SULFUR CONCRETE—A NEW CONSTRUCTION MATERIAL

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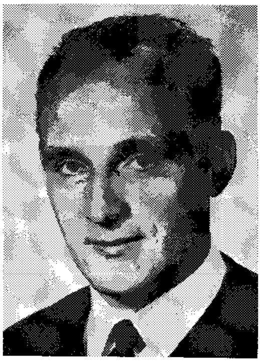
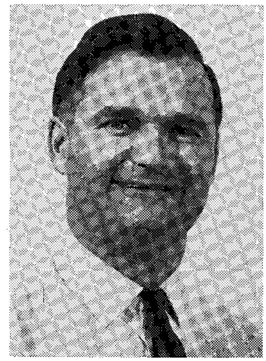
Involuntary large scale production of sulfur as a byproduct of natural gas production has resulted in rapidly increasing Canadian inventories expected to reach 22 million tons by the end of 1975. With an assurance of low sulfur prices during the foreseeable future it is now worthwhile to consider sulfur concrete for applications where its unique properties are advantageous.
This paper compares the properties of sulfur concrete with those of conventional concrete and discusses possible advantages and disadvantages of this new material.
Some possible areas of application are indicated.

Sulfur in its normal crystalline form is a pale-yellow element (see Fig. 1). Because of its properties sulfur has been considered as a possible cementing agent for different aggregates since the turn of the century. Proposed uses have ranged from pipe to industrial tanks and roofing as well as pavements, coatings, and jointing or grouting compounds.

In an early patent granted in 1900 McKay[1] described a sulfur composition which he claimed was suitable for roofing, conduits, pavements, ornamental figures, and the coating of steel ship





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hulls to prevent barnacle growth. Not much additional activity was recorded until 1920 when a sulfur-sand mortar was apparently successfully used for jointing a sewer for conveying acid waste from a pulp mill.[2]

Sulfur was actively considered for a variety of uses during the 1920's and 1930's. In 1924 Kobbe[3] reported on the acid-resistant properties of cements and concretes prepared from sulfur-coke compositions. Duecker[4,5] actively studied sulfur-aggregate compositions in the 1930's and reported on their potential use for construction and repair of acid tanks, flooring, and corrosion resistant pipe. He was perhaps the first to demonstrate that fluctuating temperatures had a deleterious effect on the strength of sulfur compositions but that plasticizers such as olefin polysulfides (Thiokol) would significantly improve their durability.

Many subsequent investigators have attempted to plasticize sulfur, that is, stabilize it in its polymeric form. Dale and Ludwig[6] have shown that the polymeric form has a tensile strength more than 12 times that of the crystalline, orthorhombic form, but unfortunately the solid polymeric sulfur normally will slowly (over a period of months) revert to the stable crystalline form with a concomitant reduction in its tensile strength.

Plasticizers for sulfur have tended to be expensive and therefore not suitable for use in construction materials. Many of these plasticizers impart a particularly objectional odor to the resulting product. As a result of recent unpub-

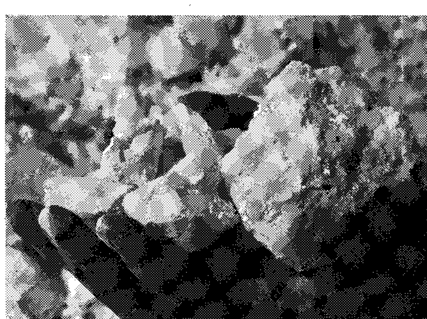

Fig. 1. Handful of pure crystalline sulfur.

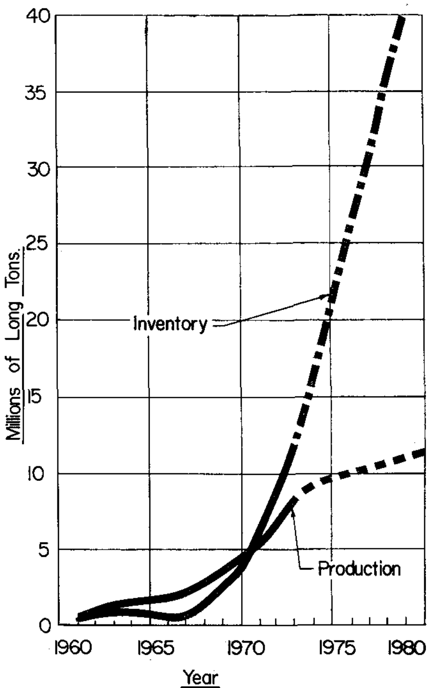

Fig. 2. Comparison of growth of Canadian sulfur production and inventory.

