A Study of Development and Performance of Sulphur-Based Construction Blocks

by

Syed Qudrath Ali

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CONTENTS

Chapter *Page*

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The projected surplus of sulphur, when the proposed gas liquifaction programs in Saudi Arabia become fully operational, has stimulated research to investigate the feasibility of gainful consumption of this material in construction industry.

In this study an attempt has been made to construct sulphur based construction blocks using sand, sulphur and marl. Two methods were adopted in making sulphur-marl blocks. In one method a suitable dry mix of sand, marl and powder sulphur was mixed with water and molded to form a block, which was then dried in a heated oven. This was followed by raising the temperature to melt the sulphur within the body. This process yielded blocks having relatively low strength and durability, though the blocks were of perfect shape and formation.

In the second method the design proportions of only sand and marl were mixed with water and this mixture was lightly compacted to construct a block which was dried and then immersed in molten sulphur for infiltration. The finished blocks thus produced showed good compressive strength and durability leading to the conclusion that the proposed

method can be used successfully in manufacturing good quality blocks.

A long term durability study of sulphur sand specimens with and without filler was undertaken by subjecting the specimen to alternate wetting and drying cycles for a period of 9 months. The results showed that the material is durable and can be successfully used as a construction material in hot and humid environment.

chapter 1.

INTRODUCTION

1.1 General

The concept of using sulphur in construction industry started as early as 1920's (1). The worldwide production of sulphur as a by-product of petrochemical products has created a surplus over it consumption. The projection of surplus sulphur in 1980's has generated worldwide interest in research and development of potential uses of sulphur. Saudi Arabia is one of the major producers of sulphur. At present three plants are in operation, one is at Berri near Jubail, which has a planned production capacity 1000 long tons per day. This has been in operation since 1979. Present stock at this plant is about half million tons in the form of solid blocks. Second plant is located at Shudgum has a design production capacity of 1600 long tons per day. The surplus stock at this plant is about half million tons. The third plant is located at Uthmanya and has a design production capacity of 1200 long tons per day. Two more new plants are planned with a design capacity of 800 tons per day. When the planned gas liquifaction program in Saudi Arabia becomes fully operational, it is anticipated that the Kingdom would become a major producer of sulphur.

Concrete blocks are used almost exclusively in all masonry construction in Saudi Arabia and elsewhere in the Gulf region. This total dependence on the use of concrete blocks is due primarily to the nonavailability of an alternative form of masonry construction. Past research has shown that the binding property of sulphur can be successfully used in development of new sulphur bond construction materials (2). The abundance of sulphur in this region thus has generated a great deal of interest in research, aimed at utilization of sulphur bond materials in the construction industry. It is envisaged that such materials, if developed successfully, would not only add to locally available construction materials but would also provide a source of gainful consumption of excess sulphur.

1.2 Literature Review

The potential uses of sulphur as a cementing agent is not new. 17th Century example of using sulphur to anchor metal to stone still exists in Latin America (3). At the end of World War I sulphur was in surplus supply in Europe and America, and this stimulated research into new uses of sulphur. Bacon and Davis in 1921, reported on projected uses of sulphur in construction industry (4). They found that most of the additives employed to enhance the properties of sulphur were unsuitable. More recent research into sulphur utilization in construction material was initiated by Dale and Ludwing starting in early 1960's (5-8). The considerable research works that were subsequently carried out in development of sulphur based construction materials can be categorised into four major areas (a) sulphur sand mixture (SS), (b) sulphur sand and coarse aggregate mixtures commonly called as sulphur concrete (SC), (c) sulphur infiltrated concrete (SIC) and (d) sulphur asphalt (SA). A comprehensive review of the past research work in the first three areas which are related to some extent to the nature of the present work are given.

Schwartz and Llewellyn (9) investigated the effects of adding sand to sulphur on compressive strength to determine its utility as a mortar material. It is reported that sulphur sand mix with 50% of each constituent gave an optimum strength of about 7000 psi (48 MPa) for fine sand, while coarse sand sample yielded an optimum strength of 6000 psi (46 MPa) for a mixture of 40% sand and 60% sulphur. The difference in compression strength between coarse and fine sand at 30% sulphur content was nearly 2500 psi (17 MPa) with coarse sand giving higher value. It is reported that the compositions with less than 50% sulphur were relatively weaker because of the insufficient matrix relative to the amount of sand. This was even more so with fine sand because of its greater surface to volume ratio. The higher sand content compositions were less uniform as the sand tended to settle while the sulphur was molten. In the research carried out at the University of Petroleum and Minerals (10) studied the density, compressive strength, Young's modulus and durability of sulphur sand mixtures. The effect of the addition of lime-stone powder on these properties was also investigated. The results indicated that the optimum sulphur content with no powder is about 37%. The addition of limestone powder reduces this optimum to about 20% while increasing the compressive strength by about 20%. The specimen exposed to the environment for 6 months with temperature ranging 20^oC to 50^oC and relative humidity ranging from 95% to 15% suffered no loss in strength. On other hand those submerged in saline water for 3 months (with 3 drying cycles) lost 10% to 20% of their strength. These specimen did not show any cracking or signs of disintegration. Shirve et al. (11) have reported the results of a study of durability in temperature cycles and water resistance of sulphur mortar in various environmental conditions. Their findings indicate that immersion of specimens in water containing swelling clays can cause disintegration in a short time. However sulphur mortars can be used in Civil Engineering applications if the fillers containing no swelling clays are used and better formulations are developed.

Terrel and Babaei (12) worked on mortorless sulphur concrete blocks and eliminated the conventional methods problems and established a method to fabricate the blocks. This method essentially consists of mixing moist sand and clay with powder sulphur at ambient temperature using the same procedure as utilized for portland cement concrete blocks, the damp mixture is then compressed into its final shape under high pressure in die-type mold. The mixture is strong enough to be extruded from mold and to be dried. At this point the block is dried at low temperature until moisture is driven off, resulting in a relatively rigid structure with the sulphur acting as a mineral filler. The block is then heated to melt the sulphur and allowed to cool slowly. This method would be an advantage in automated production and the physical properties of block meet the ASTM requirements. Cheveron Chemical Company (13) has developed "SCRETE" sulphur concrete that combines outstanding chemical resistance with rapid set and high early strength. Modified sulphur is the binding agent for the aggregate and sand. SCRETE looks and handles much like P.C.C. SCRETE is a thermoplastic that hardens as it cools and most of its properties are fully developed within the first hour of cooling. SCRETE is difficult to melt or burn and odour is difficult to detect. Its outstanding chemical resistance makes it ideal for use in industrial acid processing areas such as metal refining, chemical and fertilizer production and sewerage treatment. This material has been used successfully in manufacturing building blocks, decorative blocks and roof tiles. On a commercial basis a versatile sulphur concrete called "SUDICRETE" has been developed by Sulphur Development Institute of Canada 'SUDIC' (14). The SUDICRETE products possess two important properties in that it effects the whole concrete system permenantly without making it brittle. Besides SUDICRETE products have excellent strain capacity relative to their strength, superior fatigue, corrosion resistance, rapid set and strength gain. Its outstanding resistance to all acids and salts makes its use in corrosion environments.

Crow and Bates (15) have indicated the development of high strength besalt concretes. Since then, as the potential surplus of sulphur became more evident, research has further been expanded (16-22). Sulphur concretes were developed with strength properties comparable or superior to those of portland cement concretes but many of these were found to be vulnerable to destruction on exposure to weathering, thermal cycling, and alternate wet-dry conditions. The investigators are attempting to overcome these problems which will make the use of sulphur more viable.

McBee and Sulivan (23) were able to develop corrosion-resistant, highly durable sulphur concrete using limestone and quartz aggregate with modified sulphur as cementing agent. The test results indicated the modifier Dicyclopentadien (DCPD) enhanced the freeze - thaw durability and lower absorption of water. It was concluded that sulphur modified concrete can be useful in the construction of leach tanks, bridge decking, industrial flooring, pipes and tiles where performance of conventional P.C.C. is not completely satisfactory. Diehl (24) carried out an extensive study on modified sulphur with DCPD and reported that modified sulphur was found to have higher strength at lower binder content. Non-modified sulphur concrete achieved its maximum compressive strength of 6250 psi (42 MPa) at a binder content of 36% by weight while for modified sulphur concrete only 20% binder was required to achieve a maximum compressive strength of 9650 psi (64 MPa). This study clearly showed that DCPD modified sulphur concrete displayed a number of improved properties rendering the sulphur concrete economical, as DCPD is a relatively cheaper material.

Gillot et al (25) reported that inclusion of a suitable proportion of fines helps to prevent segregation and improves workability. They also concluded sulphur concrete mixes fails in compression in a much more brittle manner than portland cement concretes of similar strength. This brittleness could effect performance, thus design methods used for portland cement concrete structures may be inapplicable. Sulphur concrete creeps more at room temperature than portland cement concretes and deformation from this cause may increase rapidly with temperature.

Lee et al (26) studied the fatigue behaviour of improved sulphur concrete and concluded that sulphur concrete can withstand much higher flexural stresses in terms of percent modulus of rupture and addition of DCPD and fly ash increases modulus of rupture. Gamble and Shrive (27) have indicated that creep is greatly affected by the methods of preparation and curing prior to testing. More creep occured in specimen where larger proportions of metastable material might be expected. Under some circumstances however an opposite trend is attributed to increasingly severe stress concentration was apparent. Hence the experiments underline the complexity of even the elemental sulphur system.

Gordon et al (28) studied the properties and uses of sulphur mortar and concrete from which it follows that understanding of the behaviour of concretes and mortars made with sulphur as a binder has reached a stage where the results may be used in predicting the potential usefulness in practical applications. The differences that are being evident between sulphur and P.C.C. emphasize the fact that sulphur concrete has useful properties and in some cases special problems.

The other field of research in utilizing the sulphur as the best impregnation material is for cement concrete (SIC). Various research works have been carried out on sulphur infiltrated concrete. Paturoev et al (29) shows that one can change considerably the physico-mechanical properties of initial building materials such as sand concrete, heavy concrete, ash-concrete, concrete of water-soluble glass, asbestos cement and building ceramics by impregnating the porous space with molten sulphur. Different depth of sulphur penetration can be obtained depending on regime, with surficial impregnation the protective coating of structure acquires an increased density and resistance to different actions. Such impregnation does not increase the bearing capacity of the structure. It only improves the resistance of the exterior layer to different kinds of aggressive action. With deep impregnation, not only is the resistance of the structure of external effects of environment increased, but also its beåring capacity. It allows important reductions of concrete and reinforcement materials in the case of reinforced structures. Canada Centre for Mineral and Energy Technology has been conducting research associated with sulphur concrete and sulphur infiltrated concrete since 1971. Carette et al (30) have indicated that SIC is a specialized product in precast concrete plants and obvious applications to the small precast units for curbs, patioslabs and for use in rural areas. Other possible applications could include precast railway ties and concrete pipes. The SIC is a valuable alternate in situation where conventional PCC has limited life expectancy and can increase the life expectancy by a factor of 2 to 3. Hope and Nashid (31) reported that in case of partial impregnation, the rate of change of strength and elastic modulus and the variation of the results were increased for the originally weak and immature mixes. The role of sulphur in improving the properties of concrete materials could be on the basis of increasing the strength of cement mortars through reducing its porosity and increasing the bond between aggregate and cement mortar. The stress-strain relationship in compression showed the considerable increase in the elastic modulus and ultimate compressive strength due to impregnation and the strains at failure were not substantially higher than those of untreated specimens. Reinforced impregnated beams showed a considerable improvement in the flexural and shear strength of concrete. Yuan and Chen (32) reported that bricks, brick prisms, blocks, block prisms and concrete pipes can be successfully impregnated with sulphur at atmospheric pressure to produce significant increase in strength and modulus of elasticity. They also mentioned that sulphur impregnation also improved the resistance of bricks and concrete pipes to water absorption, acid attack, abrasion and freezing-thawing. In an other research Brown and Baluch (33,34) studied the strength and durability of sulphur infiltrated concrete, with reference to the local environment of the Eastern Province of Saudi Arabia. They concluded that SIC may prove to have sufficient durability to be used as a construction material even in the absence of coarse aggregate. Groll, et al (35), Feldan (36) and Mehta et al (37) studied the durability of SIC and showed that sulphur infiltrated cement gives superior moisture resistance. Berry and Hope (38) showed that sulphur infiltration and autoclaving are ideally suited to the production of small, mass produced, high quality concrete items.

1.3 Scope and Objective

The construction industry has been utilizing sulphur over the past decade for providing new construction materials such as sulphur concrete, sulphur asphalt sulphur foam etc. In the conventional process of making sulphur sand blocks or specimens, the design mix of sand and powder sulphur is heated to about 150^{o}C to melt the sulphur. The hot mixture of sand and sulphur is then poured into the molds and allowed to cool and solidify. The disadvantages of this hot-mix method for industrialized production are that the molds cannot be removed immediately after casting as in the case of making concrete block, and that very limited time is available to cast the molten sulphur sand mix. It is therefore of interest to develop other type of sulphur based blocks using local resources which may have some advantages over the conventional sand-sulphur blocks and may be more suitable for industrialized production.

The primary obhjctives of this study are :

(1) to carry out long term durability tests for sulphur-sand construction blocks to firmly establish its

use as a durable material under the local environment.

(2) to devevelop new type of blocks using sulphur and locally available indegeneous materials which may be more suited for automated production.

(3) to establish casting procedure and proper mix design for new type of blocks and undertake necessary tests to determine the material properties and durability.

The study covers basically two types of sulphur-based blocks. In the first type, sand sulphur and filler has been used. Sulphur Concrete (SC) has already been developed elsewhere and some products made from SC are being marketted (13). Hence only a long term durability study of SC under the prolonged hot and humid environment has been undertaken to examine their durability and suitability for use in the prevailing hot, arid environment of Saudi Arabia. For this purpose test specimens of suitable mix design were prepared and subjected to repeated wetting and drying, maintaining regular cycles over a period of nine months. Samples have been wetted both in soft water and water having high salinity.

For the second type of blocks a mixture of sand, sulphur and marl is used to develop sulphur-marl blocks (SMB). Marl is the local name of silty-sand type material found in the Eastern Province of Saudi Arabia. The low binding strength of marl has been successfully used in this study to develop SMB. Two possible methods were attempted in the development of SMB. In one method the specimen is prepared by initial pre-compression of moist mixture of sand, sulphur and marl. The mix is then dried and heated to melt the sulphur and cooled down slowly. In the second method, a pre-compressed and dried sample of sand and marl is impregnated with molten sulphur for a short time.

