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INVESTIGATION OF THE CLAY-MICA COMPOSITES AS POTENTIAL NEW BUILDING MATERIALS

Zhihong Zheng

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in the

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ABSTRACT

Investigation of the Clay-Mica Composites as
Potential New Building Materials

Zhihong Zheng

Clay-mica and clay-mica-glass composites were produced by combining common clay with natural mica flakes of the phlogopite type and ground powder prepared from recycled waste glass employing a simple firing process. Several properties have been evaluated, such as the physical properties (the bulk density, the volumetric change, the cold water and the boiling water absorption, and the water saturation coefficient), the mechanical properties (the flexural strength and the compressive strength), the durability (the flexural strength and compressive strength after 50 cycles of freezing and thawing treatment compared before the treatment), and the thermal conductivity. It was found that clay-mica and clay-mica-glass composites have very different properties compared with pure clay products. The light weight and low thermal conductivity, but low strength and high water saturation coefficient of clay-mica composite can be used for interior building applications to provide some degree of thermal insulation without the addition of external mass insulators. The display of low density, low thermal conductivity and low water saturation coefficient of the clay-mica-glass composite suggests that this type of product can be used as cladding components for building envelope exterior construction applications, and this type of product is also suitable for interior building applications comparable to the clay-mica composite. Both clay-mica and clay-mica-glass composites will contribute to energy conservation when use for building envelope design applications

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Nomenclature

Symbols

Ave : Average

BD : Bulk Density of a specimen (Kg/m^3)

BWA : Boiling Water Absorption of a specimen (%)

COV : Coefficient of Variation (%)

CS : Compressive Strength of a specimen (MPa)

CWA : Cold Water Absorption of a specimen (%)

Ind : Individual

FS : Flexural Strength of a specimen (MPa)

VC : Volumetric Change of a specimen (%)

Chapter 1 INTRODUCTION

Studies of thermal insulation materials in recent years have attracted a great deal of attention, because these materials play an important role in the conservation of energy. The Majority of the building envelopes are finished by using either cement concrete, metallic panels, clay bricks, or polymer impregnated concrete. However, all of these common building products have very low intrinsic thermal insulation value. As a result, building structures with these materials alone are poor thermal insulants. In order to maintain an effective thermal barrier around the building envelope, external thermal insulation materials of either organic foams or inorganic mineral fibers must be added adjacent to the envelope. This practice adds cost to the building structure and also requires space to accommodate the installation of the external insulating materials. To alleviate this deficiency, one approach would be to improve the thermal insulating property of the fabric components.

It is generally known that natural mica minerals such as phlogopite and muscovite possess chemical stability and excellent thermal insulating properties. In spite of these desirable properties, it is somewhat difficult to apply the inorganic mineral directly on to building structures because they are available only in particulate form. Recent research studies have demonstrated that mica-glass composite solids can be developed by mixing the mica mineral with glass (1-3). The developed mica-glass composites were found to exhibit superior thermal insulation property and mechanical strengths. Based on these positive results, it was decided to investigate natural mica mineral to a clay system and to a clay-glass system. Successful development of these composites having improved thermal insulation value could open a new avenue for the utilization of Canada phlogopite mica mineral in the future.

The main objectives of the research project are to investigate the feasibility of utilizing natural mica mineral as an additive to inorganic clay mineral designed to yield high thermal insulation values. The developed composites are then compared with conventional masonry products. The composite materials are fabricated from two material systems including clay-mica and clay-mica-glass.

The experimental research was divided into six programs:

(1) Selecting and preparing the appropriate raw clay, mica and glass components.

(2) Preparing test specimens from the different material systems including: clay, a one-component system; clay-mica, a two-component system and clay-mica-glass, a three-component system. The prepared specimen of the one-component system were used to investigate the optimum preparation parameters which included the sintering temperature, the compaction pressure and the water added to the specimen. The prepared specimen of the two-component system were used to investigate the effects of the addition of mica components on the thermal conductivities, together with their durability, physical and mechanical properties. The prepared specimen of the three-component system were used to investigate the effects of glass addition to the composite with respect

to the physical and mechanical properties, durabilities and thermal conductivities of the composite.

(3) Measuring the physical properties included the bulk density , the volumetric change, the cold water and boiling water absorption, and the water saturation coefficient.

(4) Measuring the mechanical properties included the flexural strength, the compressive strength and the compressive modulus of the specimens.

(5) Evaluating the durability of these products from the variation of flexural strength and compressive strength of the specimens before and after subjected to 50 cycles of freeze-thaw cycling.

(6) Measuring the thermal conductivities of the specimens.

The data obtained from these six programs are then systematically analysised and evaluated to determine the advantages and disadvantages for the addition of the natural mica mineral to the clay and the addition of the glass to the clay-mica mixtures in the fabrication of the clay-based mica composite products.

Chapter 2 LITERATURE REVIEW

MICA is the name given to a group of silicate minerals that crystallize in block or "book" form and can be easily split in one direction into very thin sheets. These sheets are very flexible, elastic and tough. Mica mineral in the form of large sheets or flakes has been a very important electrical insulator because of its cleavability, flexibility and high dielectric strength. Before the invention of transistors and solid state devices, mica film was used in vacuum tubes. At present, mica film is used in capacitors and in electric motors and generators. The high heat resistance of the mica flakes has also prompted many in the manufacturing industry to use it as thermal insulator in electric appliances. Because of their special electrical and thermal properties, mica mineral has been recognized as a strategic mineral in several industrial countries. There are several forms of mica and they all have similar physical properties and vary only in chemical composition and structure. All mica minerals are complex hydrous silicates with varying proportion of magnesium and potassium, usually some iron and flourine, and sometimes sodium, lithium, aluminum, titanium, barium and manganese. Mica minerals possess some very special physical, mechanical, electrical and thermal properties. As a result, these mica minerals are used extensively in various fields for industrial and commercial applications(4).

These utilize primarily two varieties of the mica family, namely muscovite and phlogopite. Although natural mica minerals are widely distributed around the world, they come only from a few specific countries around the world. The major producers of the phlogopite type mica are from Canada, India and Malagasy Republic. The major deposit of phlogopite mica in Canada are in the Eastern Townships of Quebec(5). It is estimated that phlogopite deposits in this region are close to 50 million tons. Mining and processing operation of the phlogopite in this area began in the mid 70's but on a very limited scale, for example in 1975 that the annual production rate was about 50,000 tons; the potential of this valuable mineral deposit has not been fully exploited. At present, a significant proportion of the processed phlogopite is destined for export and only a small fraction of the mica mineral is consumed in domestic applications(6).

Although Canada has a large deposit of the phlogopite mica mineral, research and development of the utilization of this native Canadian mineral appears to be limited. Literature survey showed that some studies have been carried out and the possible applications of natural mica mineral when combined with other components are report. A block diagram on the utilization of mica for product research and development(7) is shown in Figure 1.

Some commercial products such as paints(8-14), coating(15, 16), rubber(17), and wall paper contain the natural mica mineral.