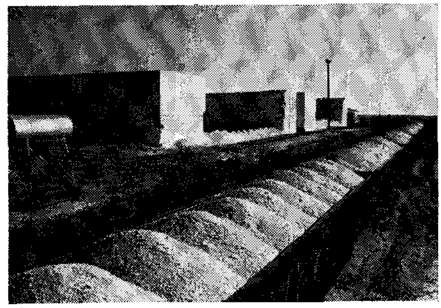

Fig. 3. Train load of slated sulfur for overseas shipment.

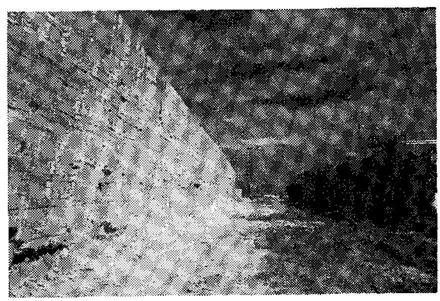

Fig. 4. Tank cars for shipping molten sulfur to Canadian and United States markets.

lished work by one of the present authors (Vroom), some inexpensive stabilizers have been found which impart both high strength and durability to sulfur concrete.

ECONOMICS

Sulfur has had a history of cyclical variation in supply and consequently price. In such an uncertain climate efforts to find new uses for sulfur have been discouraged. A sharply different trend became apparent in 1968 (see Fig. 2) when in Alberta a large number of gas-processing plants were completed. These plants remove sulfur from sour gas before the natural gas is piped to the consumer.

A large involuntary production of sulfur has therefore resulted which is linked to the ever-increasing demand for natural gas. The result is that Canada is now the world's largest exporter of sulfur and is a close second to the United States in total production. In spite of recent low prices for sulfur, Canadian inventory is presently approximately 11 million tons and is expected to reach 22 million tons by the end of 1975 (see Figs. 3 and 4).

The large sulfur surplus which has developed has caused concern in both industry and government. Increased activity has been aimed at developing large volume uses for sulfur.[7,8] The Canadian Government, the Alberta Provincial Government and the sulfur-producing companies have recently established the "Sulphur Development

Institute of Canada" (SUDIC) with headquarters in Calgary, Alberta. This organization will provide funds to encourage research and development likely to create new markets for sulfur.

The current market price for molten sulfur at producing plants in Alberta is $12 per long ton. Transportation costs increase the selling price in other areas (in Chicago the current price is $30 per long ton). Sulfur is normally shipped to overseas markets in the form of slates (Fig. 3) but more commonly shipped to Canadian and United States markets in tank cars (Fig. 4).

SULFUR CONCRETE

One of the uses for sulfur which is again being considered is as the cementing agent in concrete instead of portland cement. Recent reports and papers[9-12] have considered the properties and potential applications for sulfur concrete. Members of the Department of Civil Engineering at the University of Calgary are actively engaged in studies which, it is hoped, will help to resolve some of the present uncertainties which impede use of this material.