The blocks were tested in direct compression to determine their compressive strength. The casting procedure and mix design adopted was aimed at producing best quality blocks in terms of strength, workability and durability.

chapter **2**

MATERIALS

2.1 General

The materials used in this study consisted of locally available sulphur, sand and marl. To some extent filler is also used. This chapter deals with the properties of each of these materials.

2.2 Sulphur

Sulphur, an element with atomic number 16 and atomic weight of 32.02, exists as rhombic and monoclinic crystals, which changes reversibly at 95.4°C with the absorption of 5.386 Btu per lb. Between this temperature and the melting point, monoclinic sulphur is the stable form. Ordinary commercial sulphur weighs between 24 to 90 lbs per cubic feet in bulk and melts at 112.8°C. Molten sulphur is straw yellow and transparent. Its temperature is usually maintained between 127°C and 150°C.

Various plasticizing agents have been used to modify the properties of sulphur and sulphur composites (24). The additives cause reduction in strength and elastic modulus. Energy required to melt sulphur is far less than that required to produce most cement. In the melted state elementary sulphur is an excellent binder for aggregates such as sand, gravel, crushed stone, and similar materials.

Sulphur composites are new class of materials that resulted from recent advances in the chemical and physical modification of elemental sulphur. They can be made strong and durable, resistant to weathering and resistance to attack by many common chemicals. A number of construction uses have been investigated for sulphur and sulphur composites. In this study, a standard commercial grade sulphur of 99.5% purity was used.

2.3 Sand

Beach sand and to some extent dune sand are the two main sources of fine aggregate in the Eastern Province of Saudi Arabia. The beach sand usually has smooth rounded grains. Sand from halfmoon beach, a local source, consists mostly of quartz. The specific gravity of sand is about 2.7, absorption 0.227 percent and the fineness modulus in most cases is in order of 1.3. Nearly all of it pass No.30 sieve, and 10 to 20% passes No.100 sieve. The surface area increases greatly due to the fineness of sand. The excessive fineness of sand and its narrow grading leads to a gap graded particle size distribution.

Sieve analysis data of sand used in this study is shown in Table 2.1. It is observed that while the percentage passing No.30 and No.100 sieves is 96.16 and 21.9 respectively. Only about 1 percent passed No.200 sieve.

2.4 Marl

Carbonate soils are locally referred to as marls. They are found in many areas of the Eastern Province of Saudi Arabia. These may be formed as a result of physical and chemical weathering of parent carbonate rocks. According to Fookes and Higginbottan (43), often the original characteristics of carbonate rocks are obscured or even erased due to their burial with detrital sediments. The carbonate minerals tend to be soluble, chemically reactive, easily recrystalizable and very dense in origin. Hence the academic classification of carbonate materials is extremely complex and depends on whether origin, texture, mineral composition, or the nature of the organic constituents is seen as the main factor. The mineral composition of these carbonate sediments is calcite ($CaCO_3$), aragonite ($CaCO_3$), dolomite CaMg $(CO_3)_2$ and siderite ($FeCO_3$). The properties of these carbonate soils are mainly affected by grain size and the post depositional changes which lead to induration (hardening without specifying a particular

TABLE 2.1

Sieve Analysis of Sand

Sieve No.	% Passing
4	100
8	100
16	99.96
30	96.16
50	61.366
100	21.906
200	0.968

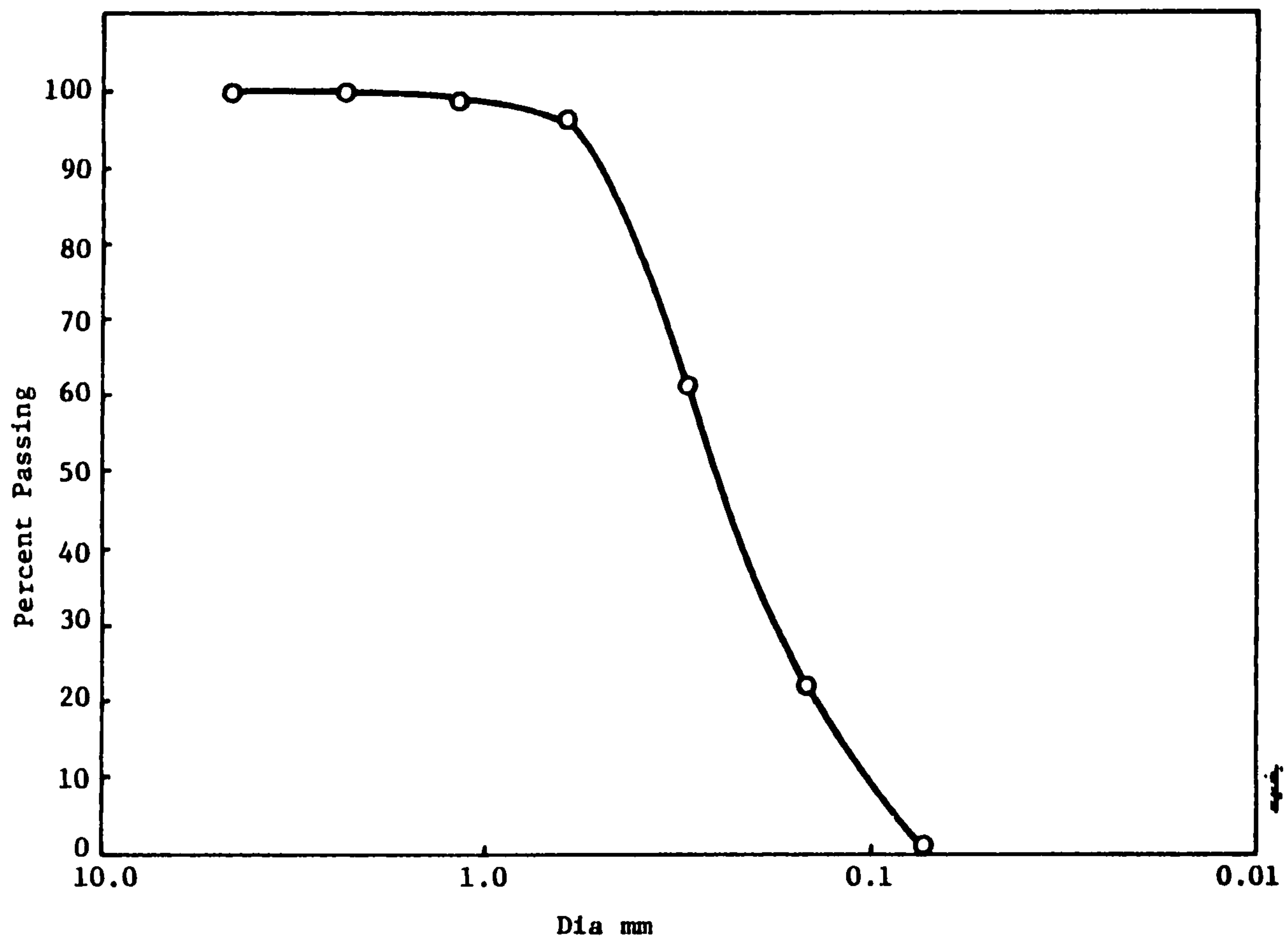


Figure 2.1 : Grain Size Distribution of Sand

process of hardening) and increase in strength.

According to Akili (44) preliminary reconnaissance work in the vicinity of Dammam, Eastern Saudi Arabia, has revealed the existence of different types of these carbonate dẻposits in terms of colour, composition, and gradation. Majority of these surface soils exists in cemented layers that overlie highly weathered carbonate rocks. Some may be burried by upto two meters of recent wind blown sediments.

The different types of marls used in this study were obtained from four separate locations in Dhahran and Dammam.

Type I	excavation near airport at a depth of 3-4 meters.
Type II	excavation near Aramco North Compound at a depth of 3 meters.
Type III	excavation near airport-Dhahran road at a depth of 1.5 meters.
Type IV	excavation near to Dammam-Riyadh road at a depth of 2 meters.

When marl is mixed with water and then allowed to dry, it hardens thus exhibiting some binding strength which is attributable to the presence of carbonates. This binding property of marl has been utilized in constructing sulphur marl blocks.

The properties of marls used in this study are listed in Table 2.2 The chemical analysis was done in the Environmental Lab of UPM as per the procedure given in "Soil Chemistry" by Jackson. Mechanical and the hydrometer analysis are given in Tables 2.3 and 2.4. The combined grain size distribution is plotted in Figure 2.2.

2.5 Filler

Filler used in this study was a crusher powder of lime stone obtained from quarries in the Eastern Province. The filler powder passed No.80 sieve. When filler is used it helps reducing to some extent sulphur consumption and increases the workability. It occupies voids in the sand and hence with use of some filler specimen strength increases.

TABLE 2.2

Properties of Marl

Description	Type			
	1	2	3	4
Grain size analysis percentage passing No.200	31.4	25.5	23.5	21.5
Percentage silt size (0.06 mm - 0.002 mm)	17.2	12.9	9.5	8.3
Percentage clay size (C 0.002 mm)	3.1	4.3	6.2	7.6
Liquid limit	-	-	38	43
Plasticity index	-	-	9	11
Specific gravity	2.75	2.73	2.79	2.80
pH	7.3	6.25	7.4	6.25
Electrical conductance mmhos/cm	10800	14000	3100	14500
Total dissolved solids mg/kg	9080	12592	2500	14276
Total hardness as $CaCO_3$ mg/kg	4320	7530	840	8330
Calcium hardness as $CaCO_3$ mg/kg	400	7170	800	7680
Magnesium hardness $CaCO_3$ mg/kg	3920	360	40	650
Total alkalinity as $CaCO_3$ mg/kg	1200	250	720	250
Sulphate as SO_4 mg/kg	3800	9407	600	10452
Chloride as CL mg/kg	737	461	184	1199

TABLE 2.3

Sieve Analysis of Marl

Sieve No.	% Passing
10	100.0
20	94.9
40	90.0
60	86.3
100	79.2
200	46.8
325	18.0

TABLE 2.4

Hydrometer Analysis

Elapsed Time min	Temp. ^{o}C	Actual Hydro-meter Reading	Corr Hydro-meter Reading	$\frac{L}{cm}$	$\frac{L}{t}$	Dia in mm	K	% Passing
1	29	31	28	11.1	11.1	0.043	0.0129	26.54
2	29	21	18	12.7	6.35	0.033	0.0129	17.39
3	29	16	13	13.5	4.27	0.027	0.0129	12.81
4	30	14	11	13.8	3.45	0.024	0.0128	10.98
8	30	12	9	14.2	1.775	0.017	0.0128	9.15
15	30	10	7	14.5	0.97	0.013	0.0128	7.32
30	30	9	6	14.7	0.49	0.009	0.0128	6.4
60	30	8	5	14.8	0.25	0.006	0.0128	5.5
120	30	8	5	14.8	0.125	0.005	0.0128	5.5
480	30	7	5	1.5	0.03	0.002	0.0129	4.52

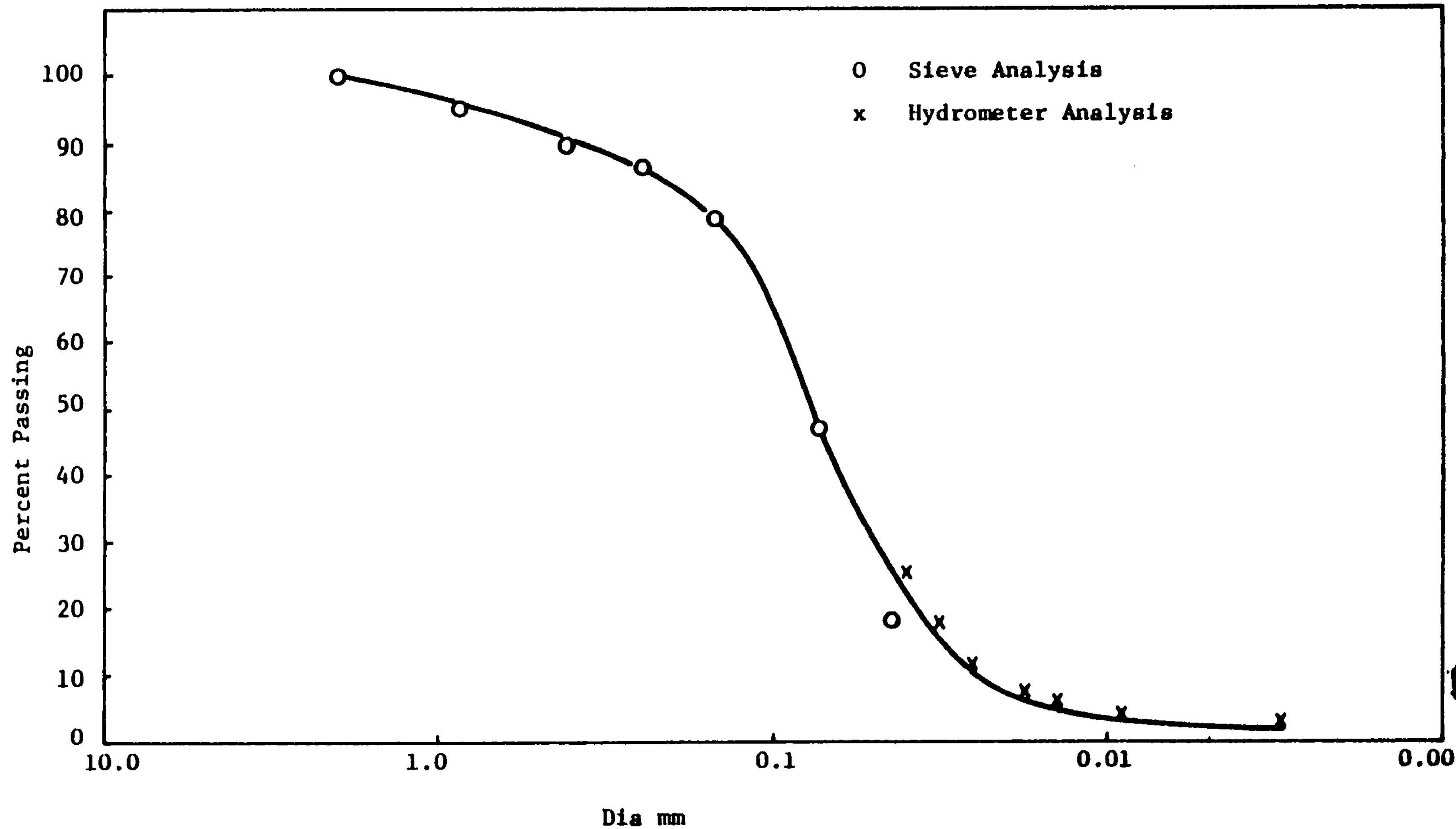


Figure 2.2 : Grain-Size Distribution of Marl

chapter **3**

METHODOLOGY

3.1 Casting Procedure

In this chapter, the details of the mix proportions and casting procedures as used in this study are given. Basically there were three types of mixtures : (a) Sulphur-sand mixture (b) Sulphur-sand and filler mixture and (c) Sulphur, sand and marl mixture. Apart from blocks, test specimens also included 2 in (50 mm) cubes and 3 x 6 in (75 x 150 mm) cylinders. For casting of all test specimens under each category of mixture, the casting technique described herein for each class was strictly followed.