The aluminum paints containing mica particles protect the more reactive aluminum particles. This is especially noticeable in corrosive atmospheres(8). A number of traffic paint specifications also include mica as a material component because tests have shown that it adds to the wearability, gives good adhesion, and reduces flaking and cracking(9). A thin coating of mica flakes (dispensed as a dispersion in a vehicle or directly dusted on the rubber surface) overcomes rubber tackiness and sticking or otherwise functions as a mold release agent. When mica is used in metal coatings, it can reduce moisture penetration, because the flakes orient themselves parallel to the painted surface. As a result it is more difficult for moisture to penetrate to the substrate and the film integrity and strength are also upgraded, thus giving greater corrosion resistance(15, 16). The addition of mica to all types of sealants for porous surfaces (such as wallboard, masonry, and concrete blocks) has also been reported to reduce air penetration. The addition of mica to sealants permits a thicker film application and at same time reduces sagging Cracking in the sealant is also reduced by the reinforcing action of mica flakes(11). Mica is commonly used in sponge rubber and a wide variety of latex goods. Rubber hose and many industrial rubber products are coated or dusted with mica. When mica particles are incorporated in rubber, it reduces the penetration of gases(17). The most recent and sophisticated application of mica waste is in the form of reconstituted mica known as Mica paper. It is a thin, homogeneous, flexible, self-supporting paper like material in the form of continuous sheet(13).

Phlogopite mica has been found to be an excellent reinforcing filler for a variety of thermoplastic and thermosetting resins(18-22). When phlogopite mica is added to organic polymer, it can provide a unique balance between the desired properties and cost. Many advantages have been reported in polymer-based composites incorporated with phlogopite mica mineral. These included increased rigidity and strength and improved dimensional stability of structural members.

Results of recent research indicated that the addition of a small amount of mica flakes to cement parts can significantly increase the flexural strength and fracture toughness of the composite. Mica flakes are a possible low cost alternative to glass fibre as reinforcing agent in the cement system(23,24,25).

It has been reported(26) that the tensile strength of concrete is increased by the addition of high aspect-ratio mica reinforcement.

Previous research projects conducted at the Center for Building Studies have shown that natural phlogopite mica powders and ground glass powders prepared from recycled waste glasses can be mixed together and synthesized into two distinctive glass-mica composite products, one product with a cellular structure consisting of both closed and open cells, the other with a very densed ceramic structure containing very little porosity(1-3, 27,28). The research results show that a series of sandwich type products of the glass-mica composite solids, in which a cellular structure layer is sandwiched between two densified structure layers or vice versa can be developed.

There is little information concerning the effect of mica to clay products can be found in literatures. That is why I do this project to investigate how the mica and preparation parameters affect properties of clay-mica composite products.

Chapter 3 EXPERIMENTAL PROCEDURES

This section describes the identification and selection of the starting raw materials, the procedures for the preparation of test specimens, the evaluation of the physical properties, the mechanical properties, the durability test by freeze-thaw cycling treatments, and the thermal conductivities.

3.1 Identification and Selection of Starting Raw Materials

Three major raw material components were used in the project. These included: clay, mica and glass. The material characteristics of each of these components are described in the following sections.

3.1.1 Clay

Clay is a finely-grained rock which becomes sticky when wet and can be moulded and then transformed into a hard, dense, permanent shape by the action of heat.

Clay can be made as building bricks, roofing tiles and floor tiles. These products usually have high density, water absorption, compressive strength, and low thermal insulation value.

The clay used in the investigation was a greyish type of clay* containing 60%wt SiO_2, 15%wt Al_2O_3, 6%wt Fe_2O_3, and other oxides. A screening analysis was carried out to determine the clay size distribution. The results showed that 20% of the clay particles are in the range of 150 — 600 μm, and about 80% of the particles are in the range of 600 – 1180 μm. The clay particles used for specimen preparation were mostly in the range of 150 — 600 μm. The large particles were ground into fine powders by a dry ball-mill grinding process for a period of about 3 $hours$ using corundum grinding media. After the grinding process, about 90% of the clay particles were reduced to the range of 150 – 600 μm, and the remaining 10% of the clay particles were reground again until all particles were in the range of 150 — 600 μm.

3.1.2 Glass

Common glasses are hard and brittle. They products of the melting of crystalline materials at elevated temperatures to produce liquids which have subsequently been cooled to rigid condition without crystallization.

The soda-lime-silica glass has high density, high thermal conductivity (around 0.8 – 1.0 $W/m^\circ C$), low water absorption, and low softening point (around 700 – 730$^\circ C$). The glass expenses with temperature increasing. (29)

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* The greyish clay was supplied by Domtar Inc., Montreal, Canada

The glass powders were prepared from the recycled colorless soda-lime-silica glass cullet*. The glass cullet was first pulverized into fine grains (in the range of $0.2 - 0.5\ mm$) by a mechanical pulverizer. The pulverized glass grains were then ground into fine powders by a dry ball-mill grinding process for a period of about 10 *hours*. The glass powders used for specimen preparation were mostly in the range of 150 – 300 μm. Chemical analysis as reported(1) showed that the recycled glass powders consist of the following components: 71.3%wt SiO_2, 11.3%wt Na_2O, 8.39%wt CaO, 2.24%wt Al_2O_3, 0.09%wt MgO, 0.43%wt Fe_2O_3, and 6.25%wt other oxides.

3.1.3 Mica

Mica is in the form of flakes with cleavability, flexibility, high dielectric, and high heat resistant. The mica flakes used for the investigation were of the phlogopite type and were obtained from a local producer *. The mica flakes used for the specimen preparation were finer than 300 μm, and their chemical composition as reported by the producer is known to be as follows(30): 40.9%wt SiO_2, 20.6%wt MgO, 15.8%wt Al_2O_3, 10.0%wt K_2O, 7.8%wt FeO, 2.2%wt F, 1.2%wt Fe_2O_3, 0.5%wt BaO, 1.0%wt H_2O.

3.2 Specimen preparation

The experimental procedures for specimen preparation described in this section are applicable to all three material systems: the one-component system – clay product,

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* Suppl.ied by a local glass manufacturer, Consumer Glass Ltd , Montreal Canada

* The phlogopite type mica is processed in Boucherville, Quebec (near Montreal) from a high purity ore by the Marietta Resources International Inc in joint venture with Societe Mineralurgique Laviolette, Inc. Montreal, under a trade name known as "SUZORITE" mica

the two-component system – clay-mica composite and the three-component system – clay-mica-glass composite. Two different shapes of samples were prepared as the ASTM required(31-32). The rectangular steel mold which was used to prepare the specimens for the evaluation of the physical properties, the mechanical properties and the durability test is shown in Figure 2. The dimensions of this mold are about 130(length) × 65(width) × 100(height) *mm*. The round steel mold which was used to prepare the specimens for the evaluation of the thermal conductivities is shown in Figure 3.. The diameter of this mold is about 152 *mm*. Triplicate specimens were used to evaluate the bulk density, the volumetric change, the cold water absorption, the boiling water absorption, the water saturation coefficient, the flexural strength, and the durability. A pair of specimens were used to evaluate the thermal conductivity.