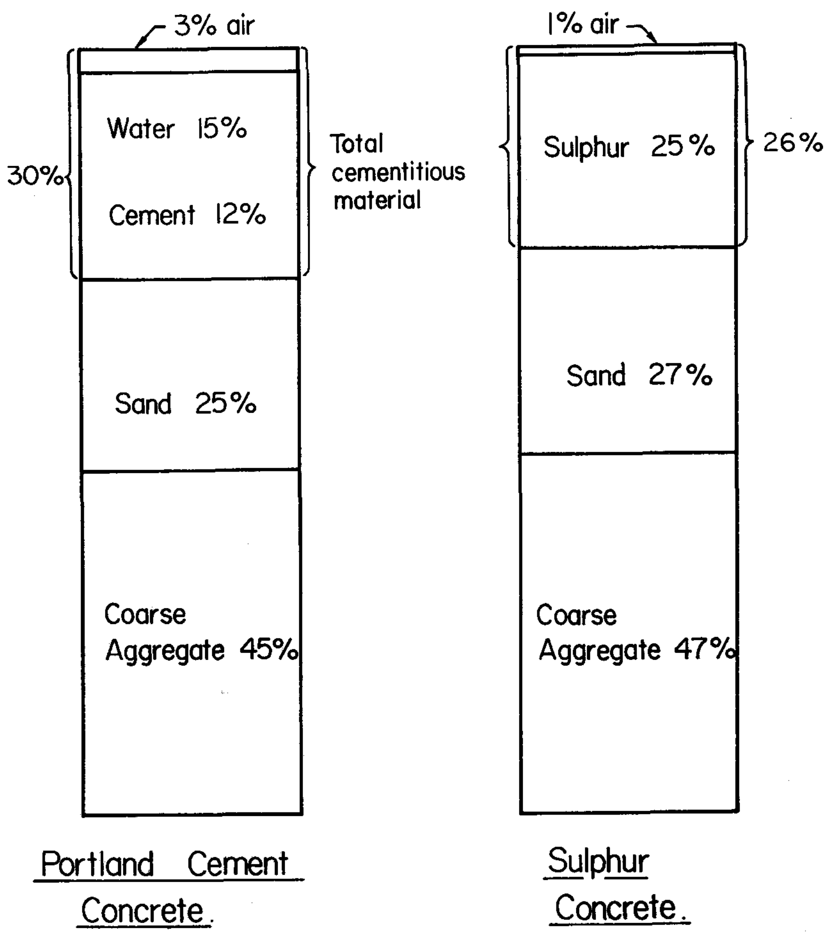

Fig. 5. Comparison of mix proportions for sulfur concrete and portland cement concrete (5000-psi at 24 hours).

Table 1. Cost comparison between sulfur concrete and portland cement concrete.

Material	Cost, dollars per cu yd	
	Portland cement concrete	Sulfur concrete
Aggregate	3.70	3.80
Cementitious material		
(a) Portland cement	10.50	—
(b) Sulfur	—	4.80
(c) Heating cost	—	1.75
Total	$14.20	$10.35

It is useful to compare a new material such as sulfur concrete with a traditional construction material such as portland cement concrete. Sulfur may be combined with fine and coarse aggregates to produce a concrete with a strength of 6000 to 7000 psi. Fig. 5 compares the mix proportions for a cubic yard of sulfur concrete with portland cement concrete of roughly equivalent strength. It is clear that the volumes of cementing material and filler material are roughly the same.

The materials costs shown in Table 1 have been based on present estimated costs in Calgary (portland cement $33 per ton, sand $3.20 per ton, coarse aggregate $2.20 per ton, sulfur $12.50 per long ton). The cost of the materials for producing sulfur concrete may be expected to exceed portland cement concrete in areas with high sulfur costs. However, even with a small cost differential, sulfur concrete warrants consideration where its special properties may be advantageous compared to portland cement concrete.

Fig. 6, which compares the rate of strength development of sulfur concrete, and portland cement concrete indicates possible potential in applications where high early strength is desired. The early strength of portland cement concrete may of course be increased above that shown by using high early strength cement, by steam curing or by recently developed "hot concrete" methods;[13] each of these methods does, however, entail additional expense. Sulfur concrete can develop as much as 90 percent of its ultimate strength in 6 hours by simply cooling to ambient temperatures.

Some of the problems associated with the use of portland cement concrete result from shrinkage and creep. While sulfur concrete exhibits no shrinkage, a roughly equivalent problem may occur through the thermal contraction resulting as the concrete cools from its crystallization temperature of 240 F to the ambient temperature. Thermal movements of sulfur concrete can be expected to be significant moreover because the coefficient of thermal expansion of pure sulfur is greater than that of steel or concrete. (In these respects sulfur concrete is similar to epoxy compounds.[14])

Present indications from unpublished work by Gamble[15] (Fig. 7) are that sulfur concrete exhibits considerably more creep than portland cement concrete.[16] This can be a disadvantage if increased deflections are a problem.

