to have application as road surfacing material; and (4) silica-asphalt mixtures were not suitable for road surfacing. The shortcoming of the original research was that the silica was obtained from evaporite deposits at a silencer. Since this source was not typical of the majority of silica waste at Cerro Prieto, additional samples were obtained from their disposal ponds.

This project was started in July 1995 and was completed by October 1996. The project is 100% completed, except for the construction of a test wall at Cerro Prieto, which is the responsibility of CFE.

PROJECT OBJECTIVES

This project investigated the utilization of waste silica from the evaporation ponds at Cerro Prieto geothermal field in Mexico. The main objective was to mix various combinations of hydrated line, portland cement, and plastic fibers with the waste silica to determine their suitability for use as insulating bricks in low-cost housing.

Technical Objectives

- Produce mixes by combining the silica with various additives to determine their suitability for use as insulating bricks in low cost building construction, and
- Produce a mixture of silica with either cement or asphalt that would be suitable for a low-volume road surfacing.

Expected Outcomes

- Utilization of waste silica produced as a result of geothermal power generation would stabilize and eventually decrease the area required for the evaporation ponds which cover 18.6 square km.

- Demonstrate the advantages of starting a brick and tile manufacturing process utilizing the waste silica, based on (1) low cost (25 percent reduction over commercial material), (2) high insulating value (low-thermal conductivity) and (3) lighter weight (60 percent lighter than clay or concrete tiles).

APPROACH

Silica samples were obtained from the Cerro Prieto disposal pond. The initial sample, taken from an evaporite deposit at a silencer, will be referred to as Sample 1. Two later samples were obtained from different locations in the disposal pond, and will be referred to as Sample 2 or 3 in this summary.

The silica was combined with various additives: hydrated lime, cement, hydrated lime with fibers, and cement and hydrated lime in different proportions. The mixture was then formed into 7.60 cm by 5.10 cm by 15.2 cm brick molds for flexural testing and 5.10 cm square molds for compression testing. The samples were then allowed to cure for 7, 14 or 28 days by a moist- (water bath @ 25°C) or heat- (sealed container @ 60°C) curing method. Following the allocated curing time, the bricks were tested for their flexural strength by a 3-point loading method and the cubes tested in compression. The samples were completely dried and then subjected to a 10 day weathering cycle and thermal conductivity testing.

The more promising mixtures were subjected to an accelerated laboratory weathering test. This involved a wet-dry test where a dried brick was first sprayed with water, then soaked overnight (about 12 hours), then oven dried at 60°C for 12 hours, before the cycle was repeated. A total of 10 cycles were performed and the initial weight was compared to the final dry weight to determine a percentage loss.

The thermal conductivity was determined by USGS in Menlo Park by using the conventional needle probe in a half-space mode (Sass, et al., 1984).

RESEARCH RESULTS

Silica

The term "silica" is used here to describe material that is mainly silica, but does contain other chemical species. Three separate samples of silica waste were taken and shipped from Cerro Prieto during the two years of the study. The initial sample, unknown to us, was from an evaporite deposit at a silencer; whereas, the later two samples were actually taken from the evaporation ponds. The evaporite deposit had a specific gravity of 2.29 and was extremely fine grained (over 90% passed the #200 sieve). The two pond samples had specific gravities of 2.27 and 2.18, and were much coarser with visible amorphous particles (Figure 1.). The latter samples had approximately 75% and 30% passing the #200 sieve. Since the initial sample results were not typical of what could be obtained from the larger source in the evaporation ponds, the results were not considered, but are documented in (Lund, et al., 1995a).

Hydrated Lime

The silica-hydrated lime mixtures produced the lowest specific gravities; thus, indicating that they would have the best insulating values (low thermal conductivity). These mixtures also produced the lowest strengths of all the various additive combinations.

The results of the 7-day flexural strength testing are shown in Figure 2. In the Phase II testing, it became apparent that there was something wrong with our testing procedure since the 14-day and 28-day strengths were less than the 7-day strength. This is contrary to classical testing of lime mixtures (Transportation Research Board Committee on Lime and Lime-Fly Ash Stabilization, 1987), where strengths increase with the time of curing. This anomaly in our test results was not so evident in the original testing, but is readily apparent with the Phase II mix designs. Upon a detailed investigation, it appears that our samples were drying out in the oven which prevented adequate curing and produced minute thermal cracks in the bricks (Figure 3). The longer the curing time, the more thermal micro-cracks that were produced. The samples then failed along these thermal cracks.