3.1.1 Preparation of Sulphur-Sand Specimens

In proportioning sulphur-concrete (sulphur and sand) it is of economic interest to keep the proportion of sulphur to its lowest possible level that would be satisfactory from the view point of strength, workability and durability. Work carried out by Schwartz and Llewellyn (9) on different-sands reveals that 50 percent of sulphur will be sufficient to give maximum strength. However, this is a costly proportion. In another research carried out at University of

Petroleum and Minerals (10), it was shown that 35 percent of sulphur was sufficient to give maximum strength. This study also showed that for local sand 28 percent of sulphur would give sufficient workability and strength. Hence in this study the amount of sulphur was kept to a maximum of 28 percent by weight of the total mix.

Specimens for the study of long term durability test have been prepared using hot mix process. A 10 in bowl was used for mixing each batch containing 2 kgs mix, which was sufficient to produce one 3 in x 6 in (75 x 150 mm) cylinder. Steel molds were used for all specimens.

The sand was washed, dried, weighed and then heated to about 165^{o}C for about 4 hours. Sulphur in powdered form was mixed with hot sand. The mixture was then placed in an electric oven for about 10 minutes. After mixing the sulphur the temperature was maintained at about 145^{o}C. At this temperature the viscosity of molten sulphur is low, this improves the workability of the mix. Mixing was continued for 2-3 minutes to produce a uniform and workable mix.

Molds were mildly preheated since such molds would provide a relatively longer casting time by preventing rapid loss of heat from the mix which would be the case with unheated molds. Excessive heating of molds may,however, cause local separation at the interface. The casting was continuous and not in layers, thus avoiding any formation of joints. The mix was lightly compacted in the mold. The finished specimens were left to cool at room temperature for about 2-3 hours after which they were removed from the molds. This was possible due to the fact that sulphur concrete whose gain in strength is related to the speed of its heat-removal, requires only about 2 hours to gain about 80 percent of its strength.

3.1.2 Preparation of Sulphur Sand Filler Specimen

Research work at UPM (10) showed that 25 percent sulphur, 10 percent of filler and 65 percent of sand provides good strength and workability. Hence in this study same proportion was adopted. The method used for preparation and casting of specimens was similar to that of sulphur sand mix, except that the filler was mixed with sulphur prior to mixing it with hot sand. Test specimens were prepared using preheated molds and continuous pour.

3.1.3 Preparation of Sulphur-Sand and Marl Specimens

Two methods were adopted in the preparation of sulphur sand and marl specimens.(a) "Melting Method" and (b) "Infiltration Method". For both methods, prime consideration was given to the desirability of minimum use of marl in seeking a mix design that would produce specimens, (particularly blocks) having acceptable strength, workability and durability. The reason for this is that marl is not as easily and abundantly available as sand. Thus, it was decided from the outset that the content of marl should be kept within the maximum limit of 25 percent for both methods.

(a) Melting Method : This method of casting was conceived after the research work of ref (12) in which clay was successfully used as an initial binder. As there is very little clay available in the Kingdom, the use of marl instead of clay was very suggestive and appeared appealing. In this method, sand powdered sulphur and marl with various proportions indicated in Table 3.1 were mixed with water which was 8 percent by weight of total dry mixture. This amount of water was determined after several trials to yield best results. 2 in (50 mm) cubes, 3 x 6 in (75 mm x 75 mm) cylinders and 5 x 3½ x 3 in (128 mm x 88 mm x 75 mm) blocks were prepared. For each casting the measured quantities of materials were mixed thoroughly using a mechanical mixer. Specimens were prepared by compacting with a pressure of about 100 psi. This pressure was decided on the basis of trials, which showed that excessive pressure resulted in cracks in the specimens after they were removed from the

TABLE 3.1

Mix Proportion

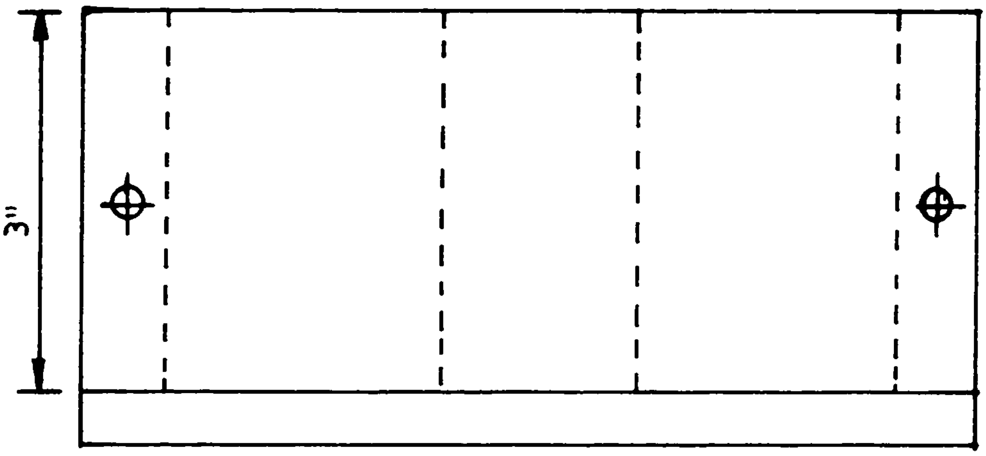
Method	Mix No.	Percentage of Dry Weight		
		Sand	Marl	Sulphur
Melting	A1	60	15	25
	A2	55	15	30
	A3	55	20	25
	A4	50	20	30
	A5	50	25	25
	A6	45	25	30
Infiltration	B1	85	15	-
	B2	80	20	-
	B3	75	25	-

molds. This was probably due to rebound of the specimen. At this stage the specimens were hard enough due to the binding strength provided by the marl, for easy handling. It was then transfered to a heated oven, where it was dried for about 24 hours at the temperature of 75°C. This was followed by raising the temperature to 150°C in two steps in order to melt the sulphur in the body of the unit. To avoid loss of sulphur due to over heating and subsequent possible segregation the time of heating at 150°C was restricted to half an hour, which was determined from several trials. The temperature in oven was then lowered in stages and brought back to room temperature to avoid rapid change in ambient temperature, which may yield cracks.

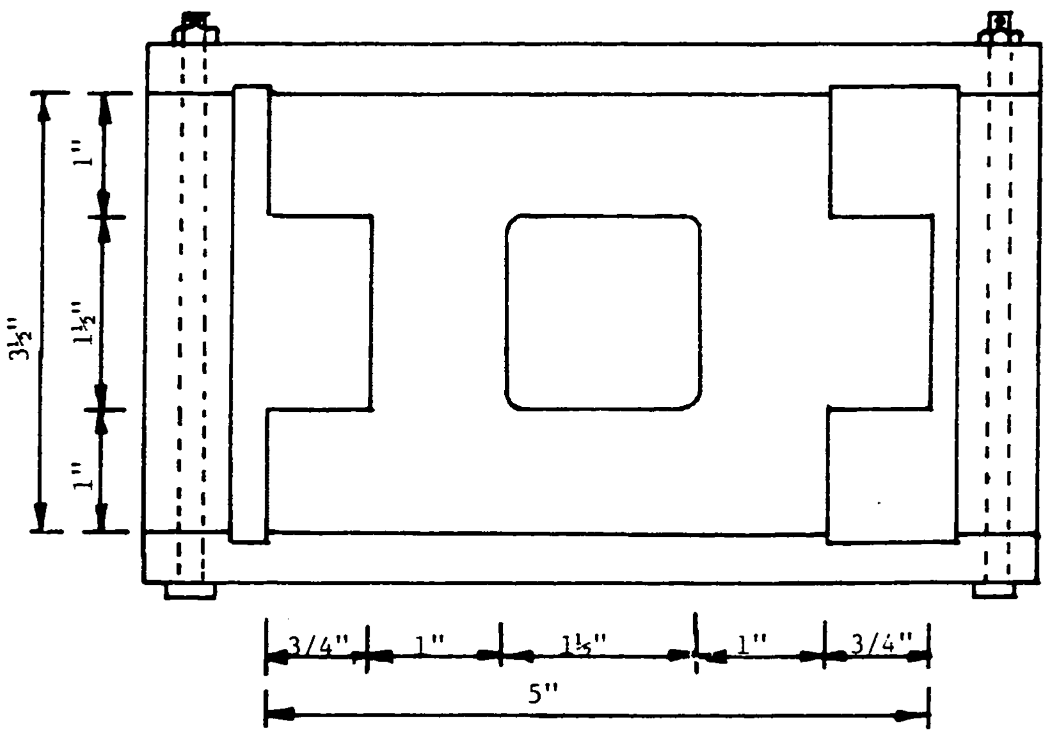
(b) Infiltration Method : In this method, only the mixtures of sand and marl were used in varying proportions as shown in Table 3.1. The amount of marl varied from 15 to 50%. The initial preparation of the specimens which included cubes, cylinders and blocks was exactly the same as used in the "melting method". Measured quantities of the specimens were thoroughly mixed with water, 8 percent by weight of the total dry mixture. For casting of a specimen the mold was filled in with the moist mixture which was then compacted under a pressure of 100 psi. The specimen was withdrawn from the mold and then transferred to an oven where it was dried for about 12 hours at a temperature of about 75°C. Subsequently the temperature was raised to 100°C for a period of another 8 hours. The temperature was raised to 150°C for about 4 hours prior to infiltration with molten sulphur. The specimens were immersed in a tank of molten sulphur at 150°C. for a short period of time. For most specimens, time of infiltration was limited to 5 minutes as the test results with longer infiltration time show that over 70 percent of the ultimate strength can be gained with five minutes of infiltration. The effect of infiltration time on strength has been discussed in the test results (Chapter 5). The samples after infiltration were removed from molten sulphur after desired infiltration had been achieved and allowed to cool at room temperature for 2-3 hours.

3.2 Description of Mold for Blocks

For blocks, a special steel mold with removable sides was designed and fabricated to produce hollow blocks. Fig.3.1 shows the details of the mold. Due to the intended future use of blocks in masonry wall tests, the block was designed to have keys in the longitudinal direction. To provide central opening an aluminum extender was built and used as a separate piece. It was slightly tapered for easy removal.



(a) Elevation



(b) Plan

Figure 3.1 : Mold Details

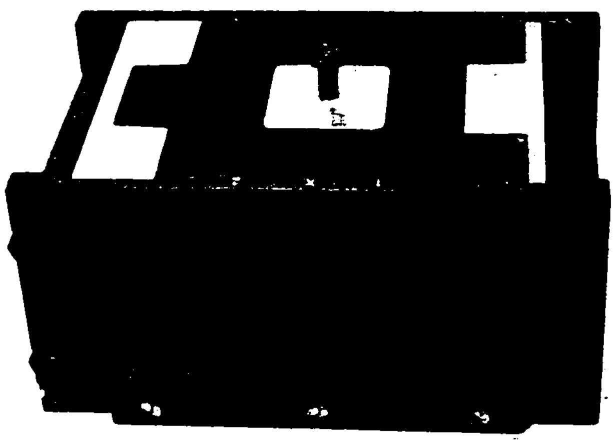


Figure 3.2 : Mold

At the time of molding the central piece was secured in position by connecting it to the bottom plate with a small screw. Similar unit of 3 in (75 mm) height was used on the top of the mold to hold the mix before compaction. A separate steel plate of block shape was used to compact the mix. Details of complete assembly are shown in Fig.3.2. A 3" (75 mm) dia. pipe piece of 5 in length (128 mm) was used to apply the load uniformly on the top plate. After compaction the entire mold can be unscrewed and sample can be removed easily.

3.3 Durability Monitoring

3.3.1 Sand-Sulphur With and Without Filler

In order to determine the possible loss of compressive strength due to water absorption four cylinders of each mix were preweighed and immersed in soft and saline water. Saline water was prepared by mixing 45 grams of salt with one litre of soft water. This salt content was chosen because it is reported that the maximum salinity of Gulf water is around 45 grams per litre. For long term durability study samples were subjected to repeated wetting and drying cycles for a period of nine months. Each complete cycle consisted of submerging the specimen in water for four days and drying them in oven at 30°C for the next two days. The dry samples were again submerged in water. A continuous period of nine months of repeated wetting and drying was considered to be a satisfactory simulation of long term weathering in hot and humid environment. Materials which are proven to be capable of withstanding such environmental effects without significant loss of basic properties and strength can be classified as durable against normal weathering.

3.3.2 Sulphur-Marl Blocks

The blocks of various mix were kept in water for a period of 48 hours to observe the loss of strength and to determine the water gain. Further the blocks were subjected to repeated wetting anddrying for a period of 2 months, to determine the strength of blocks and to monitor durability.

chapter 4

TEST PROGRAM

4.1 Compressive Strength

For compressive strength, selected blocks were tested under direct axial compression on a soil compression machine having a maximum loading capacity of 60,000 lbs. The load was applied through a head which covered the entire top surface of the blocks. Since the blocks were prepared with smooth and horizontal top and bottom surfaces, no additional measure was required for testing.

To obtain data for cube strength of this material, 2 in cubes were prepared following the same proportions and casting procedure as were used for blocks. They were tested in accordance with ASTM Standards.