3.2.1 One-Component System – Clay

The detailed procedures for the preparation of a pure clay specimen in the one component system involved the following steps:

(1) A quantity of 650 *grams* of the dry clay was weighed and then put into a mechanical blender;

(2) About 19.5 *ml* of tap water equivalent to about 3 %*wt*(water content on dry weight bases), was added to the clay powders during the mixing operation;

(3) The clay-water mixture was thoroughly mixed for a period of 10 *minutes*;

(4) After the mixing operation, the mixed clay powders were loaded into the steel mold;

(5) The clay-water mixture was compressed at a pressure of 5.0 MPa;

(6) After removal from the mold, the compressed powder compact was placed on a refractory slab and dried in air at room temperature for 24 $hours$;

(7) After the air drying process, the clay compact was placed in an electric heating furnace for sintering;

(8) The temperature of the furnace was heated from ambient to 750°C at a heating rate of about 150°$C/hour$;

(9) The furnace was kept at 750°C for a period of 4 $hours$;

(10) After heated at 750°C, the furnace was cooled down to room temperature at a rate of 100°$C/hour$.

Following similar preparation procedures, similar specimens prepared by changing the preparation conditions have also been prepared which included the use of a 4 %wt and of a 5 %wt water content as used in step (2), the use of a compaction pressure of 10.0 MPa as used in step (5), and the use of three other temperatures such as 800°C, 900°C and 1000°C as used in step (8).

3.2.2 Two-Component System – Clay-Mica

The detailed procedures for the preparation of the clay-mica composite specimens in the two-component system were very similar to those as described in section 3.2.1 for the one-component system. However, several steps were modified. These include the following:

(1) The appropriate proportion of the clay particles (95 %) and mica flakes for amounting to 650 *grams* was weighed;

(2) The weighed mica flakes equivalent to 5 %*wt* of the total mixture was added to the clay particles in the mechanical blender. The dry clay-mica powders were thoroughly mixed for a period of about 5 *minutes*;

(3) About 26 *ml* of tap water equivalent to 4 %*wt*, was added to the mixture during the mixing operation;

(4) The mixture was then mixed for another period of 10 *minutes*;

(5) The remaining steps for the preparation of the clay-mica composite specimens were similar to steps 5 to 10 as described in Section 3.2.1.

Following similar preparation procedures, other groups of the clay-mica two-component specimens have also been prepared which included the use of a compaction pressure of 10.0 MPa, the use of other two sintering temperatures at 900°C and 1000°C and the use of a sintering time period of 7 *hours*. The mica content in these clay-mica composite mixtures was varied within the range of $5-25$ %*wt* with a 5 %*wt* increment.

3.2.3 Three-Component System – Clay-Mica-Glass

The procedures for the preparation of the clay-mica-glass composite specimens in the three-component system were also similar to the one-component system. However, several modifications have been implemented. These included the following steps:

(1) The appropriate proportion of the clay particles, the mica flakes amounting to 650 *grams* were weighed;

(2) The weighed mica flakes equivalent to 5 %*wt* of the total mixture was added to the clay particles in the mechanical blender. The dry clay-mica powders were thoroughly mixed for a period of about 5 *minutes*. A 10 %*wt* of the clay particles was replaced with the ground glass grains. This meant that the total weight of the clay-glass mixture remained the same as compared with the two-component system with respect to the clay-mica ratio. The glass powders were added to the clay-mica mixtures in the mechanical blender, and the dry clay-mica-glass powders were thoroughly mixed together for a another period of about 5 *minutes*;

(3) About 26 *ml* of tap water equivalent 4 %*wt* was added into the mixture during the mixing operation;

(4) The clay-mica-glass mixture were mixed for a period of about 10 *minutes*;

(5) The remaining steps for the preparation of the clay-mica-glass composite specimen were similar to steps 5 to 10 as described in Section 3.2.1.

Following similar preparation procedures, other groups of the clay-mica glass composite specimens have also been prepared. These included the use of 20 %*wt* and 40 %*wt* glass content. The mica content in these clay-mica-glass composite mixtures has been varied within the range of 5 – 25 *wt*% with a 5 *wt*% increment.

3.3 Physical Properties Evaluation

The evaluation of physical properties for the specimens included the determination of the bulk density, the volumetric change, the cold water and boiling water absorptions, and the water saturation coefficient. The procedures for the measurement of the physical properties are described in this section.

3.3.1 Bulk Density Determination

The dry weight of the specimen was weighed to an accuracy of about ±0.1 g. The length, width and thickness of the specimen were measured to an accuracy of about ±0.2 mm. The bulk density of the specimen was determined according to ASTM C67 by dividing the dry weight of the specimen by the volume of the specimen. The formula of the bulk density of the specimen is:

$$B = \frac{10^6 \times W_d}{L \times W \times H}$$

where:

B = bulk density (Kg/m^3);

W_d = dry weight of the specimen (g);

L = length of the specimen (mm);

W = width of the specimen (mm);

H = height of the specimen (mm).

3.3.2 Volumetric Change Determination

The length, width and thickness of the specimen were measured to an accuracy of about ±0.2 mm before and after the sintering processes. The volumetric change of the specimen was determined according to ASTM C67 as the ratio (in percentage) of the difference between the final volume of the sintered specimen and the initial volume of the unreacted specimen to the initial volume of the specimen. The calculation of the volumetric change is:

$$V = \frac{100 \times L' \times W' \times H' - L \times W \times H}{L \times W \times H}$$

where:

V = volumetric change (%);

L' = length of the specimen after sintering (mm);

W' = width of the specimen after sintering (mm);

H' = height of the specimen after sintering (mm);

L = length of the specimen before sintering (mm);

W = width of the specimen before sintering (mm);

H = height of the specimen before sintering (mm).

3.3.3 Cold Water Absorption Determination

The cold water absorption of the specimen was determined according to the procedures described in ASTM C67 Section 7.3 (31). The determination was carried out in the following manner: the dry and cooled specimen was immersed in tap water at room temperature for a period of about 24 *hours*. The wetted specimen was then removed from the water and the excess surface water was wiped off with a cloth. The saturated specimen was weighed to an accuracy of about ±0.1 g. The weighing of each specimen was carried out within 5 *minutes* after removing the specimen from the bath. The ratio of the difference between the saturated weight and the dry weight to the dry weight is considered to be the cold water absorption. The calculation of the cold water absorption is following:

$$CWA = \frac{100 \times (W_s - W_d)}{W_d}$$

where:

CWA = cold water absorption (%);

W_d = dry weight of the specimen (g);

W_s = saturated weight of the specimen after submersion in the cold water (g).

3.3.4 Boiling Water Absorption Determination

The boiling water absorption of the specimen was determined according to the procedures described in ASTM C67 Section 7.4. The specimen that has been subjected to the cold water absorption measurement was reimmersed in a water bath. The water around the specimen was allowed to circulate freely on all sides of the specimen. The water was then heated to boiling within a period of about 1 *hour*. The specimen was allowed to remain in the boiling water continuously for a period of 5 *hours*. The water was then allowed to cool to room temperature by natural cooling. The specimen was then removed from the water and the excess water was wiped off with a cloth. The saturated specimen was weighed to an accuracy of about ±0.1 *g*. The weighing of each specimen was carried out within 5 *minutes* after removing the specimen from the bath. The ratio of the difference between the saturated weight in boiling water and the dry weight to the dry weight was considered to be the boiling water absorption. The calculation of the boiling water absorption is:

$$BWA = \frac{100 \times (W_b - W_d)}{W_d}$$

where:

BWA = boiling water absorption (%);

W_d = dry weight of the specimen (g);

W_b = saturated weight of the specimen after submersion in boiling water (g).