Since the strength of lime-stabilization is both time and temperature dependent, it was found that curing temperatures above 50°C should be avoided, with 40°C recommended without introducing pozzolanic reactive products that significantly differ from those expected during field curing (Transportation Research Board, 1987). Based on the above finding, two changes in our procedure were introduced (1) heat curing at 40°C instead of 60°C, and (2) curing in a moisture-proof plastic bag instead of tape-sealed pans. As a result, almost no moisture was lost from the bricks and higher strengths were produced which increased with time. The silica from Sample Site 3 were mixed with a silica to lime proportion from 1:1 all the way to 19:1 (50% to 5% lime by total dry weight of mix), and cured using the revised procedure the results are shown in Figure 3.

Portland Cement

Portland cement mixtures (using Type II cement) produced higher strengths as compared to those obtained from the Phase I testing (Figure 4). The strengths are approximately twice that of the corresponding silica-lime samples (based on the revised curing procedure). The flexural strengths are dependant upon the amount of mixing water used, as the lower water/cement ratios produce higher strength. Additional testing was performed concerning the water/cement ratio Mix N and O were mixed with the same proportions; but, N had 20% more water added which produced a higher water/cement ratio. The results of the 7-day flexural strength test for Mix N and O were 3,792 kPa and 3,921 kPa respectively.

Portland Cement and Hydrated Lime

The results from the combined cement and lime stabilization produced strengths between those obtained from just lime or cement alone. There appears to be no strong advantage to using this combination of additives; unless, the cost of lime is considerably less than cement, and strengths higher than those obtained from just lime stabilization are desired.

Hydrated Lime and Plastic Fibers

Approximately eight grams of plastic fibers, varying between 1.4 and 2.7 percent of dry weight of sample was used to provide additional flexural strength to the lime stabilized samples. This produced significantly higher strengths than those samples cured at 60°C and only sightly higher strengths when compared with those cured at 40°C.

Weathering

The new silica:lime and silica:cement samples performed well during the wet-dry weathering test. The "2" samples ranged from 2.3 to 47.0 percent loss, and the "3" samples ranged from 2.0 to 100 percent loss, compared to the original samples which ranged from 3.7 to 100 percent loss. With the advent of a lower curing temperature for the silica-lime "3" samples, the silica-lime samples had less than 6 % loss, except for the 10% and 5% lime content samples as shown in Figure 5.

Thermal Conductivity

Thermal conductivity was determined from various samples of bricks using the conventional needle probe in a half-space mode at the USGS laboratory in Menlo Park, California (person communication with Colin Williams). The thermal conductivities varied from 0.27 to 0.44 W/mK. In general, the lower the specific gravity of the mixture, the lower the thermal conductivity. Also, for a particular sample of silica, the thermal conductivities of the bricks decreased with increasing silica content as can be seen in Figure 6. Specific gravities of the silica-lime samples varied from 0.635 to 0.991 and for the silica-cement samples from 0.571 to 1.244. The silica from sample "3" produced the highest specific gravities and the highest thermal conductivities. The thermal conductivities compare with values for common brick at 0.72, gypsum or plaster board at 0.17, glass fiber insulation at 0.043 and urethane foam at 0.026 W/mK.

Conclusions

- Silica-lime mixtures have low strength and weather resistance. However, they have insulating properties comparable with other building materials. With controlled curing conditions, at ambient temperatures up to 40°C and without loss of moisture, the strengths can be improved by 180 percent. The addition of fibers to the mixtures increases the strength (75 percent) and weather resistance (100 percent),

- Silica-cement mixtures have high strength and weather resistance. However they have slightly lower insulating properties than silica-lime mixtures. These mixtures can better be used in load-bearing walls, and

- Silica-cement mixtures also appear to have application as road surfacing material with the addition of an asphaltic chip seal for erosion protection.

FUTURE PLANS

It is proposed to test several walls constructed of silica-lime and silica-cement in the Imperial Valley area. This will provide long-term field testing of the various types of bricks and determine if they need protective coatings, reinforcing, etc. This field testing will be the responsibility of CFE.