Compressive strength of cylinders prepared with sand sulphur with and without filler was tested both in dry condition and subjecting the specimens to alternate wetting and drying.

4.2 Stress-Strain Relation

To obtain data on load-deformation relationship tests were conducted on 3 x 6 in (75 mm x 150 mm) cylinders fitted electrical strain gauges at the mid-height. In order to ensure uniform stressing by the bulk head of the testing machine, three electrical gages were used at mid-height at about 120° apart to check the consistency of readings. Static loads were applied by Instron 1196 Testing Machine and the strains in the specimen were recorded for each load. To record correct instantenous strain readings for each static load, the following procedure was used to exclude the effect of creep. After the reading for one load was recorded, this load was removed and then the next load was applied after allowing a small time gap in between. Fig.4.1 shows a typical specimen under Instron Testing Machine.

4.3 Creep Testing

Selected 3 x 6 in (75 mm x 150 mm) cylinders were fitted with electrical strain gauges at mid-height. Initial creep test was conducted on Instron 1196 testing machine by applying a static load of 50 kN and strains were recorded at various time intervals.

4.4 Measurement and Instrumentation

For the measurement of weights of various test specimens weighing scales were used with an accuracy of 0.1 gram. To check consistency of test data and to obtain an average

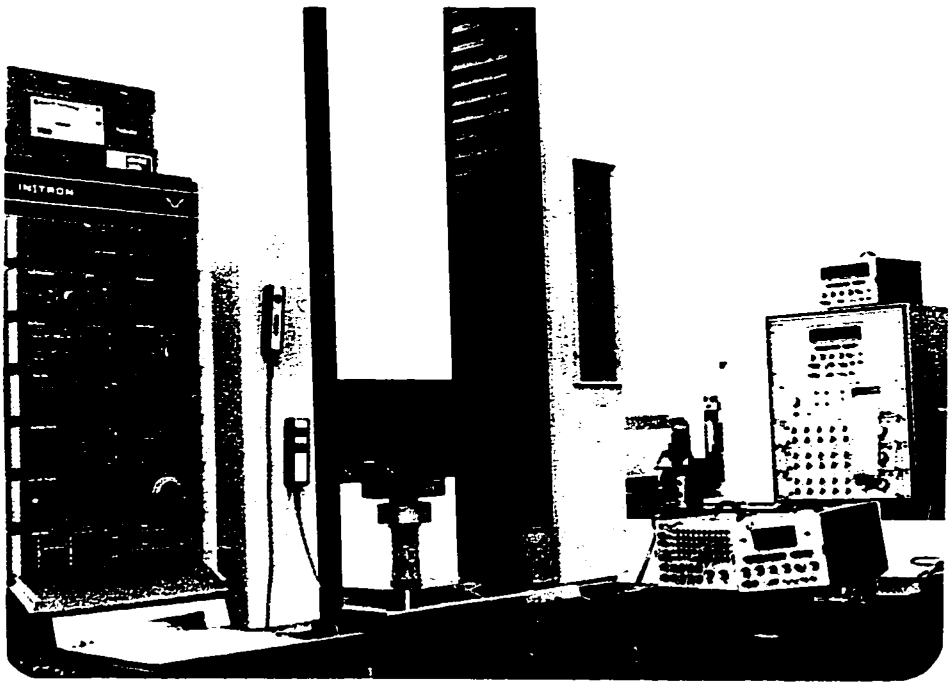


Figure 4.1 : Specimen Under Instron Testing Machine

value of test readings, whenever possible tests were repeated at least three times. For test specimens, only the good ones that reflected good casting and no visual imperfection were selected.

Electrical strain gauges, type FAE 37-12-56EL were used for record of strains. They are fitted to the specimens following standard procedure and practice.

chapter **5**

TEST RESULTS AND DISCUSSION

5.1 Comparison of Two Casting Methods for Sulphur-Marl Blocks

Test conducted on blocks and specimens constructed by the melting method showed both lack of adequate strength and durability with no visual cracks or other imperfections. The compressive strength of blocks showed an average stress level of only 300 psi. Due to high water absorption, the wet specimens showed even much lesser strength and some sign of disintegration and deterioration after prolonged immersion in water. The reason attributed to this low durability in water is that the units remained very porous with sulphur failing to fill in the voids so as to effectively decrease the permeability. Attempts were made to improve properties considering various proportions of sulphur, marl and sand, and using graded sand and very fine powdered sulphur and marl. However, no significant improvement in results was obtained, thus leading to the general conclusion that the melting method is not suitable to produce S-M blocks. While clay has been successfully used to produce blocks following similar procedure as the melting method, properties of marl being not comparable with those of a good clay, the method was unsuccessful in producing good blocks.

The infiltration method on the other hand, yielded S-M blocks that were of much superior quality both in terms of strength and durability. Because of this reason, the melting method was eventually discontinued in favour of the infiltration method which was examined at much greater depth. Thus the results obtained from the infiltration method are reported herein.

5.2 Physical Properties of S-M Blocks

The weight and composition of three types of blocks, made by the infiltration method are shown in Table 5-1. Since the specific gravity of marl used was slightly higher than that of sand, the dry weights of the units varied only marginally. The final weight was controlled by the amount of sulphur absorbed during infiltration, due to increase in the content of marl, the final weight appeared to increase marginally. The over-all dimensions of each block was 5 x 3½ x 3 in (128 mm x 88 mm x 75 mm). The cross section area and the volume was 16.625 in^2 (8145 mm^2) and 37.88 in^2 (6210 mm^2), respectively. A photographic view of blocks is shown in Figure 5.1.

TABLE 5.1

Data for Blocks

Mix No.	Av. Initial Dry Weight (in lbs)	Av. Final Dry Weight (in lbs)	Unit Weight in (lbs/ft^3)	Composition in Percentage of Final Weight		
				Sand	Marl	Sulphur
B_1	2.116	3.051	132.20	58.9	10.4	30.7
B_2	2.122	3.069	140.02	55.3	13.8	30.9
B_3	2.127	3.082	140.61	51.6	17.2	31.2

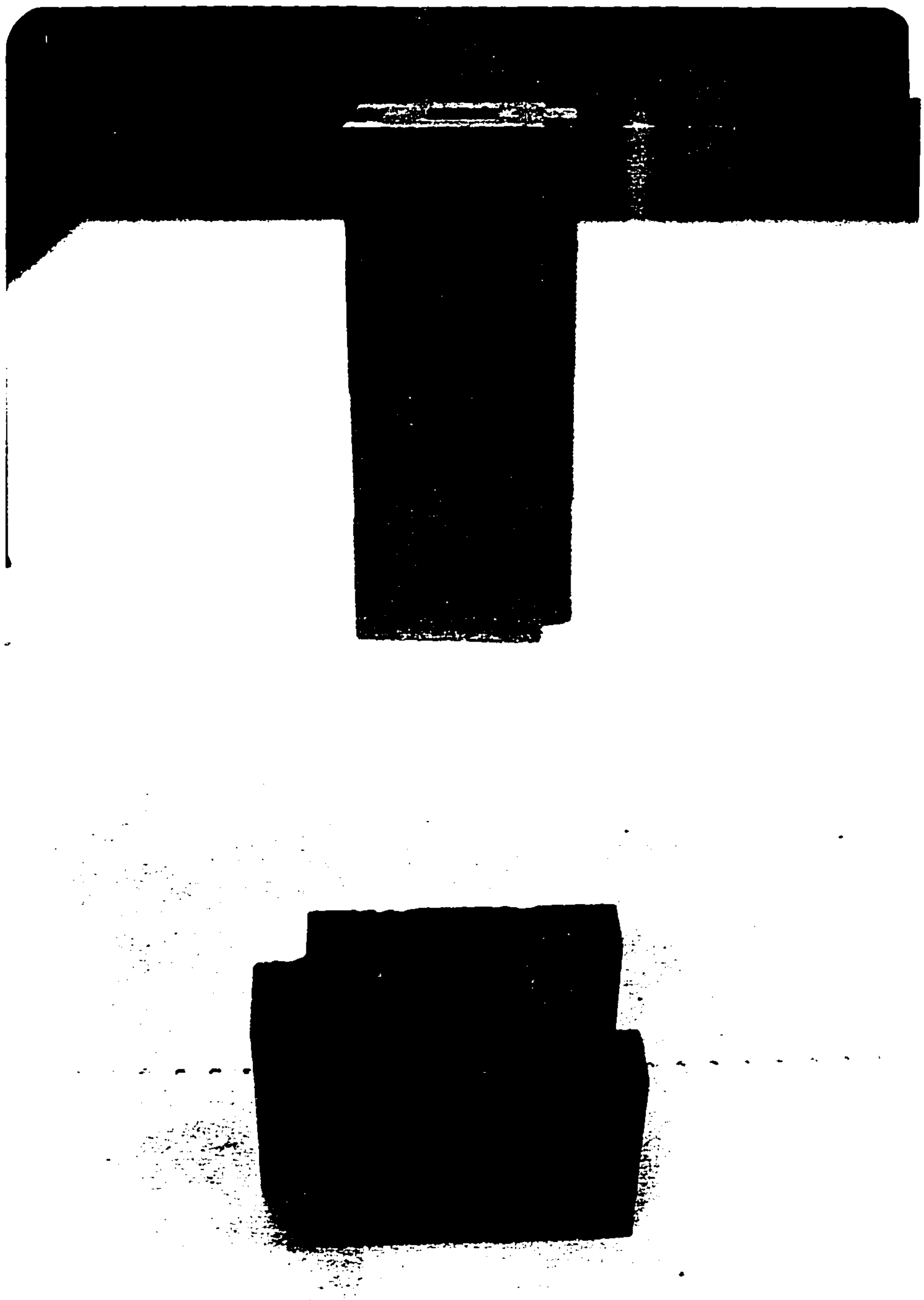


Figure 5.1 : Photographic View of Block

5.3 Effect of Different Marl

In this study four types of marl were used. The chemical analysis of marl used is shown in Table 2.2. It was observed that marl with plasticity developed cracks in the specimens, during the process of cooling in both types of casting methods. Eventhough the compressive strength of such specimens was satisfactory, the appearance of cracks clearly indicated all types of marl cannot be used in producing good blocks without cracks. Marl of type I and type II are non-plastic and this type was found to be satisfactory for production of sulphur-marl blocks. The types III and IV marl contained some clay which imparts plasticity. The specimens produced from these types developed cracks during the process of cooling and hence unsuitable for production.

It was not possible at this stage to evaluate the level of contents and type of clay in marl. A thorough chemical analysis and X-Ray defraction technique would be necessary to identify the contents and other possible factors causing cracks in the sulphur-marl blocks.

5.4 Compressive Strength

5.4.1 Effect of Marl Content

In order to determine the effect of marl content on the compressive strength, the quantity of marl was varied from

15 to 50 percent by weight with an increment of five percent. Cube specimens were used for this purpose. As the proportion of marl was increased, the strength of the cubes also showed an increase as indicated in Figure 5.2. The time of infiltration was kept at five minutes for all cases. Results depicted in Figure 5.2 show that the compressive strength of cubes increases with the content of marl increasing to about 40 percent. With further increase in the amount of marl beyond 40 percent, the strength remains essentially unchanged. To determine the compressive strength of blocks marl was varied from 15 to 25 percent with an increment of five percent. Figure 5.3 (Table 5.2) shows the compressive strength of blocks. The average strength of a block with 15 percent marl and five minutes infiltration time was 2450 psi compared with an average strength of 4175 psi for a 25 percent marl block.

5.4.2 Effect of Infiltration Time

Figure 5.4(a) shows the variation of the compressive strength of 2 in cubes with infiltration time and Figure 5.4(b) shows the relation between the amount of sulphur consumed with infiltration time. The marl content was varied from 15 percent to 25 percent by an increment of five percent. Time of infiltration was varied from 2 minutes to 2 hours.