Some of the factors which affect the durability of portland cement and sulfur concretes are indicated in Table 2. The problems are substantially different, indicating that one concrete or the other may have an advantage for any particular application. Sulfur concrete's excellent resistance to deicing salts can be expected to interest bridge and highway engineers.

It should be mentioned that admixtures can be added to sulfur to prevent it from burning.[17] However, sulfur will remelt when heated to 240 F. The list in Table 3 identifies other properties of sulfur concrete which may govern its use. In particular, the possibility of acid formation under the combined action of sunlight and water must be regarded as a major problem to be avoided or overcome.

PRELIMINARY TESTS

To gain some experience with the design, construction and testing of structural members made with sulfur concrete, a series of preliminary tests have been conducted at the University of Calgary. These preliminary beam tests in conjunction with material properties tests are ultimately expected to provide a rational basis for structural design. The results from these tests will be presented in a subsequent report but it may be useful to indicate some of the problems that have been encountered to date.

Table 2. Comparison of durability for sulfur concrete and portland cement concrete.

Portland cement concrete	Sulfur concrete
Major	Major
Freeze-thaw mechanisms Salts (deicing) Dilute acids Sulfate attack Alkali-aggregate reaction	Thermal cycling Concentrated acids Heat and fire
Minor	Minor
Wetting and drying	Concentrated sodium hydroxide solutions Reinforcement corrosion Bacterial attack

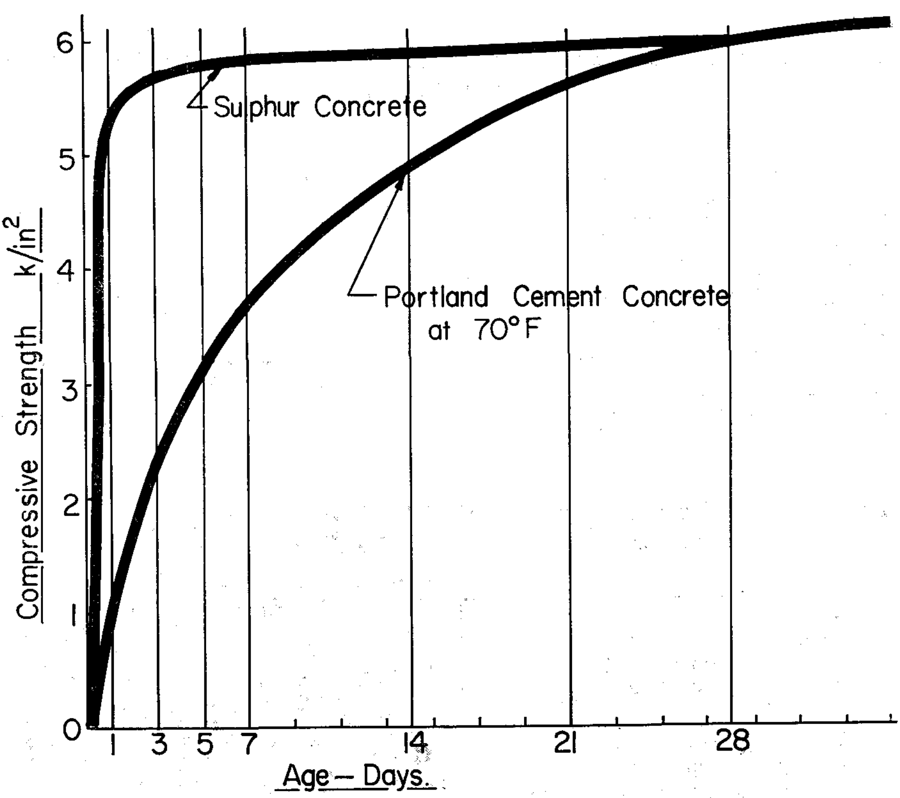

Fig. 6. Comparison of strength gain of sulfur concrete and portland cement concrete.