3.3.5 Water Saturation Coefficient Determination

The water saturation coefficient of each specimen is taken as the ratio (in percentage) of the cold water absorption to the boiling water absorption. The calculation of the water saturation coefficient is:

$$SC = \frac{W_s - W_d}{W_b - W_d}$$

where:

SC = water saturation coefficient;

W_b = saturated weight of the specimen after submersion in boiling (g);

W_d = dry weight of the specimen (g);

W_s = saturated weight of the specimen after submersion in cold water (g).

3.4 Mechanical Properties Evaluation

The evaluation of the mechanical properties included: measurements of the flexural strength and compressive strength. All measurements were carried out using the INSTRON Universal Testing machine. The test procedures for evaluation flexural strength and compressive strength were carried out according to the ASTM C67.

3.4.1 Flexural Strength Test

The flexural strength was determined using a 3-point support system with a loading at the midspan as shown in Figure 4.. The load was applied at the upper surface of the specimen. The supports for the test specimen were free to rotate in both the longitudinal and transverse directions of the test specimen such that it would be against to the loading direction. The loading rate for flexural strength test was 0.5 $mm/min.$. The calculation of the flexural strength of the specimen is following:

$$S = \frac{3 \times W \times l}{2 \times b \times d^2}$$

where:

S = stress in specimen at midspan (MPa);

W = maximum load indicated by the testing machine (N);

l = distance between the supports (mm);

b = average overall width, face to face, of the specimen (mm);

d = average overall depth, bed surface to bed surface, of the specimen (mm).

3.4.2 Compressive Strength Test

The specimens used for the compressive strength test were about 45(length) × 45 mm(width). These test specimens were prepared from the failed samples which have been subjected to the flexural strength. Six pieces of specimens were used to evaluate the compressive strength. The load was applied perpendicular to the specimen surface at a loading rate of about 0.5 $mm/min.$ until failure occurred. The yield point was used to determine the compressive strength. The calculation of the compressive strength of the specimen is following:

$$C = \frac{W}{A}$$

where:

C = compressive strength of the specimen (MPa);

W = maximum load (N);

A = average of the gross areas of the upper and lower bearing surfaces of the specimen (mm^2).

3.5 Durability Evaluation (Freeze-thaw Cycling Test)

The durability of the clay-based composite products was determined by subjecting the specimens to a freeze-thaw cycling treatment using the SOILEST FREEZE-THAW TESTER (Model CT-110). The procedures for the durability test were carried out in accordance with the procedures as described in the ASTM C 67 test method Section 8.. The test was carried out in the following manner: The specimens were first immersed in cold water for a period of 24 *hours* and in boiling water for another period of 5 *hours*. The water saturated specimens were then cooled to room temperature by natural cooling. Each water saturated specimen was then placed in a plastic bag and sealed. The specimen and the plastic bag together were then placed in the container of the freezing-thawing machine. The instrument was programmed to cool during 90 *minutes* up to $-12°C$, and then to heat up to $+10°C$ during 60 *minutes*. These cooling-heating cyclings were continued until a total of 50 cycles were completed. The specimen was then weighed and compared with the weight of the specimen before the freezing-thaw cycling treatment. After this, the specimen was dried at $85°C$ for 24 *hours* with subsequent the flexural strength and the compressive strength tests. The results before and after the freezing-thaw cycling treatment were then compared to determine the durability.

3.6 Thermal Conductivities Evaluation

The thermal conductivity of sintered clay and clay composite products was determined employing a Dynatech Guarded Hot-Plate apparatus according to the procedure described in the ASTM C177 test method(32). For thermal conductivity tests, one pair of specimens each of 650 *grams* in weight and measuring 152 *mm* in diameter and about 15 *mm* in thickness was prepared. All specimens were prepared at the sintering temperature of $900°C$ for a sintering time period of 4 *hours* and at a compaction pressure of 10.0 *MPa*. After the sintering process, all specimens for thermal conductivity evaluations were kept in a room in which the ambient temperature was maintained constant in the range of $22 - 24°C$ and the relative humidity was maintained constant within the range of $50 - 55\%$ *R.H.*

The thermal performance test of the sintered clay products was carried out in the following manner:

(1) The thickness of each specimen in the pair of samples was measured to an accuracy of about ±0.01 *mm*;

(2) The specimens were mounted on the test column of the guarded hot-plate apparatus such that the heater is in close contact with the surfaces of the test specimens;

(3) A known electrical power was input to the heater of the apparatus, such that it would generate a constant mean temperature of about 24°C in the specimen when the steady state condition was attained;

(4) The temperature differential across the specimens between the hot surface and the cold surface was maintained at about 18°C;

(5) The temperature distributions on the hot surface and on the cold surface, the temperature differential across the specimen, and the electrical power input to the apparatus were monitored by a computer program in every 30 *minutes* interval;

(6) The thermal conductivity value (k-factor) and the thermal resistance (R-value) corresponding to the thickness of the specimen, and the mean temperature of the test specimen were also calculated by the computer program. These computations were also carried out in every 30 *minutes* interval;

(7) When the steady state conditions in the test were attained and thermal conductivity value deviated by to or less than 0.3%, the computer program terminated the test.

(8) In this thermal property evaluation program, the thermal conductivity of the specimens was measured at three different mean temperatures: 5°C, 24°C, and 45°C;

(9) Steps (1) to (7) were carried out for measurement at each mean temperature level;

(10) When the mean temperature in the test specimen was changed, step (1) to (7) were repeated after the temperature of the coolant which was used to cool the cold plate was changed to a pre-determined setting.

3.7 Calculation of Coefficient of Variation

The coefficient of variation was calculated for each set of specimens and marked in tables. The formula of coefficient of variation of specimens are:

$$COV = \frac{100 \times \sqrt{\frac{\Sigma(M_n - \overline{M})^2}{n}}}{\overline{M}}$$

where:

n = number of specimens;

M_n = individual test value;

$\overline{M}$ = n times average test value;

COV = coefficient of variation (%).

Chapter 4 PHYSICAL AND MECHANICAL PROPERTIES

Three types of clay products have been prepared. These included: the single clay product, a one-component system, the clay-mica composite products, a two-component system, and the clay-mica-glass composite products, a three-component system. These clay products were found to exhibit very different physical properties (the bulk density, the volumetric change, the cold water and boiling water absorptions and the water saturation coefficient) and mechanical properties (the flexural strength and the compressive strength). The variations of these physical and mechanical properties can be correlated with the product fabrication parameters, such as the composition, the sintering temperature, the sintering time, the compaction pressure and the water content. The various results are discussed under separate headings in the following sections. Three specimens are used to evaluate the bulk density, volumetric change, cold water absorption, boiling water absorption, water saturation coefficient, and flexural strength. Six specimens which had been used to evaluate all physical properties and the flexural strength were used to test the compressive strength. The data for each test, the average values and the standard deviation are given in the Tables 1-38. And the average values are also plotted in graphical forms.