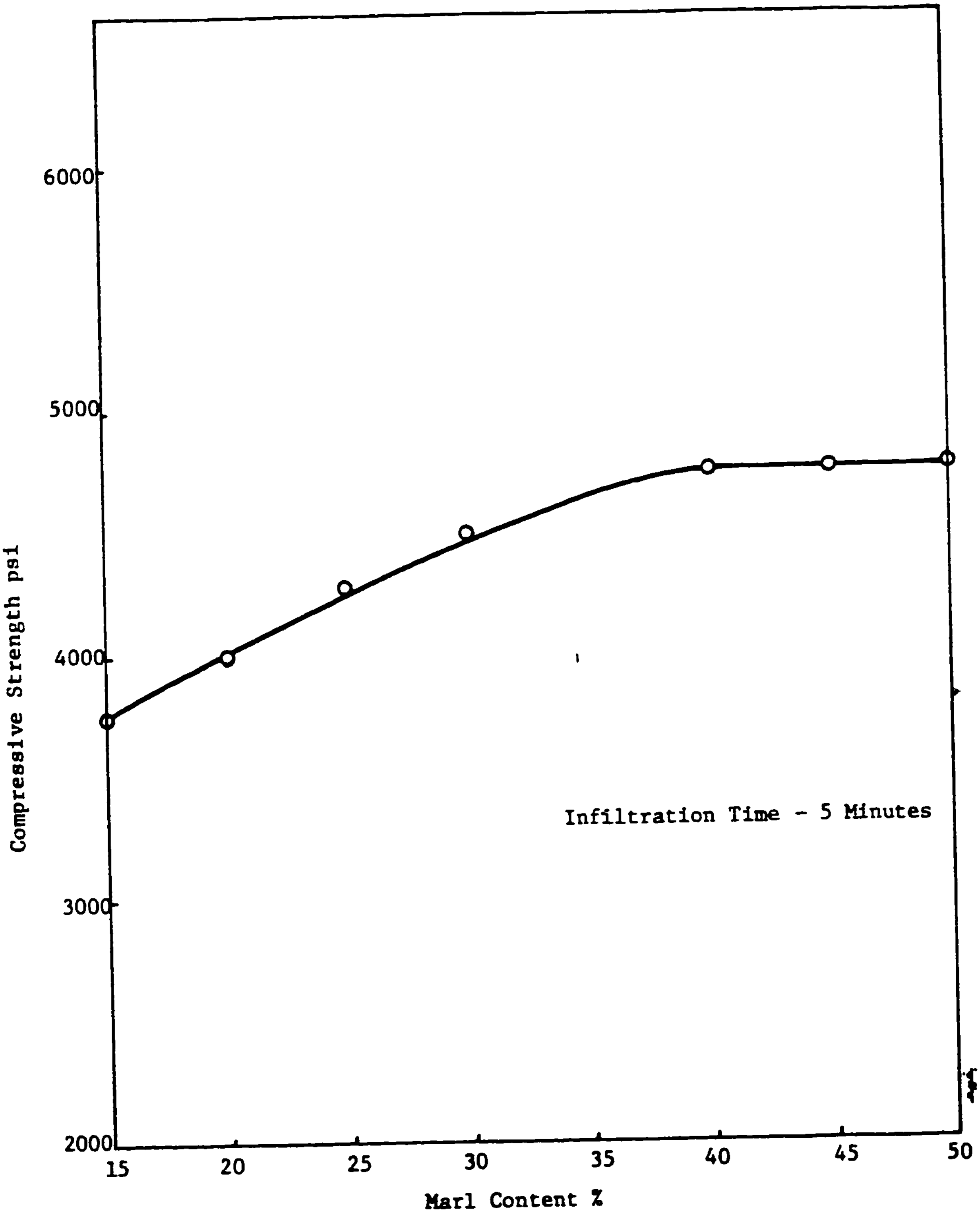


Figure 5.2 : Compressive Strength vs. Marl Content

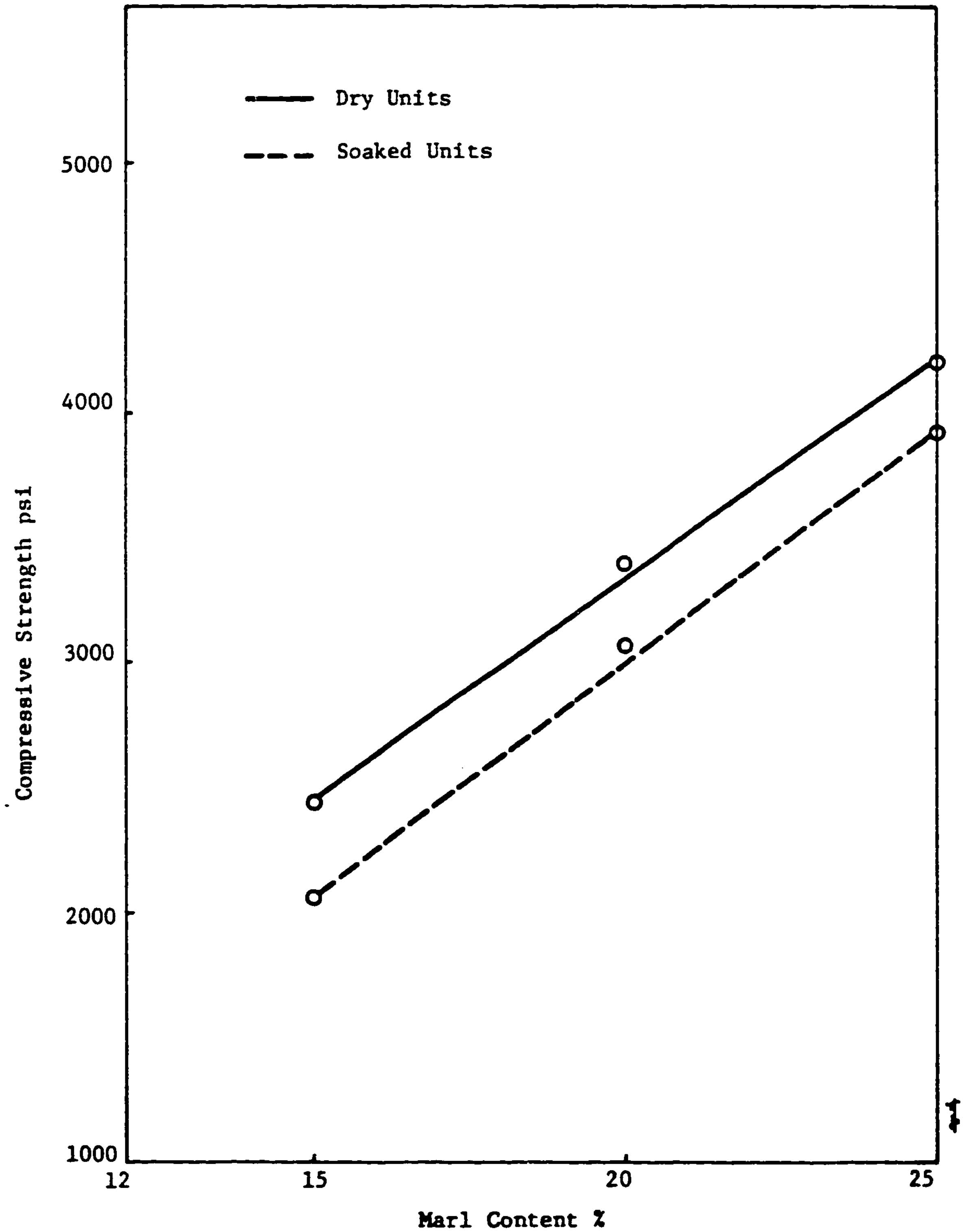


Figure 5.3 : Compressive Strength of Blocks vs. Marl Content

TABLE 5.2

Compressive Strength of Blocks vs. Marl Content

Marl Content %	Av. Compressive Strength (psi)
15	2450
20	3400
25	4175

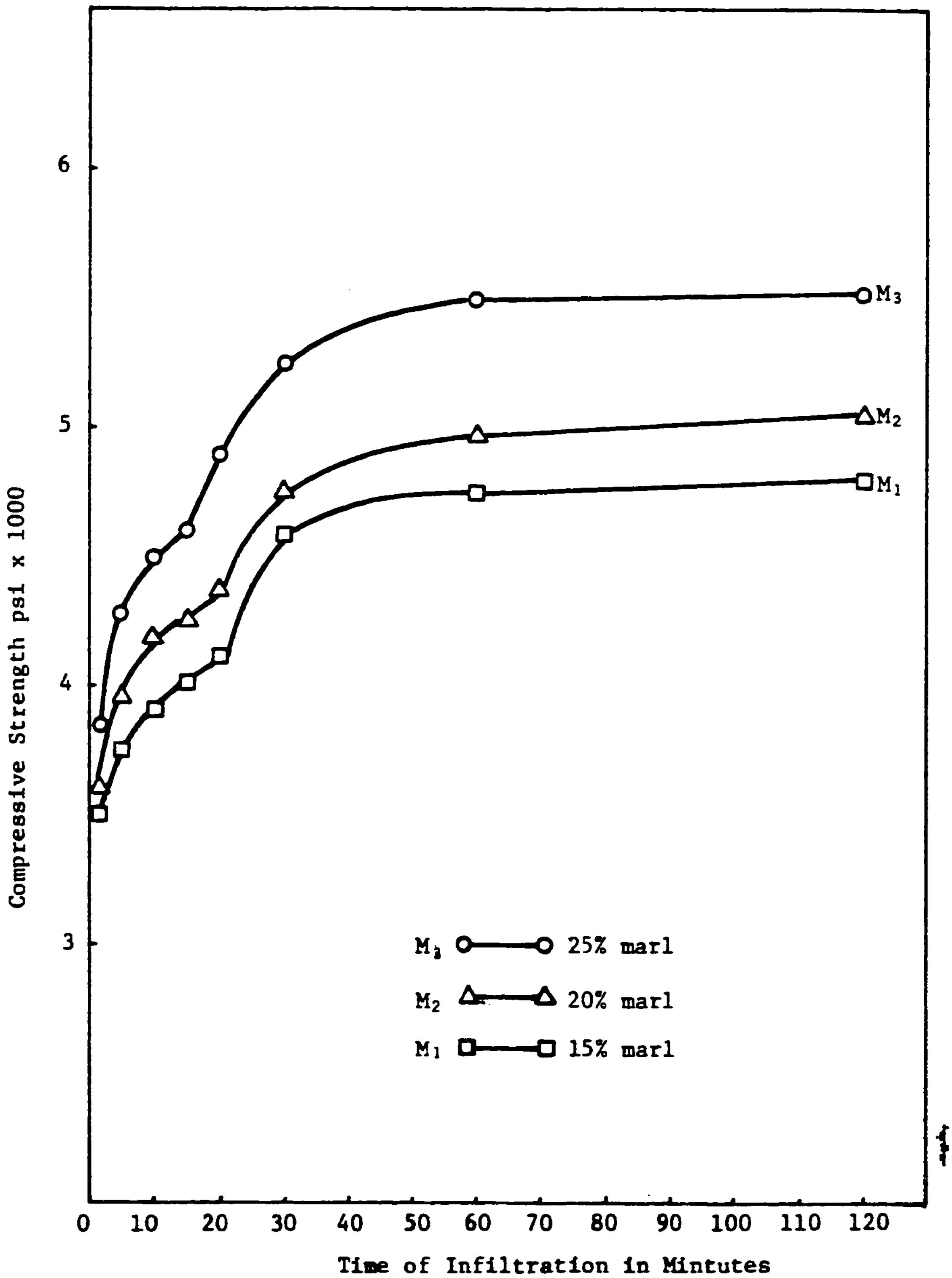


Figure 5.4(a): Compressive Strength vs. Infiltration Time

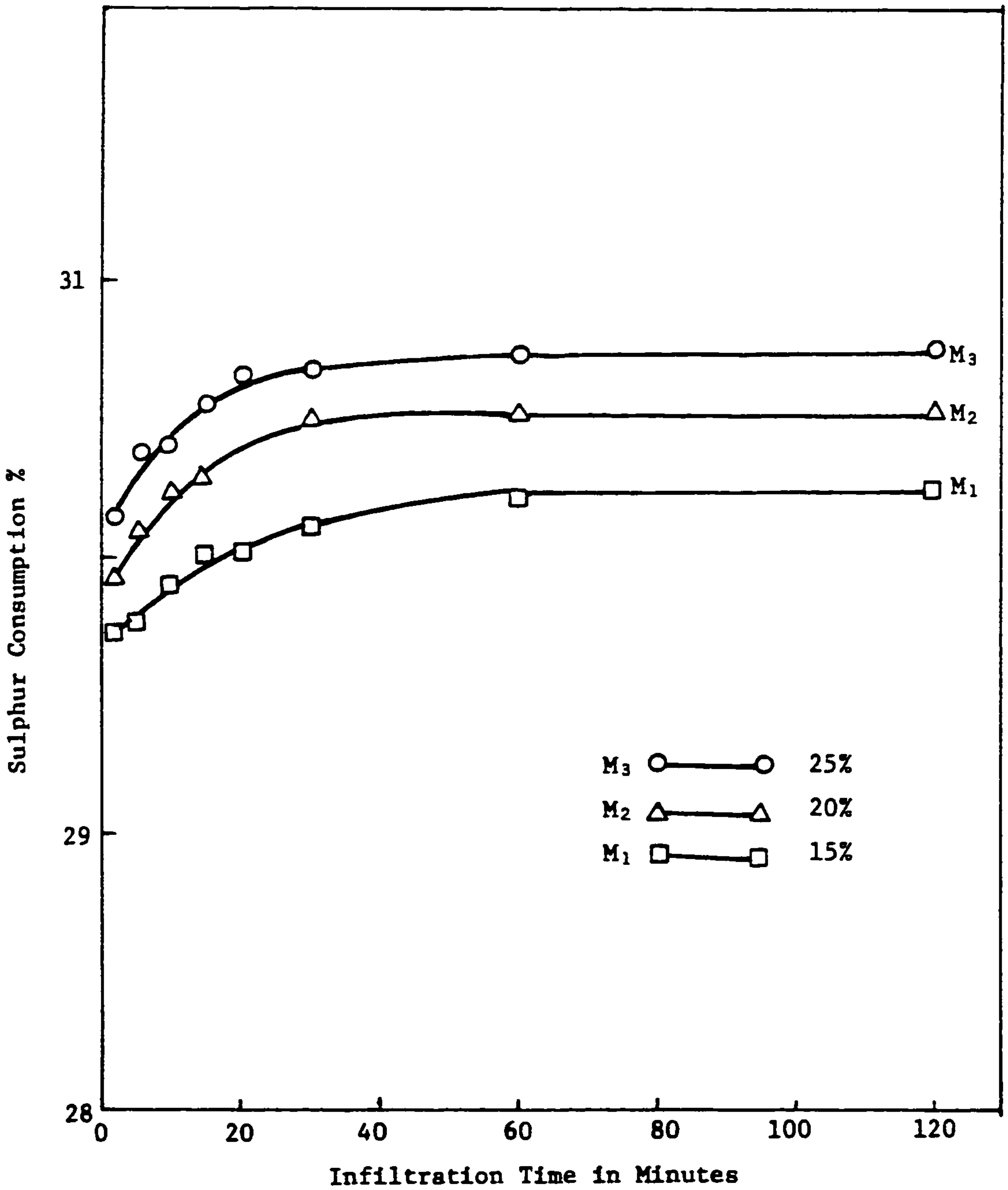


Figure 5.4(b) : Infiltration Time vs. Sulphur Consuption

As seen from Figure 5.4 the time of infiltration plays a significant role in the development of the compressive strength.With longer period of infiltration, the compressive strength increases, but the increase in strength becomes insignificant after about an hour. Thus it can be concluded that approximately an hour long infiltration time is required for a complete infiltration to achieve the ultimate compressive strength.

In order to minimize the time of infiltration which would definitely be the objective of an automated production, a period of five minutes was adopted as the minimum time required for infiltration to produce a satisfactory level of strength. This time was decided considering the plots in Figure 5.4 which indicate that about 75 percent of the ultimate compressive strength gained at an hour infiltration time can be achieved with a five minutes period of infiltration time. Thus, this time was used for all specimens.