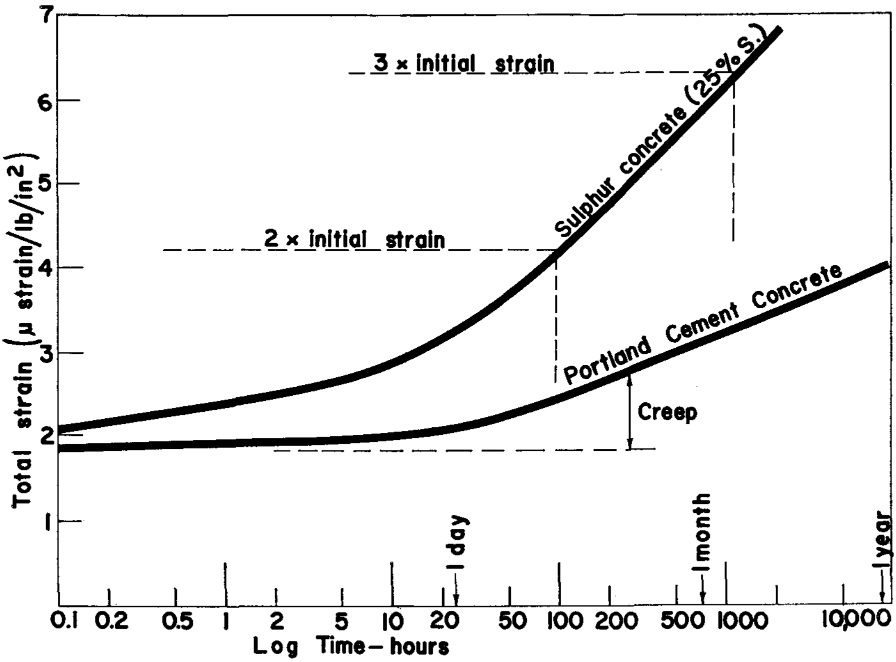

Fig. 7. Creep behavior of sulfur concrete and a comparable portland cement concrete at 70 F.

Two reinforced and two prestressed beams each 10 ft 6 in. long x 6 in. wide x 5 in. deep were fabricated (Fig. 8). The dimensions of the members were chosen so that the camber and deflections would be sensitive to shrinkage and creep strains. The dimensions and reinforcement were the same as those used in a previous investigation which compared the behavior of prestressed, partially prestressed and reinforced concrete beams.[18]

The sulfur concrete was mixed in a 1 cu ft capacity rotating drum mixer with insulation wrapped around the drum. The mixing procedure presently used involves the following steps:

1. Preheat coarse aggregate and sand

Table 3. Miscellaneous properties of sulfur concrete.

Impermeable
Low thermal conductivity
Low electrical conductivity
Possible formation of acid under action of water and sunlight
No adverse reaction with glass
No possibility of efflorescence
Extremely smooth finish
High coefficient of thermal expansion
Reacts with copper
Odorous when melted

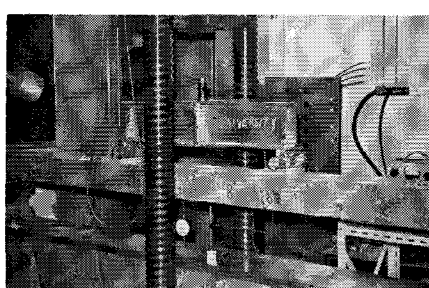

Fig. 8. Reinforced sulfur concrete beam.