During the course of the investigation, it was determined that a light weight roofing tile using portland cement, silica and cellulose fibers is presently being manufactured in Mexico City and sold through outlets in the U.S. under the brand name "Maxitile." Their advertised advantage is that they are lighter weight (60 percent lighter than clay or concrete tile at 20 kg/m^2). CFE is presently investigating the potential for use of the Cerro Prieto waste silica by this manufacturer.

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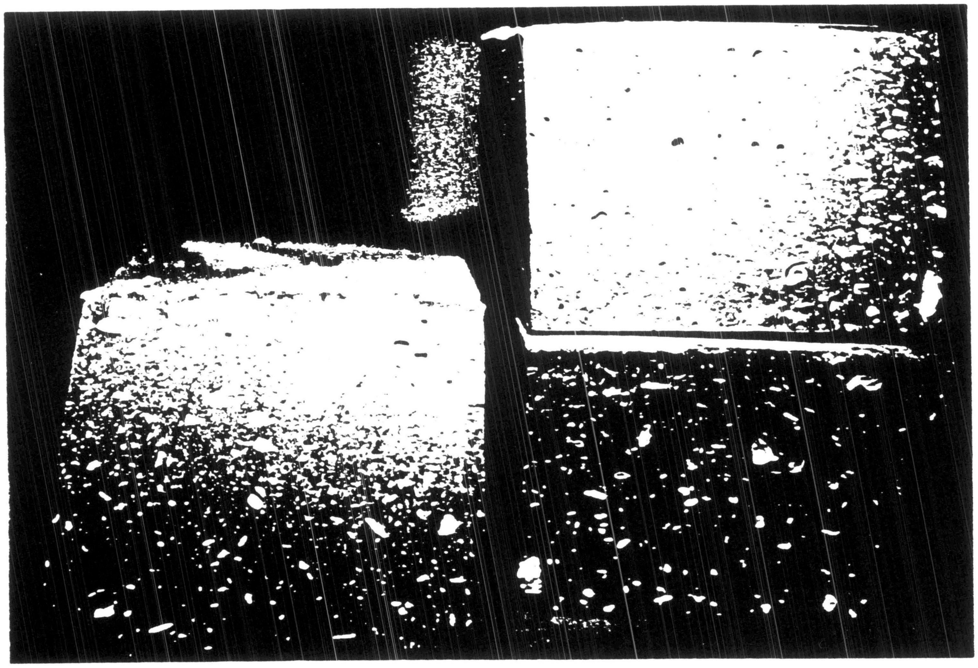

Figure 1. Cross Section of Silica-Cement Bricks showing Silica Gradation.