5.4.3 Effect of Water Content

Figure 5.5 shows the variation in compressive strength of 2 in cubes with the water content. To optimize the water content; percent of marl and infiltration time was kept unchanged. The 25 percent marl and 5 minutes infiltration time was adopted. The water content varied from 6 to 10 percent with an increment of one percent. It was observed that the strength increases with an increase in water content upto

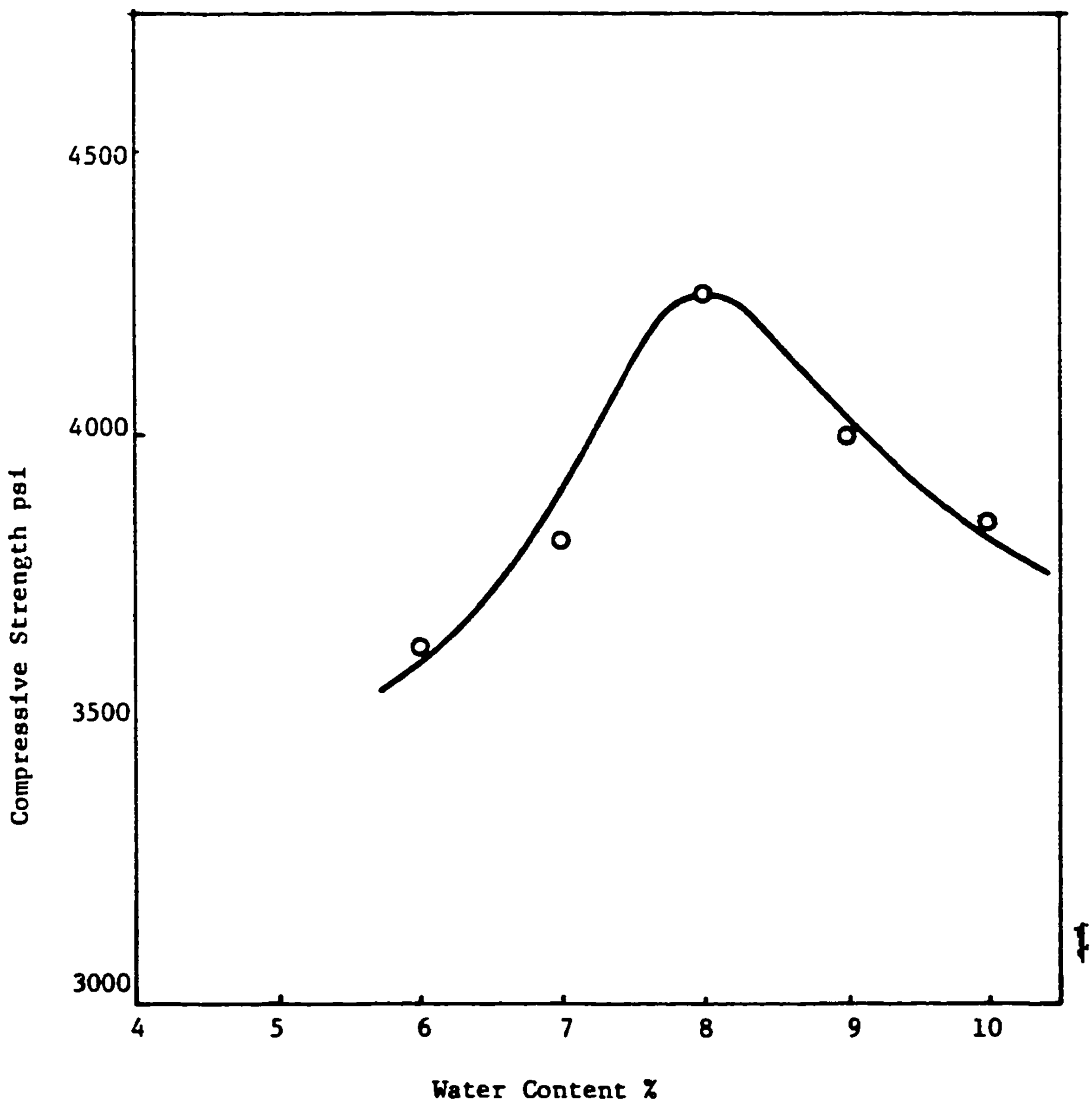


Figure 5.5 : Compressive Strength vs. Water Content

8 percent after which there is a decline in strength with further increase in water content. Thus 8 percent water content was adopted for all specimens in this study. The workability of the mixture at this level of water content was also satisfactory.

5.4.4 Effect of Wetting

To determine the possible loss of compressive strength due to water absorption, sulphur infiltrated blocks were soaked in water for 2 to 8 days. Figure 5.6 shows the compressive strength of blocks after soaking which indicates that blocks lose strength with increase in period of soaking. It was observed that loss of strength after 8 days of soaking was about 11.5 percent.

5.5 Absorption

The amount of water absorption of the blocks is related to permeability of the units, which in turn is controlled by the amount of infiltrated sulphur. Due to infiltration, the voids in the units are filled in by the sulphur, which being basically water repellant, provides a high degree of imperviousness. In order to evaluate the amount of water absorption by the units, selected blocks were immersed in water for a period of 2 days to 60 days at room temperature. It was observed that the absorption of the units increases marginally

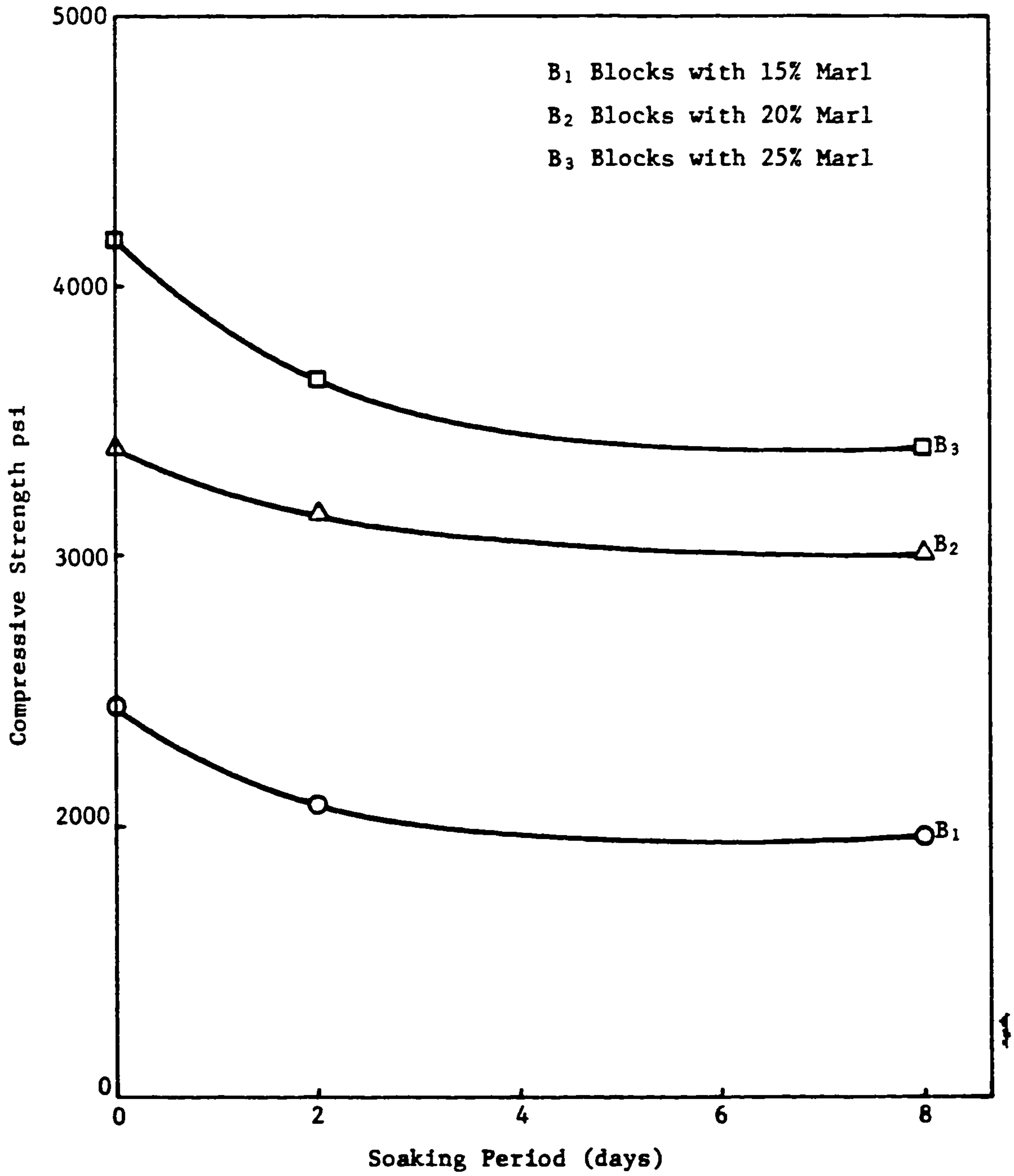


Figure 5.6 : Compressive Strength vs. Soaking Period

with reduction in marl content. The absorption data given in Table 5.3 for three types of mix design, indicates that in general, sulphur marl blocks have a low degree of water absorption.

5.6 Load-Deformation Relationship

In order to observe stress-strain relationship of the infiltrated units and to determine the modulus of elasticity, tests were conducted on 3 x 6 in (75 mm x 150 mm) cylinders. Figures 5.7 and 5.8 show a typical plot of load versus measured strains upto 50 percent of the ultimate load for the samples with 20 percent and 25 percent marl and 5 minutes infiltration time. Test results indicate that the material behaves almost linearly upto high stress level. For all practical purposes the value of modulus of elasticity can be taken from the linear stress-strain plots. For samples with 25 percent marl, an average value of modulus of elasticity was determined to be 8.75×10^6 psi, and for samples with 20 percent marl, an average value of modulus of elasticity was determined to be 7.6×10^6 psi. which is about 15 percent less than that for 25 percent marl specimens.

5.7 Creep

3 x 6 in (75 mm x 150 mm) cylinders of 20 percent and

TABLE 5.3

Absorption

Soaking Period in Days	Mix No.	Final Dry Wt.of Block (lbs)	Wt. of Soaked Blocks (lbs)	Wt. Increased (Percentage)
2	B_1	3.09	3.12	1.0
	B_2	3.116	3.158	1.34
	B_3	3.124	3.17	1.48
8	B_1	3.053	3.112	1.93
	B_2	3.074	3.128	1.76
	B_3	3.08	3.137	1.74
60	B_1	3.052	3.132	2.63
	B_2	3.066	3.142	2.45
	B_3	3.12	3.186	2.12