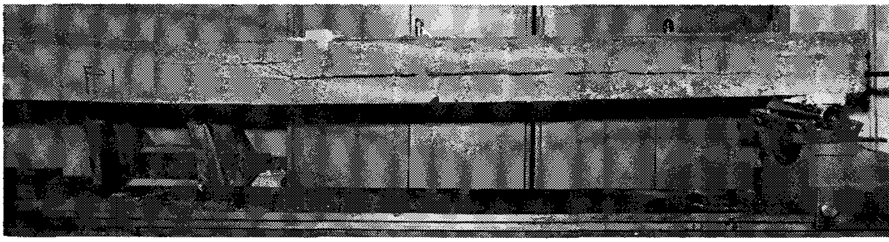

Fig. 9. Weak horizontal "cold" joint in sulfur concrete beam.

to 450 F.
2. Preheat base of drum.
3. Add preheated coarse aggregate to mixer.
4. Add powdered sulfur.
5. After sulfur melts add preheated sand and fly ash.

After thorough mixing the sulfur concrete may be either poured or shovelled into the forms. The mixes which have been used were placed without vibration. It is expected that leaner mixes could be used if vibration were used. This appears desirable to avoid some of the segregation problems which have been observed.

Provided the sulfur concrete is placed while it is well above the crystallization temperature a smooth finish will be obtained with excellent bonding between lifts. If the sulfur concrete is not sufficiently hot a weak "cold joint" may occur (Fig. 9).

Some difficulty has been experienced

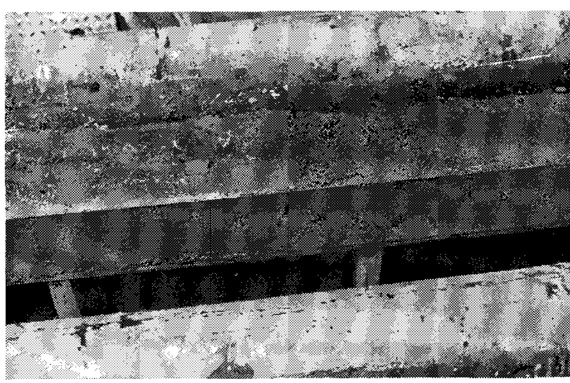

Fig. 10. Rough top surface of sulfur concrete beam.

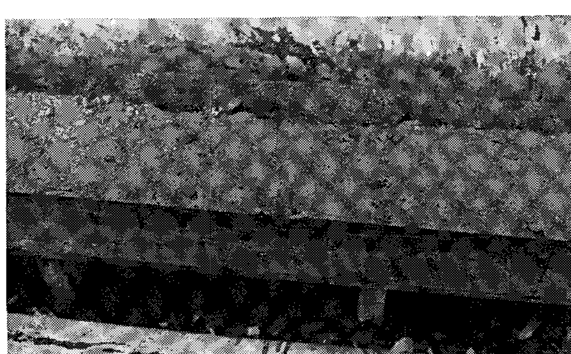

Fig. 11. Vertical thermal contraction cracking in sulfur concrete beam.

with obtaining a smooth level surface at the top of a beam (Fig. 10). A skin of crystallized material forms quite quickly so that troweling is difficult. Because sulfur contracts when it crystallizes the upper surface will dish as the sulfur hardens.

Additional difficulties were encountered because the limited mixer capacity required three batches in order to obtain sufficient concrete for a beam and accompanying flexural and compression test specimens. The concrete in the first beam was cast in three horizontal lifts.

Vertical cracking occurred in the second and third lifts as a result of the restraint provided by the hardened first lift (see Fig. 11). The problem was avoided in subsequent beams by placing the concrete with vertical casting joints between batches. The thermal contraction continues to manifest itself, however, through development of a small crack at the casting breaks.

Although testing has not yet been completed preliminary results indicate beam behavior which is comparable to the portland cement concrete beams previously tested.

It is too early to predict which of the many possible applications will ultimately prove to be suitable for sulfur concrete. The following applications appear to be worth considering: Industrial floors, bridge decks, curbs, tanks, pipes or pipe linings, and tunnel linings.

SUMMARY

Although there are difficulties which must be considered it seems probable that sulfur concrete will be found advantageous in many situations. The possible advantages of sulfur concrete combined with prospects for continuing low sulfur prices will provide a stimulus for active research, development, and use of this material.

It should be clear however that sulfur concrete cannot be considered to be a general replacement for portland cement concrete. Sulfur concrete can be expected to be used primarily for applications not suited to portland cement concrete.

ACKNOWLEDGMENTS

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