4.1 Clay Products – One-Component System

The purpose for the preparation of the pure clay product was intended to establish the optimum preparation conditions, including the sintering temperature, the compaction pressure and the water content, so that these preparation parameters can be employed as reference for the preparation of the clay-mica and the clay-mica-glass composite products. The results of the single clay products will be discussed in this section in terms of the effect of sintering temperatures, compaction pressures and water contents. Note that the sintering time period is found to be 4 hour in section 4.2.2 and will not be discussed for pure clay.

4.1.1 The Effect of Sintering Temperature

In the present study, four sintering temperatures within the range of 750 – $1000°C$ were employed to sinter the compacted pure clay mixture. The sintering temperature was observed to play a significant role in the densification of the clay product under the solid-state sintering process. Initial test results indicated that sintering temperature lower than $750°C$ was ineffective, because clay grains could not be securely bonded together under such low sintering temperature. The upper sintering temperature was limited to $1000°C$, because a bloating effect was observed to take place and the compressive strength of sintered clay product was also observed to decrease when the sintering temperature exceeds $1000°C$. When the sintering temperature was increased from $750°C$ to $900°C$, the bulk density of the sintered clay specimen was observed to increase. However, when the sintering temperature was further increased to $1000°C$, the bulk density of the clay specimen began to decrease. As a result, an optimum bulk density of 2100 Kg/m^3 was observed, when the sintering temperature was at $900°C$. The display of an optimum bulk density at 900°C was observed to take place for both series of samples prepared at 5.0 MPa and 10.0 MPa compaction pressures as shown in Figure 6. The volumetric change of the specimen was observed to decrease as the sintering temperature increased in Figure 7.. The cold water absorption was observed to gradually decrease as the sintering temperature was increased for specimen prepared under both compaction pressures, as shown in Figure 8.. The water saturation coefficient which is a ratio of the cold water absorption to the boiling water absorption was also observed to decrease as the sintering temperature increased for both compaction pressures, as shown in Figure 9..

The mechanical properties of the sintered clay products were also observed to vary depending on the sintering temperatures. The flexural strength increased linearly as the sintering temperature was increased from 750°C to 1000°C for specimen prepared at both compaction pressures, as shown in Figure 10.. However, the compressive strength displayed a non-linear change with an optimum value when the sintering temperature was at 900°C in Figure 11. The variations of the compressive strength and bulk density with the sintering temperature for the clay products are found to be very similar. As a result, a linear dependence between these two property parameters can be established as shown in Figure 12.. It is evident that the compressive strength increased as the bulk density of the sintered clay products was increased when specimen prepared at same preparation condition. It is also shown that same compressive strengthes of specimens can have different bulk densities depending on different sintering temperatures and different compaction pressures.

4.1.2 The Effect of Compaction Pressure

In the present study, two compaction pressures, 5.0 MPa and 10.0 MPa, have been employed to compress the loose clay into compacted blocks for sintering. As shown in Figure 6-11., when the compaction pressure was increased from 5.0 MPa to 10.0 MPa, the bulk density of sintered clay specimens increased by 5%. However, the flexural strength and the compressive strength for the sintered samples increased by only about $5-7\%$. The volumetric change, the cold water absorption and the boiling water absorption and the water saturation coefficient were also observed to be less sensitive to the variation of the compaction pressures. The increase of the bulk density of sintered clay products with the increase of the compaction pressure is consistent with the solid state sintering process of ceramic materials. This is due to the fact that under high compaction pressure, the solid particles are more closely packed together and facilitate the material growth and transfer process thereby enhancing the densification of the clay products(33-34).

4.1.3 The Effect of Water Content

Compaction of dry powders of ceramic materials for the solid-state sintering reaction is often facilitated by the addition of a bonding or wetting agent to the particles. This is to improve the surface adhesion property of the particles. In the present study, a small quantity of tap water varying from 3.0 $\%wt$ to 5.0 $\%wt$ was added to the clay powder mixtures prior to the compaction process to serve as a wetting agent. The limitation of 5.0 $\%wt$ of water as the upper limit was decided as a result of the following observation. When water content was or higher than 5.0 $\%wt$, the free water was observed to have a tendency to come out from edges of the mold as the wetted clay mixture was compressed during the compaction process. This was particularly so when a high compaction pressure, such as 10.0 MPa, was applied.

Experimental results showed that the quantity of water added to the dry clay powders also has a significant influence in the changes of the physical properties and mechanical properties. When clay samples were sintered at a temperature of $900^\circ C$ for a period of 4 *hours*, the bulk density of the sintered clay samples was observed to increase as the water content increased from 3 $\%wt$ to 5 $\%wt$, as shown in Figure 13.. Figure 14. shows the highest compressive strength occurred when the water content was $4\%wt$. The details of the experimental results are shown in Table 5-6..

4.1.4 Conclusion

The compressive strength is the most important fact to evaluate properties of bricks. The results of the experimental study in this part of the investigation identify that the optimum conditions of several important preparation parameters. These included: the sintering temperature of $900^\circ C$, the compaction pressure of 10.0 MPa, and the water content of 4 $\%wt$. These optimum preparation parameters will be used to prepare the clay-mica composite and the clay-mica-glass composite in the next two experimental studies.

4.2 Clay-Mica Composite Products – Two-Component System

The purpose for the preparation of the clay-mica composite product was intended to examine the effects of the addition of the mica mineral on the physical and mechanical properties of the clay-based composite products. The results of the clay-mica composite products – two component system, will be discussed in this section in terms of the effect of composition, the effect of sintering temperatures, the effect of sintering times and the effect of compaction pressures.

4.2.1 The Effect of Sintering Temperature

In the present study, three sintering temperatures, 800, 900, and 1000°C were employed to sinter the compacted clay-mica composite mixture. In this two-component system, the sintering temperature was also observed to play a significant role in the densification of the clay-mica composite product under the solid-state sintering process. It was found that the effect of sintering temperature on the physical and mechanical properties of the sintered clay-mica composite products is similar to that on the physical and mechanical properties of the sintered clay products. As observed in the sintering of the clay, single component product, the sintering temperature lower than 800°C was ineffective in modifying the sinterability between the mica flakes and the clay grains. When the sintering temperature was increased from 800°C to 900°C, the bulk density of the sintered clay-mica composite specimen was observed to increase. However, when the sintering temperature was further increased to 1000°C, the bulk density of the clay-mica specimen began to decrease. As a result optimum bulk density of the clay-mica when composite sintered at 900°C was observed for both series of samples prepared at 5.0 MPa and 10.0 MPa compaction pressures, as shown in Figure 15.. This observation was similar in the preparation of the single component, clay, products. The boiling water absorption of the sintered clay-mica composite product was observed to decrease gradually as the sintering temperature was increased as shown in Figure 16.. The water saturation coefficient of the sintering clay-mica composite specimen was also observed to decrease as the sintering temperature increased for each composition under both compaction pressures, as shown in Figure 17..