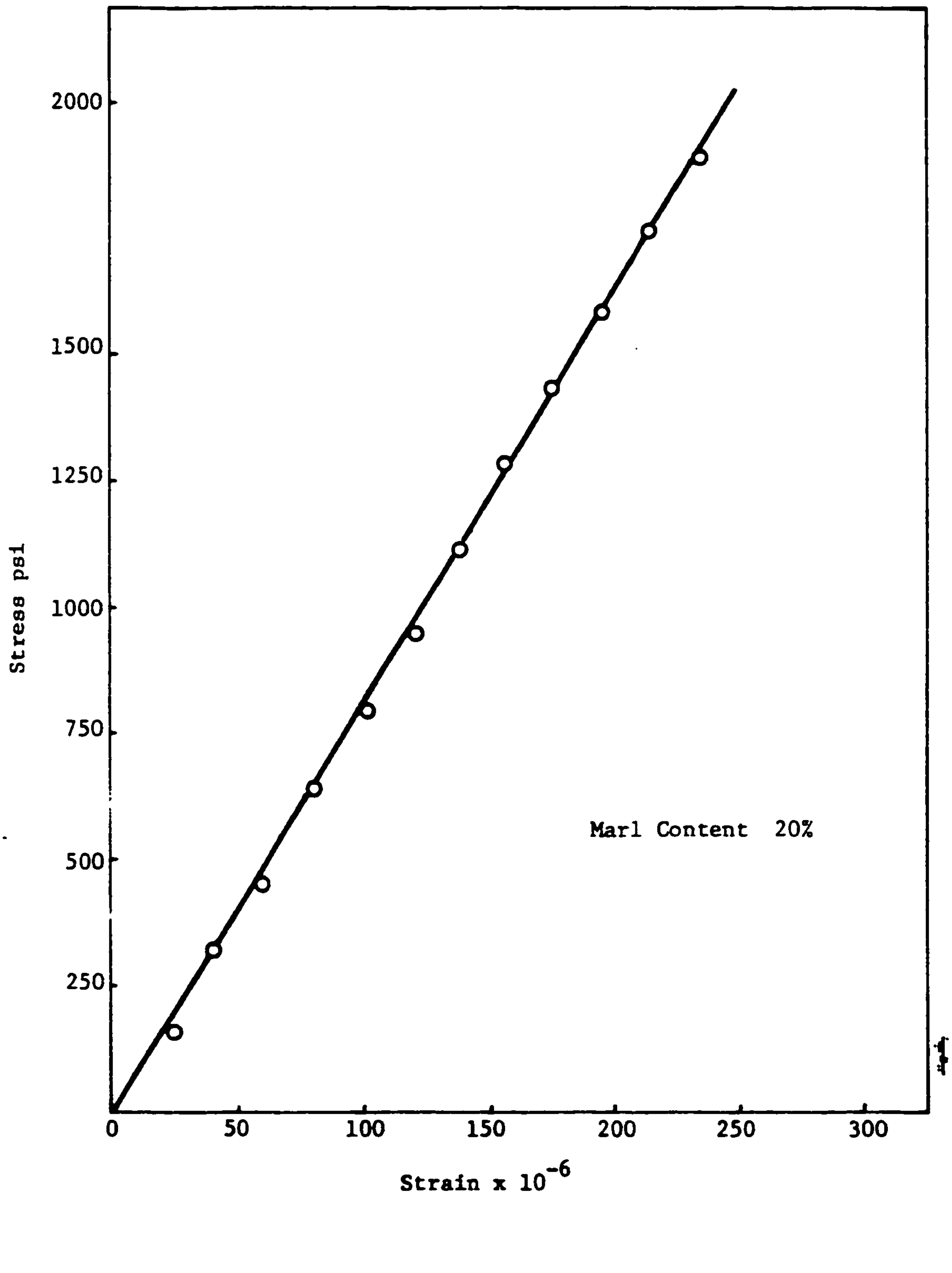


Figure 5.7 : Compressive Stress vs. Strain

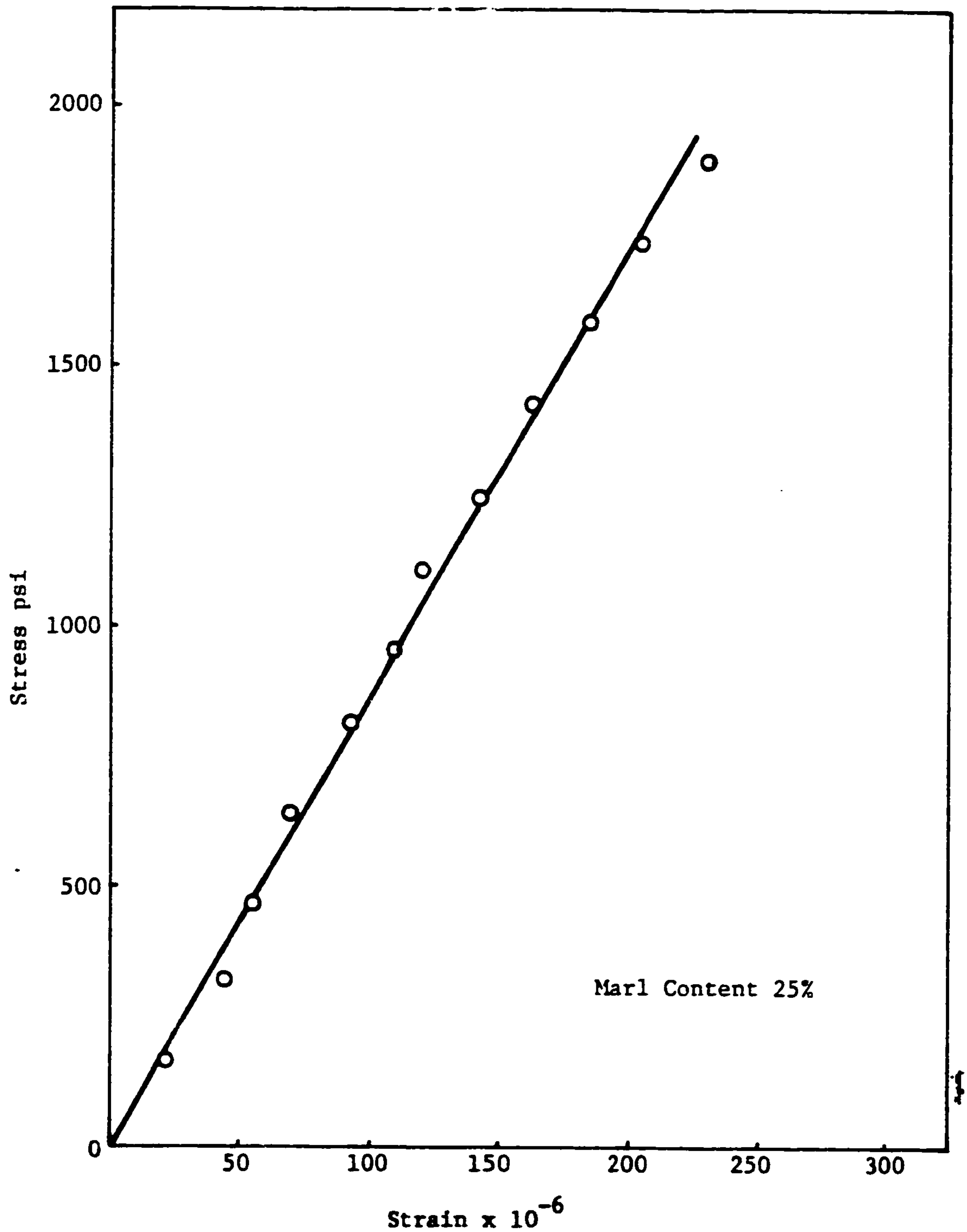


Figure 5.8 : Compressive Stress vs. Strain

25 percent marl with five minutes infiltration time were tested to gather data on creep. The specimens were loaded with fixed static load of 50 kN, corresponding to approximately 50 percent of the ultimate strength for such cylinders. The strains recorded at various time interval for the first three hours are shown in Figure 5.9, which indicate that rate of creep is about the same for both types of specimens, indicating that marl has practically no significant effect on creep behaviour. The rates of the strain at three hours to that of the initial instantaneous strain was 1.34. This ratio is large indicating that S-M specimens suffer from high creep rate. Upon removal of load, there was an instanteneous elastic recovery which was slightly less than the initial strain at time of loading. This was followed by negligible creep recovery, most of which took place within the first two hours of unloading.

To collect data for long term creep, it was intended to use MFL creep testing machine. However, because of the malfunctioning of the machine, it was not possible to conduct long term creep tests. The results for the three hours creep tests were compared with those obtained for sulphur specimens in a past research work at UPM (40). A typical long term creep result from ref (40) is shown in Figure 5.10 which indicate that the early creep behaviour of sulphur-sand

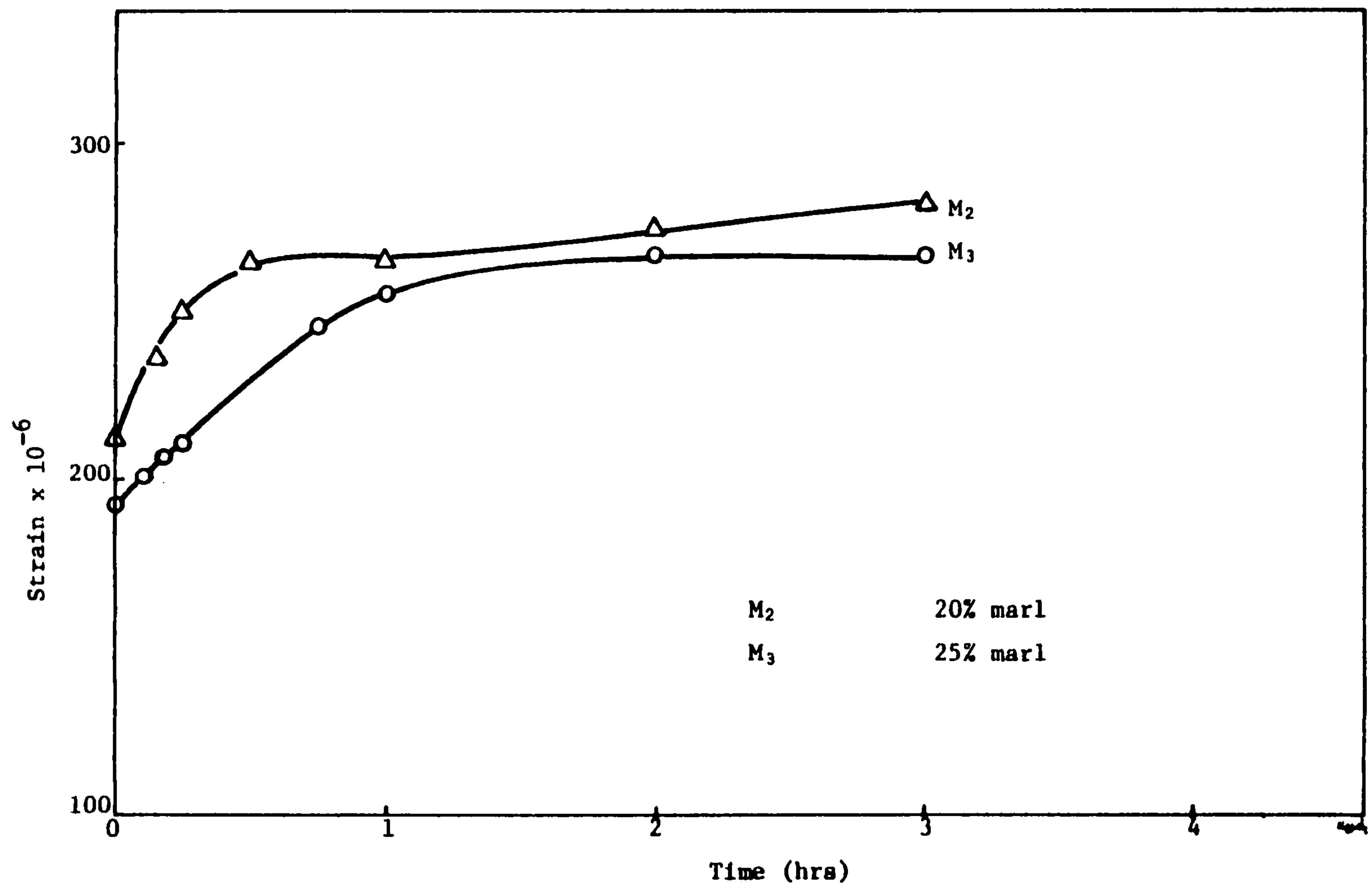


Figure 5.9 : Strain vs. Time

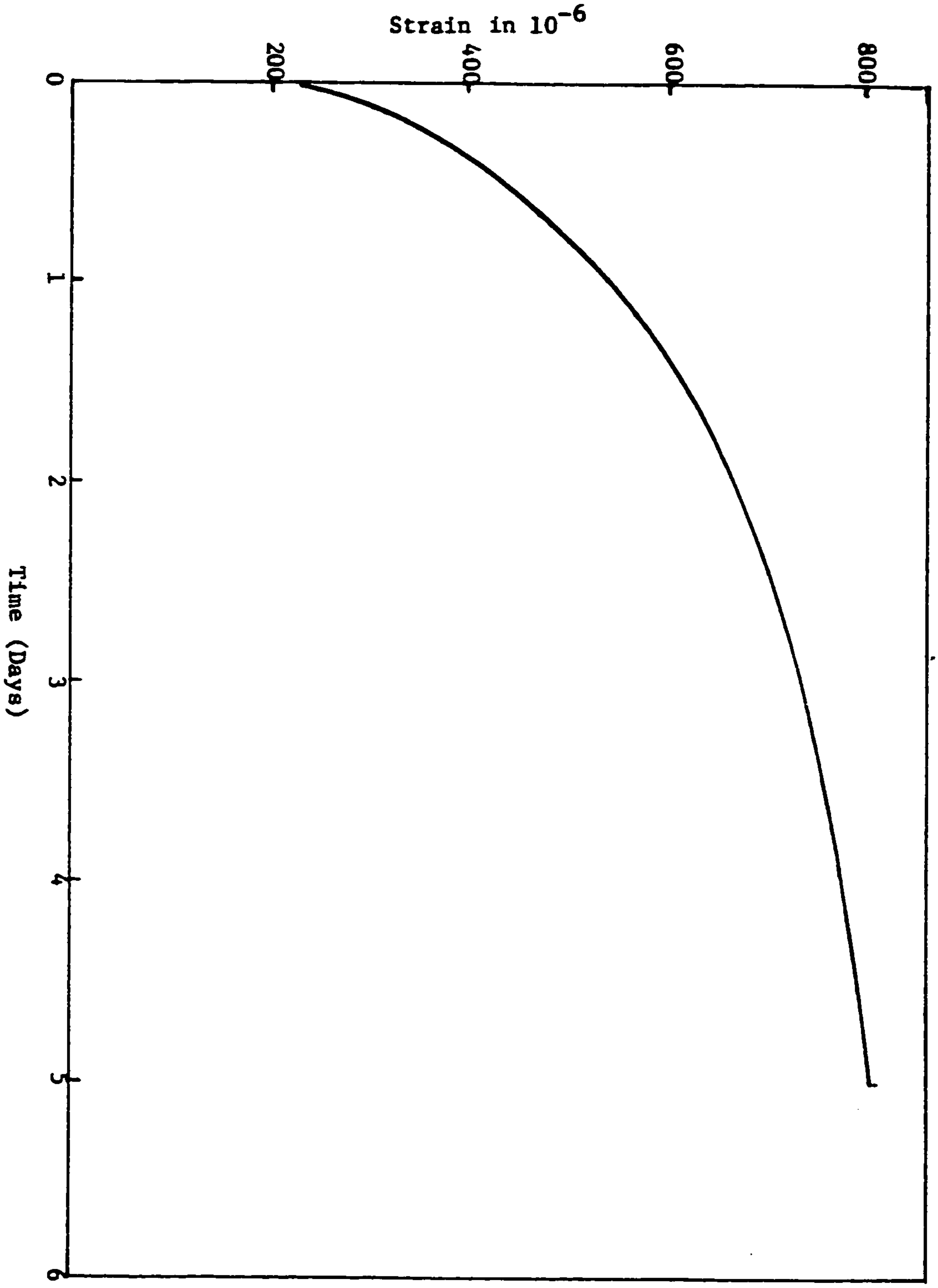


Figure 5.10 : Strain vs. Time

mixture with filler is qualitatively similar to that obtained for S-M specimens. Thus for qualitative assessment, it would be reasonably correct to say that the creep behavior of S-M specimens is similar to that of S-S mixtures with filler and that S-M specimens suffers from a high creep.

5.8 Durability of Sulphur Sand With and Without Filler

5.8.1 Compressive Strength

To determine long term durability of SS with and without filler, 3 x 6 in (75 mm x 150 mm) cylinders were subjected to repeated wetting and drying cycles for a period of nine months, both in soft and saline water. Tables 5.4 and 5.5 show the compressive strength and absorption data obtained from the two cases. Results from Table 5.4 show that sand sulphur mix soaked in saline water has lost an average strength of 44 percent and the same mix with filler has lost an average of 46 percent. This concludes that both types of specimens suffered similar loss of strength when subjected to repeated wetting in saline water and drying. Table 5.5 shows the results of loss of compressive strength of both mixes, when soaked in pure water. It was found that an average loss of strength of SS mix was about 40 percent and an average strength of mix using filler was observed to 34 percent indicating again that the amount of loss was about the same.

TABLE 5.4

Durability in Saline Water (Test Period 9 Months)

Mix Type	Average Weight (lbs)	Average Original Strength (psi)	Average Wt. After Wetting (lbs)	Average Strength End of Test Period (psi)	Percentage Absorption
SC	3.456	5150	3.477	2860	0.6
SCF	3.534	5600	3.562	3000	0.79

TABLE 5.5

Durability in Pure Water (Test Period of 9 month)

Mix No.	Average Weight (lbs)	Av. Original Strength (psi)	Av.Weight After Wetting (lbs)	Av.Strength End of Test Period (psi)	Percentage Absorption
SC	3.456	5150	3.468	3060	0.34
SCF	3.534	5600	3.541	3682	0.21

SC Sand Sulphur

SCF Sand Sulphur & Filter

5.8.2 Abscrption

The amount of water absorption for both mixes was very low, indicating the high degree of water tightness of the specimens. Tabels 5.4 and 5.5 show the absorption of soft and saline water. It was observed that the absorption of saline water was more compared to that for pure water.