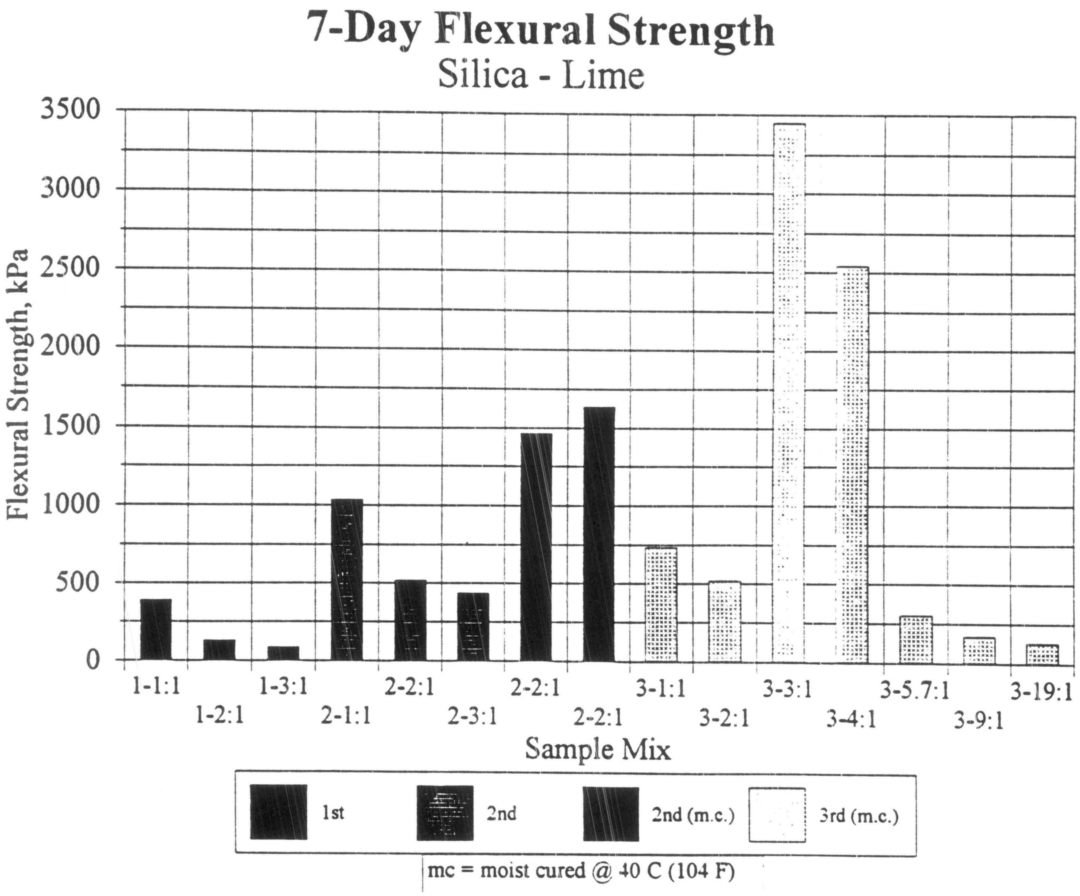

Figure 2. 7-Day Flexural Strength of Selected Silica-Lime Mixtures.

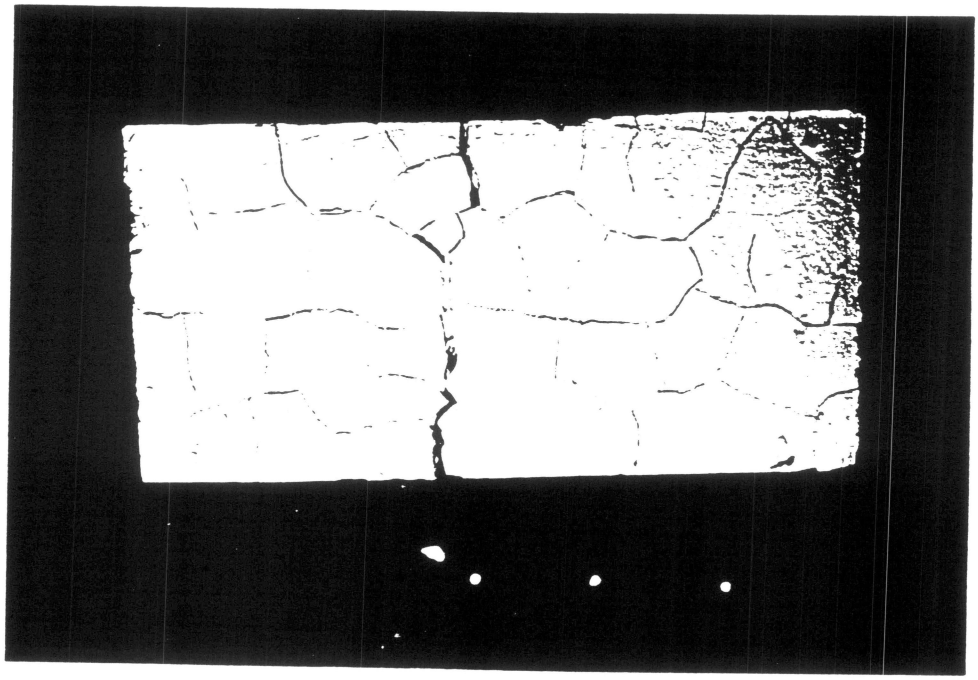

Figure 3. Top View of a Silica-Lime Brick Showing Micro-Fractures (Enhanced).