The flexural strength was observed to increase slightly as the sintering temperature increased from 800°C to 1000°C for specimens prepared with different mica content. Specimens prepared at a 10.0 MPa compaction pressure were observed to have a slightly higher flexural strength, as shown in Figure 18.. Sintered clay-mica composite samples also displayed an optimum compressive strength when they were sintered at the temperature of $900^\circ C$ as shown in Figure 19. The figure shows the correlation between the compressive strength and the mica content for specimens sintered at the 800, 900, and $1000^\circ C$ sintering temperatures. The variation of the compressive strength with the sintering temperature and variation of the bulk density with the sintering temperature for the sintered clay-mica composite products are also found to be very similar. As a result, a near linear relationship between these two property parameters can also be established as shown in Figure 20.. It is evident that specimens of sintered clay-mica products with higher bulk density displayed higher compressive strength, but for same compressive strengthes of specimens can have different bulk density depending on different mica content, sintering temperature and compaction pressure.

4.2.2 The Effect of Sintering Time

In the present study, two sintering time periods, 4-*hour* and 7-*hour*, were employed to sinter the clay-mica compacted specimens. As shown in Table 15-16. and Table 19-20., when the sintering time was increased from 4 *hours* to 7 *hours*, all physical and mechanical properties of the clay-mica composite products are essentially unchanged. This included the bulk density, the cold water and boiling water absorptions, the water saturation coefficient, the flexural strength and the compressive strength. This indicates that sintering time is not a determining factor in the preparatio [illegible] he clay-mica composite products. So, the sintering time period of 4 hours was consider as an optimum sintering time period.

4.2.3 The Effect of Compaction Pressure

In the present study, eight compaction pressures within the range of 3.0-10.0 MPa have been employed to compress the loose clay-mica mixture into compacted blocks for sintering. When the compaction pressure was increased from 3.0 MPa to 10.0 MPa, the bulk density of the sintered clay-mica composite product was observed to increase linearly as shown in Figure 21.. It was also observed that the boiling water absorption of the sintered clay-mica composite product decreased linearly as the compaction pressure was increased as shown in Figure 22.. The mechanical properties of the sintered clay-mica composite product were also observed to improve as a higher compaction pressure was applied. For example, the flexural strength increased by about 60% as the compaction pressure was doubled, as shown in Figure 23.. The compressive strength increased by about 30% as the compaction pressure was doubled, as shown in Figure 24.. The increase in bulk density and mechanical strengthes and decrease in water absorptions for the sintered clay-mica composite products with the increase of the compaction pressure are consistent with the solid state sintering process of ceramic materials(34). This is due to the fact that under high compaction pressure, the solid particles are more closely packed together and facilitate the material growth process thereby enhancing the densification of the clay products, improving the mechanical strengthes and decreasing the water absorption.

4.2.4 The Effect of Composition

Several compositions in the clay-mica system were used in the investigation. It was found that the addition of natural phlogopite mica flakes to clay mixs has a significant modification on both the physical and the mechanical properties of the clay products Since the intrinsic density of the phlogopite mica flakes (d=433 Kg/m^3) is very low(30), gradual addition of the mica flakes to clay grains was found to lower the bulk density of the sintered clay-mica composite solids quite effectively. For example, the bulk density of a sintered clay-mica composite solid can be reduced from 2108.1 Kg/m^3 to 1935.0 Kg/m^3 by adding only 20 $\%wt$ of mica flakes to the clay mix with the mixture having compacted at a presure of 10.0 MPa and sintered at 900°C for 4 $hours$ (see Fig 15). In a general trend, the bulk density of sintered clay-mica composite product was observed to decrease as the mica content in the mixture was increased. This same trend was observed for specimens prepared at all three sintering temperatures and two compaction pressures, as shown in Figure 15., which shows the variation of bulk density of clay-mica composite as a function of mica content for specimens prepared at the sintering temperatures of 800, 900 and 1000°C and compaction pressures of 5.0 and 10.0 MPa. These experimental results indicated that clay-mica products with pre-determined bulk density can be readily prepared simply by selecting the appropriate clay-mica composition.

Addition of mica flakes to clay grains was also found to produce a few undesirable material characteristics of the composite products. The degree of the cold water and of the boiling water absorption in the sintered clay-mica composite solids after submersion in cold water at ambient temperature for 24 $hours$ and submersion in boiling water for 5 $hours$ has been observed to increase. The magnitude of the increase varied depending on the amount of mica flakes added to the clay grains. Figure 16. shows the variation of the boiling water absorption as a function of the mica content for several series of composite samples which were prepared at three sintering temperatures and two compaction pressures. For example, pure clay specimens compacted at 5.0 MPa and sintered at 900°C showed a 11.25% water absorption after 5 $hours$ submersion in boiling water. However, when 20 $\%wt$ of mica flakes was added to the clay mix and the mixture was then prepared at similar temperature and compaction pressure, the sintered composite product displayed a water absorption of about 18.82%. In spite of this large increase in the boiling water absorption, the water saturation coefficient which is a ratio of the cold water absorption to the boiling water absorption was observed to show a very flat linear increase as the mica content was increased as shown in Figure 17.. The increase in the water absorption is probably attributed to the lack of sinterability between the mica flakes and the clay grains, thus increasing the porosity in the sintered product.

Incorporation of mica flakes into clay grains was also found to reduce the flexural strength and the compressive strength of the clay-mica composite solids. The flexural strength of the sintered clay-mica composite product was observed to decrease almost linearly as the mica content increased for all composite samples prepared at the three sintering temperatures and compaction pressures as shown in Figure 18.. Similarly, the compressive strength of the sintered clay-mica composite product was observed to decrease as the mica content increased for all composite samples prepared at the three sintering temperatures and two compaction pressures, as shown in Figure 19.. For example, the compressive strength of the clay-mica composite products decreased by almost 65% when 20 $\%wt$ of mica flakes were added to the clay mixes and sintered at a temperature of $1000°C$ and a compaction pressure of $10.0MPa$. This significant decrease in flexural strength and compressive strength in the clay-mica composite products is evidently attributed to the lack of densification of the clay mixes and also to the lack of sinterability between the mica flakes and the clay grains. Furthermore, this large decrease in strength in the clay-mica composite solids indicates that the amount of mica flakes which can be beneficially added to the clay mixes will be controlled by the final application of the resultant clay-mica composite product.

4.2.5 Conclusion

The results of the experimental study in this part of the investigation also confirmed the optimum conditions of pure clay to be the same as for the preparation of clay-mica composite products. These included the sintering temperature at $900°C$, the sintering time period for 4 $hours$, the compaction pressure at 10.0 MPa, and the water content of 4 $\%wt$. The physical appearance and the product handling of the clay-mica composite solids were found to be very similar to those of the pure clay products with the exception that the clay-mica composite solids are much lighter. The display of lower flexural strength and compressive strength and high water absorption for the clay-mica composite products may render this type of products to be less desirable as exterior components for load-bearing or cladding elements in the design of building envelopes. However, this type of products would be more suitable for interior building applications, such as for wall partitioning, roofing deck or subfloor structure to provide some degree of thermal insulation without the addition of external mass insulators.