5.8.3 Load-Deformation Relationship

Figures 5.11 and 5.12 show typical plots of load versus measured strains for both types of mixture. Tests results show that the material, after being subjected to prolonged period of wetting and drying also behaves linearly upto a high stress level and the failure was found to be of brittle nature. The average values of modulus of elasticity of SS mix was 2.72×10^6 psi and 2.40×10^6 psi when soaked in pure water and saline water, respectively. These compare with average value of modulus of elasticity of untreated specimens as 4.15×10^6 psi (without filler).

Figure 5.12 shows the plot of load versus measured strains of sand sulphur mix with filler. The measured modulus of elasticity was 3.10×10^6 psi and 2.79×10^6 psi when soaked in pure and saline water respectively. These compare with average value of modulus of elasticity of untreated specimens as 4.6×10^6 psi.

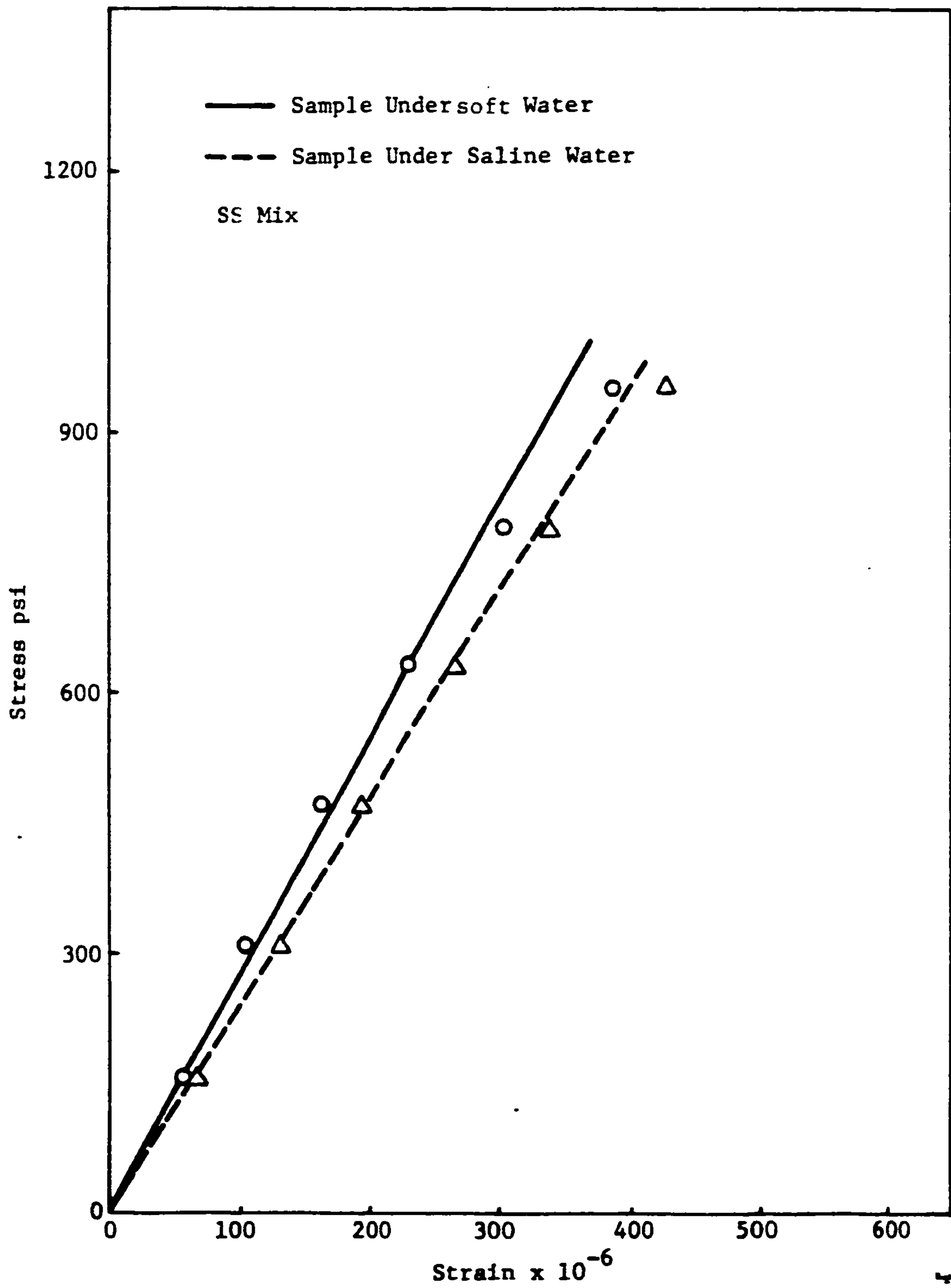


Figure 5.11 : Compressive Stress vs. Strain

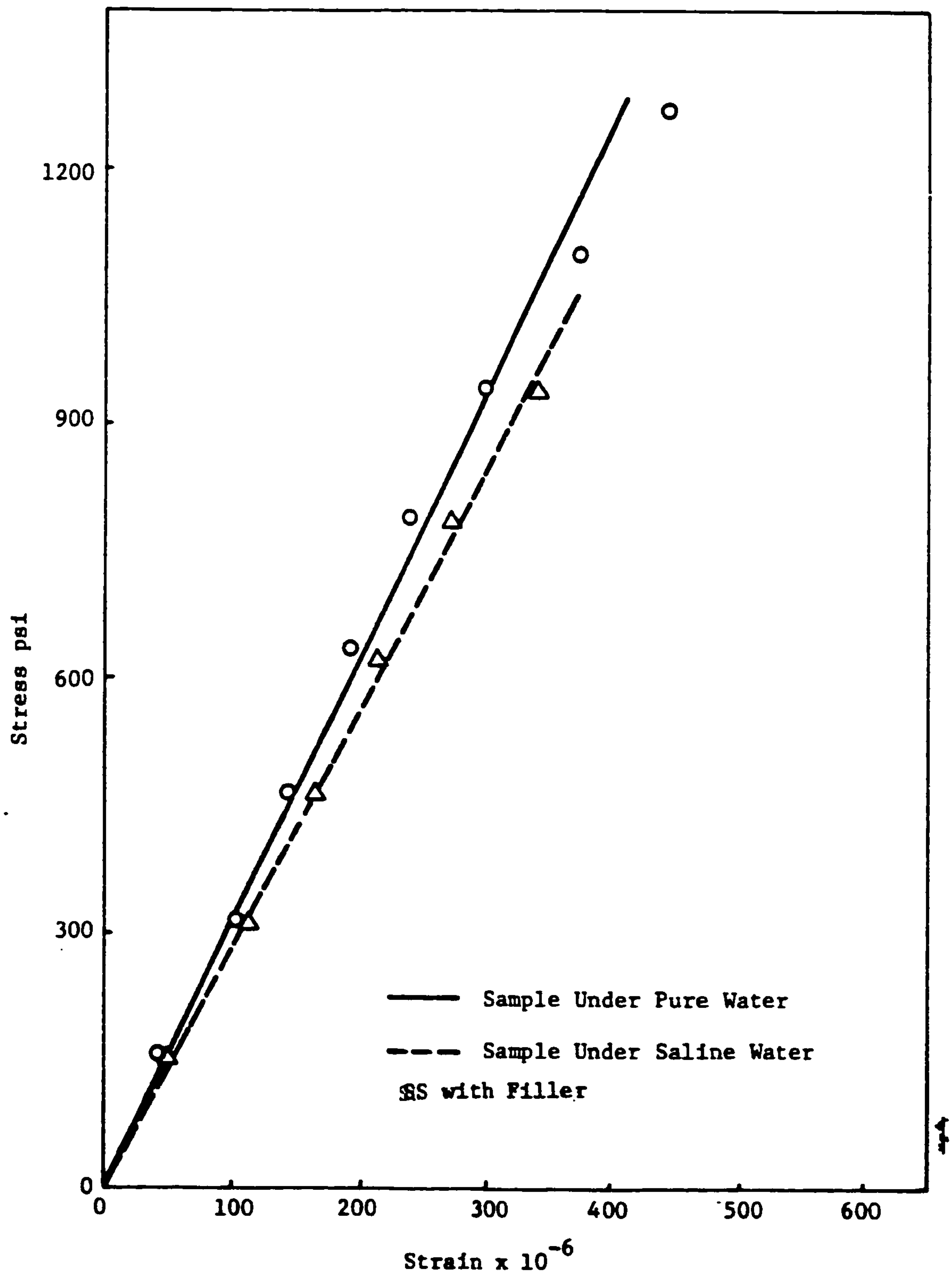


Figure 5.12 : Compressive Stress vs. Strain

Test results essentially concluded that the material maintained its basic characteristics even after a prolonged period of wetting and drying. They also showed retention of a good compressive strength, losing about 40 percent of the original strength. Thus both types of sulphur sand mixtures, with and without filler are durable and can be used as durable material under adverse hot and humid environmental condition.

5.9 Durability of Sulphur-Marl Blocks

To determine the possible loss of compressive strength due to repeated wetting and drying cycles, sulphur infiltrated blocks were soaked in water for a period of 60 days. The loss of strength was observed to be 14.7 percent. Thus the sulphur blocks are durable and can be used as durable material.

5.10 Failure of Sulphur-Marl Specimens

The compressive failure of all sulphur-marl specimens are essentially, of brittle nature. Failures are sudden with no regular pattern, sometimes showing vertical splitting, conical and diagonal failures. In load-deformation tests, the material did not show any sign of plastic deformation. Thus no visual prior warning in form of excessive deformation is expected. Figure 5.13 shows broken specimen after failure.

Figure 5.13 : Broken Specimen After Failure

5.11 Feasibility of S-M Blocks

Based on the test results presented, it is observed that the sulphur-marl blocks, made by infiltration method attain relatively high compressive strength, comparable with or even better than the most ordinary hollow concrete blocks. The amount of marl which required is also low (recommended 20 percent), and the amount of sulphur absorption is of the order of 31 percent. The time of infiltration has been kept only five minutes thus requiring only a short waiting time. The blocks have also a good durability and show a high degree imperviousness. All these factors convincingly lead to the conclusion that sulphur marl blocks have a good potential for being an alternative source of blocks for masonry construction.

The disadvantage for the method of manufactureof these blocks is that the molded raw specimen of marl and sand must be fully dried at high temperature before infiltration. If the cost of this energy does not become a serious setback, it is anticipated that sulphur-marl blocks could become a viable source of a new sulphur based construction blocks.

chapter **6**

SUMMARY AND CONCLUSION

6.1 Summary

The study on the development of sulphur based construction blocks has shown that blocks can be successfully constructed from a mixture of sand and marl. As all the ingredients of such blocks, namely, sand, marl and sulphur are readily available locally, it is of significant interest to develop sulphur based construction blocks that could be used as a substitute for concrete blocks in some areas of construction.

In developing construction methods for such blocks, consideration was given to the possibility of reusing the molds as quickly as possible after each casting. This would be an advantage for automated production and would be comparable to the rapid use of molds in making concrete blocks. It has been shown that the binding property of marl can be successfully used in molding blocks from a moist mixture of sand and marl that are of sufficient strength to permit handling and subsequent treatment for strength. In using marl, due consideration was given to keep the content of marl as low as casting procedures allowed, since marl is not as abundantly and readily available as sand.

The first of two methods developed thus far the so called "Melting Method", in which the powdered sulphur was used in the specimens and subsequently heated to melt the sulphur in the body, yielded blocks that had of poor strength and low durability, though the blocks are perfect shape and formation with no visual cracks.

In the "Infiltration Method", the lightly compressed blocks molded from a mixture of sand and marl only were dried and then infiltrated with sulphur by immersion in molten sulphur. A duration of five minutes was allowed for infiltration. The finished blocks were of reasonably high compressive strength, in the neighbourhood of 3500 psi and were durable against wetting and drying by water. A small loss of strength resulted when soaked in water.

Early research (39) showed that a wall can be constructed by dry stacking of such blocks and surface bonding them by spraying the sulphur slag formulation contained 100 parts of sulphur, 10 parts of tale, 3 parts of fiber glass, and 2 parts of dicyclopendien.

For sulphur sand blocks two disadvantages were observed. Firstly, the molds could not be reused immediately after casting a certain time should be alowed for cooling. Secondly, the finished top surface may not be plane due to shrinkage of sulphur during cooling.

The durability of material consisting of sulphur sand (SS) with and without filler was studied by wetting and drying the specimens in soft and saline water for a period of nine months. It was found that the material maintained its basic characteristic with a loss of about 40 percent strength.

6.2 Conclusion

Based on this investigation, the following conclusions are drawn.

(1) Good quality sulphur based construction blocks of acceptable strength and durability can be made from a mixture of sand and marl by the infiltration method. The method is suitable for an industrialized production.

(2) The compressive strength of blocks increases moderately with an increase in the content of marl. Its content in neighbourhood of 20 percent is recommended, considering workability, handling and minimising the use of a material not as abundant as sand.

(3) The study showed that only certain types of marl can only be used for production of crack-free blocks.

(4) While the strength of blocks increases with the increase in the infiltration time, a period of 5 minutes impregnation is ample to develop acceptable level of strength, thus maintaining a minimum loss of time due to infiltration.

(5) The material behaves almost linearly upto 80 percent of the rupture load and fails in a brittle manner.

(6) Results indicate that creep is very significant for sulphur-marl mixture. Due to excessive creep sulphur marl blocks may not be suitable for load bearing walls.

(7) Both types of sulphur sand mixtures with and without filler are durable and can be used as a durable material under adverse hot and humid environmental conditions.

(8) Sulphur-marl blocks were found to be durable under hot and humid environmental conditions. Only a small loss of strength was observed after a prolonged period of repeated wetting and drying.

6.3 Recommendation for Future Research

(1) A detailed study to find a suitable method to evaluate the performance of masonry wall constructed by SMB, under axial and transverse loadings is needed. This can be done either constructing wall and loading it to failure. Or a model room can be constructed and the long

term effect due to loads can be observed.

(2) The sulphur-marl block based construction requires a fire proof coating. Hence a study to find a suitable fire resistant coating material is essential.

(3) A thorough chemical analysis of marl and X-Ray defraction technique would be necessary to identify the contents and other possible factors causing cracks in the sulphur-marl blocks.

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