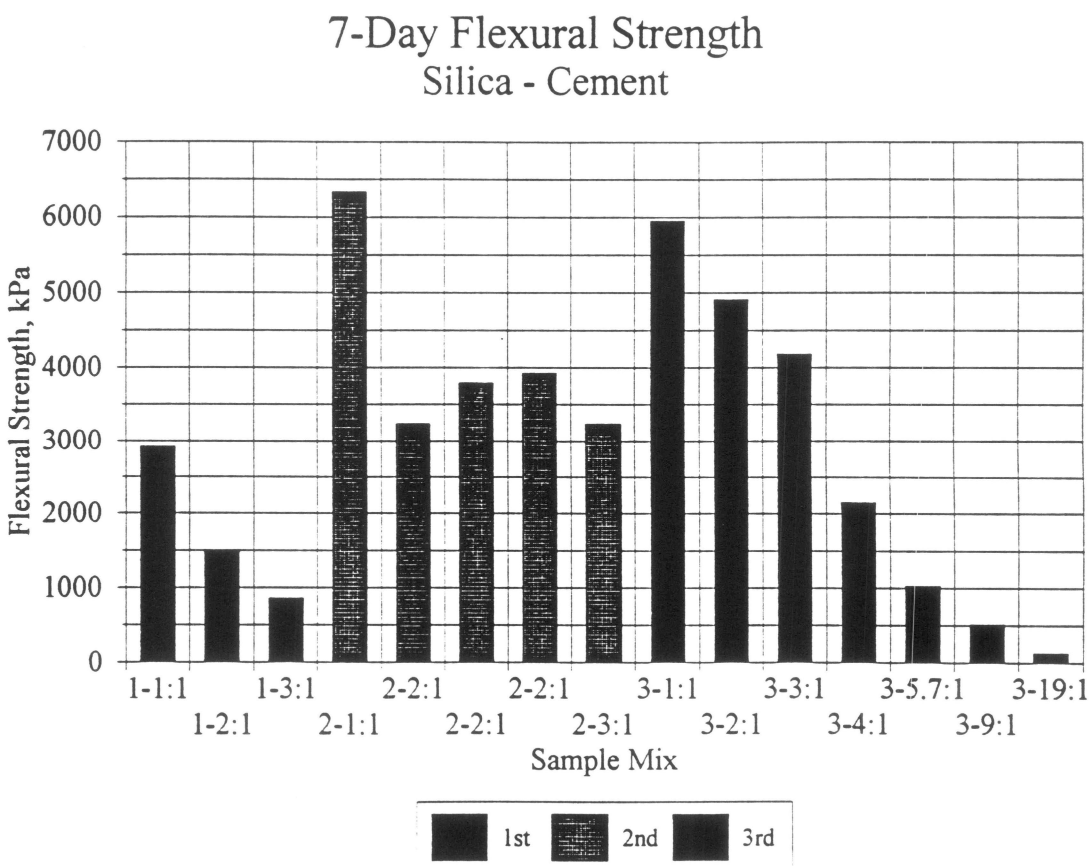

Figure 4. 7-Day Flexural Strength of Selected Silica-Cement Mixtures.