4.3 Clay-Mica-Glass – Three-Component System

The purpose for the preparation of the clay-mica-glass three-component composite product was intended to examine how the glass content may be able to improve the physical and mechanical properties of the clay-mica composite products.

4.3.1 The Effect of Composition

Several compositions in the clay-mica-glass system were used in the investigation. It was found that the addition of natural phlogopite mica flakes to the clay-glass mixtures has a significant modification on the physical and the mechanical properties of the clay products when the glass content in the composition was kept constant.

Since the intrinsic density of the phlogopite mica flakes (d=433 Kg/m^3) is very low, gradual addition of the mica flakes to the clay-glass mixtures was also found to be very effective in lowering the bulk density of the sintered clay-mica-glass composite solids. In a general trend, the bulk density of the sintered clay-mica-glass composite product was observed to decrease as the mica content increased as shown in Figure 25.. It was also observed that the volumetric change of the clay-mica-glass composite product increased as the glass content increased as shown in Figure 26.. The cold water absorption of sintered clay-mica-glass composite also increased as the glass content increased as shown in Figure 27., Figure 28. shows the variation of water saturation coefficient of clay-mica-glass composite as a function of mica content for specimens containing the glass content. The water saturation coefficient which is the ratio of the cold water absorption to the boiling water absorption decreased significantly as the glass content increased.

The decrease of the water saturation coefficient in the clay-mica-glass composite product is probably attributed to the following fact. Many of the interconnecting pores in the sintered bulk are closed and even the water boiling action was not able to penetrate into these closed pores. The water absorption process took place mostly at ambient temperature. Figure 29. shows a correlation between the water saturation coefficient and bulk density. It is evident that a composite product with a low bulk density and a low water saturation coefficient can be prepared from the clay-mica-glass material system.

4.3.2 The Effect of Replacement of the Clay Portion

In the present study, two different proportions of glass, 10% and 20%, have been individually added into the clay-mica mixture. The addition of the waste glass powders to clay-mica mixtures was also observed to modify significantly the properties of the sintered products.

The flexural strength of the clay-mica-glass composite product was observed to decrease as the glass content increased as shown in Figure 30.. The compressive strength of the clay-mica-glass composite product also decreased as the glass content increased as shown in Figure 31.. Replacement of clay grains with glass powder resulted in the formation of a ternary clay-mica-glass composite solid which showed lower flexural strength and compressive strength, as compared with the binary clay-mica composite solids. This was unexpected. It was anticipated that, during sintering at temperature above the melting point of the glass, glass powders would melt and spread out to cover both the mica flakes and clay grains, thus forming a stronger bond in the densified mica-clay matrix. However, this prediction was not borne out in practice. The decrease in flexural strength and compressive strength of clay-mica-glass composite is probably attributed to two possible factors: the lack of sinterability among the components because of the application of a lower sintering temperature, and insufficient spread of the molten glass components to cover all clay and mica particles thus yielding a weak bonding between the clay and mica particles and lower density with glass. The decrease in compressive strength of the clay-mica-glass composite solids with the substitution of the clay grains by glass powders observed in the present study was found to be inconsistent with the result reported in the literature. It has been reported that partial replacement of clay grains with ground glass powders could increase the compressive strength of sintered clay products(30). The different result is probably attributed to the addition of the third component, mica flakes in the clay-glass system. The nature of the bonding of the molten glass phase to the clay grains and to the mica flakes is probably very different thus resulting in different material characteristics.

4.3.3 Conclusion

When clay grains in the clay-mica mixture were replaced with the glass powders, a significant modification in the physical properties of the sintered clay-mica-glass composite products was observed. These changes were probably attributed to the following facts. When the sintering temperature was above the melting point of the glass. The glass powders would melt and spread out to cover both the mica flakes and the clay grains. At the same time both mica flakes and clay grains would undergo a dehydration process at the elevated temperature. The released water vapor was trapped in the interior matrix. As a result. the entrapped water vapor developed a strong vapor pressure which caused the molten glass to expand in the continuous heating process. Upon sudden cooling the liquid glass becomes solidified, thus resulting in a volume expansion. When glass was added into the clay-mica mixture, larger volume expansion has been developed. This accounts for the decrease of the bulk density and increase of the water absorption in the three-component composite products. The display of low density and low water saturation coefficient of the clay-mica-glass ternary composite products suggest that this type of product can be used as cladding components for building envelope exterior construction applications. This type of product would also be suitable for interior building applications comparable to the clay-mica composite products.

Chapter 5 DURABILITY

All three types of clay products including: the single clay product, a one-component system, the clay-mica composite product, a two-component system, and the clay-mica-glass composite product, a three-component system have been subjected to the durability tests. The durability test was carried out by cycling the water saturated samples between the freezing and thawing environment within the temperature range of $-12°C$ to $+10°C$ for 50 cycles. The mechanical properties of the treated samples were then evaluated. The test results are discussed under separate headings of the product type in the following sections. The numerical data for each test and the average values are given in Table 27-36.. And the average values are also plotted in graphical form.

5.1 Clay Products - One-Component System

Clay specimens which were prepared at the following sintering temperatures 750, 800, 900, and $1000°C$ and compressed at the compaction pressures of 5.0 MPa and 10.0 MPa were subjected to the freezing and thawing test. Results showed that both the flexural strength and the compressive strength of the treated clay product after the cycling treatment was essentially unchanged as compared with those before the treatment. Figure 32. shows the variation of the flexural strength of sintered clay product as a function of sintering temperature for specimens prepared at both 5.0 MPa and 10.0 MPa before and after the freezing and thawing treatment. Figure 33. shows the variation of compressive strength of sintered clay product as a function of sintering temperature for specimens prepared at both 5.0 MPa and 10.0 MPa before and after the freezing and thawing treatment. This indicates that the sintered clay products prepared in the present investigation were capable to withstand environmental temperature changes without catastrophic failure.

5.2 Clay-Mica Composite Products - Two-Component System

Three series of clay-mica composite specimens were sintered at 800, 900, and 1000°C and compressed at the compaction pressures of 5.0 MPa and 10.0 MPa for the freezing and thawing test. Test results also showed that both the flexural strength and compressive strength of the clay-mica composite product are unchanged after the cycling treatment. Figures 34. and 35. showed respectively the flexural strength and the compressive strength of sintered clay-mica composite product before and after the treatment. These results indicate that the addition of the mica flakes to the clay grains did not affect the stability of the composite products when they were subjected to the environmental changes.

5.3 Clay-Mica-Glass - Three-Component System

Two series of the clay-mica-glass composite specimens were prepared for the durability tests. In these three-component composites, the sintering temperature of 900°C, the compaction pressure of 10.0 MPa and the mica content of 10 $\%wt$ were kept constant. Only the clay portion was replaced with 10% and 20% of the glass powders. Test results also showed that both the flexural strength and compressive strength are unchanged after the cycling treatment. Figures 36. and 37. show respectively the variation of the flexural strength and compressive strength as a function of the mica content for the clay-mica-glass composite containing different glass contents before and after the freezing and thawing treatment. These results indicate that the replacement of the clay grains with the ground waste glass powders did not modify the product characteristic of the composite products thereby enabling these composite product to withstand the environment temperature changes.