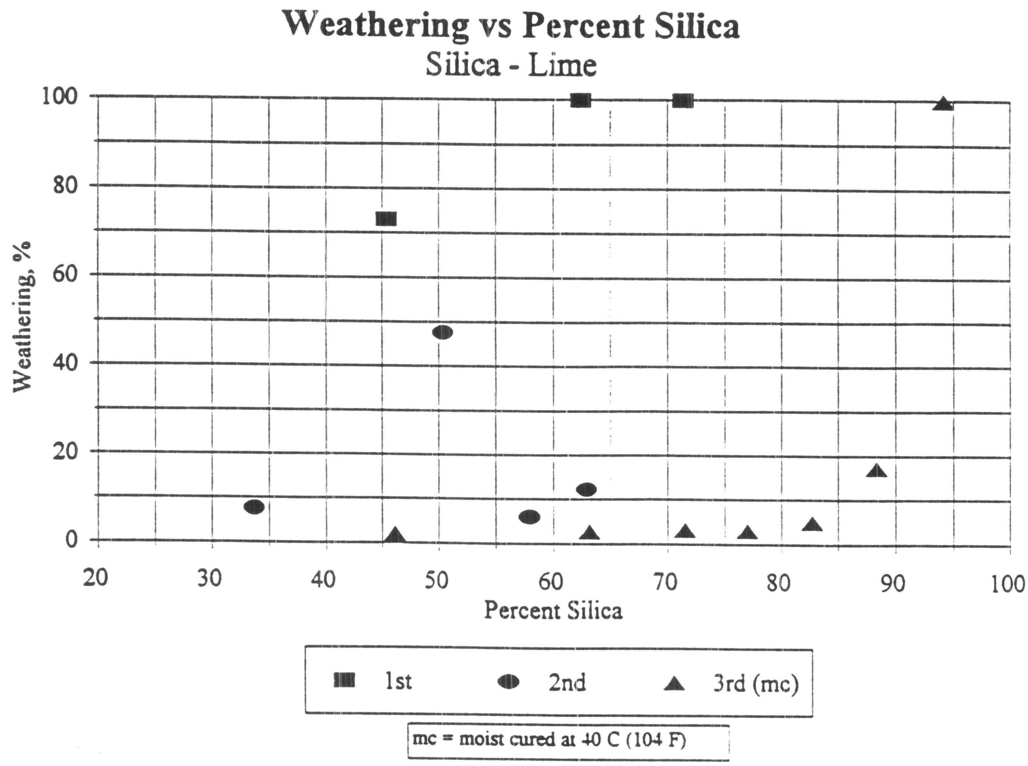

Figure 5. Weathering vs. Silica Content for Selected Silica-Lime Samples.

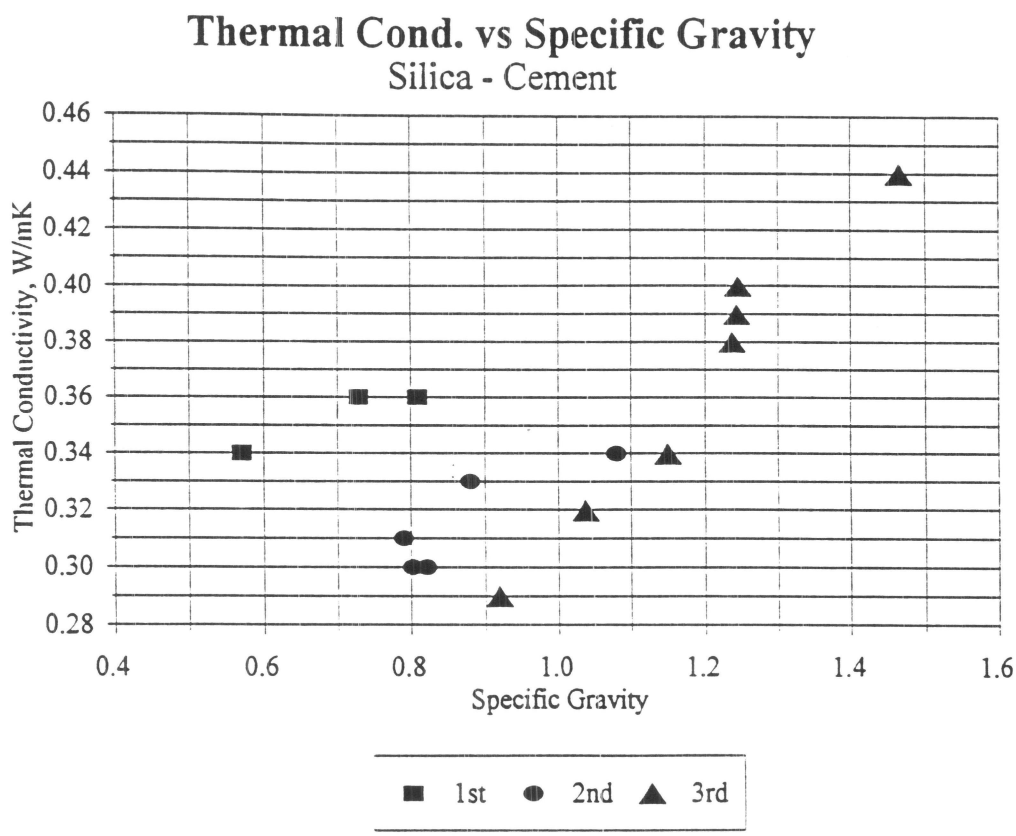

Figure 6. Specific Gravity vs. Thermal Conductivity of Selected Silica-Cement Samples.