5.4 Conclusion

The results of the experimental study in this part of the investigation show that sintered clay products prepared at different temperatures and with different compaction pressures were capable to withstand environmental temperature changes within the range of $-12°C$ and $+10°C$ without catastrophic failure. The addition of the mica flakes to the clay grains has not weakened the stability of the clay-mica composite products when they were subjected to the environment changes. The replacement of the clay grains with the ground waste glass powders has also not modified the clay-mica-glass composite product characteristic. As a result, these new composites were able to withstand the environmental temperature changes. It must be pointed out that the freezing-thawing cycling treatment was carried out for only 50 cycles. It is uncertain as to what would be the final result if the cycling treatment is carried out beyond this limit.

Chapter 6 THERMAL CONDUCTIVITY

The steady-state thermal conductivity of all three types of clay products including: the single clay product, a one-component system, the clay-mica composite products, a two-component system, and the clay-mica-glass composite products, a three component system has been measured at several mean temperature levels. The DYNATECH guarded hot plate apparatus was used for the measurements. The measurements have been made at the following three mean temperature levels, 5°C, 23°C and 45°C. The test results are discussed in this section. The data for each test are given in the Table 37-38., and are also plotted in graphical forms.

6.1 Thermal Conductivity of Clay Product

The clay specimens which were prepared for the thermal conductivity measurements were prepared at the sintering temperature of 900°C and the compaction pressure of 10.0 MPa. Measurement results showed that the thermal conductivity of the sintered pure clay increased linearly as the mean temperature increased as shown in Figure 38.. At the mean temperature of 20°C, the steady-state thermal conductivity of the pure clay product was about 0.562 $W/m°C$. This experimental value was observed to be a little bit lower compared with the thermal conductivity value of about $0.570 W/m^\circ C$ as reported in the literature(33).

6.2 Thermal Conductivity of Clay-Mica Composite

Three series of clay-mica composite specimens have been prepared for the thermal conductivity measurements. All specimens were sintered at $900^\circ C$ and compressed at the compaction pressure of 10.0 MPa. Test results also showed that the thermal conductivity of the sintered clay-mica composite increased linearly as the mean temperature increased as shown in Figure 38.. Guarded hot-plate measurements showed that the thermal conductivity of sintered clay products containing no foreign additions was in the range of 0.517 - 0.581 $W/m^\circ C$ when measured at the temperature range of $3^\circ C$ - $43^\circ C$. However, when about 10 $wt\%$ of mica flakes were added to the clay grains, the sintered clay-mica composite solids showed a thermal conductivity in the range of 0.266 - 0.297 $W/m^\circ C$ when measured at similar temperature range. When the mica content in the clay mixes was further increased, the thermal conductivity of the sintered composite products decreased further. Figure 39. shows the variation of thermal conductivity of clay-mica composite as a function of mica content for specimens prepared at a sintering temperature of $900^\circ C$ and compaction pressure of 10.0 MPa with specimens measured at different temperature levels. It is evident that addition of phlogopite mica flakes to clay mixes is an effective method in lowering the thermal conductivity of the clay products thus improving their thermal insulation values.

6.3 Thermal Conductivity of Clay-Mica-Glass Composite

Only two series of the clay-mica-glass composite specimens were prepared for the thermal conductivity measurements. All specimens were sintered at 900°C and compressed at the compaction pressure of 10.0 MPa. Test results also showed that the thermal conductivity of the sintered clay-mica-glass composite increased linearly as the mean temperature increased as shown in Figure 38.. Guarded hot plate measurements showed that the thermal conductivity of the clay-mica-glass composite solids containing 10% mica flakes and without glass content is in the range of 0.266 – 0.297 $W/m°C$ when measured over the temperature range 3 – 43°C. However, when clay grains were replaced with 10% of glass powders, the overall thermal conductivity of the clay-mica-glass composite solid was lower to the range of 0.232 - 0.260 $W/m°C$ when measured at similar temperatures. When the glass proportion in the clay-mica-glass system was increased to 20%, the thermal conductivity of the clay-mica-glass composite solid increased to the range of 0.294 - 0.325 $W/m°C$ when measured at similar temperatures. Figure 40 shows the variation of thermal conductivity of the clay-mica-glass composite as a function of the glass content for all specimens containing a mica content of about 10 wt%, and prepared at a sintering temperature of 900°C and compaction pressure of 10.0 MPa for measurements carried out at different temperature levels. This indicates that in the clay-mica system, a replacement of the clay grain with 10 wt% glass powders would result in the fabrication of a clay-mica-glass composite solid which shows the most attractive thermal insulation properties as compared to the pure clay products.

6.4 Conclusion

The results of the experimental study in this part of the investigation have shown that the thermal conductivity of all clay including the pure clay - one-component system, the clay-mica composites, a two-component system, and the clay-mica-glass composite, a three-component system all increased as the measuring mean temperature increased. This is consistent with the thermal behavior of ceramic products as reported in the literature(34). Test results also indicate that natural mica flakes is an effective component which can be mixed with clay grains and formed a clay-mica composite product. The clay-mica composite products exhibits lower thermal conductivity as compared with the clay product. Replacement of clay grains with ground glass powders were also found to be effective in lowering thermal conductivity of the clay product. However, only a very specific proportion of the clay grains in the mixture can be replaced in order to obtain the optimum in the thermal performance of the clay products.

Chapter 7 GENERAL DISCUSSION

Three types of clay products have been prepared. These included: the single clay product, a one-component system, the clay-mica composite products, a two-component system, and the clay-mica-glass composite products, a three-component system. These clay products were found to exhibit very different physical properties, which included the bulk density, the volumetric change, the cold water and boiling water absorptions and the water saturation coefficient, mechanical properties, which included the flexural strength and the compressive strength, durability, which included the flexural strength and the compressive strength after 50 cycles freezing and thawing treatment, and thermal conductivity. The variations of these properties can be correlated with the product fabrication parameters, such as the composition, the sintering temperature, the sintering time, the compaction pressure and the water content.

In the one-component system, it was observed that the optimum bulk density and compressive strength occurred when the sintering temperature was at 900°C. It is very similar to the other clay products sintered at temperatures in the range of $800-900°C$ exhibited optimum compressive strength and a sintered bulk density. It was also found that the sintered pure clay product had very high thermal conductivity value similar to those report by others(28).

7. GENERAL DISCUSSION

It was reported by some researchers that the addition of a small amount of mica flakes to the cement could significantly increase the flexural strength and fracture toughness in the mica-cement composites(23-25). It has been reported(26) that the tensile strength of concrete is increased by the addition of high aspect-ratio mica reinforcement. It has also been reported that the developed mica-glass composites were found to exhibit superior thermal insulation property and mechanical strength(1-3). In this project, the developed clay composite products containing mica mineral have been found to reflect not only improved thermal insulation value but also some unique features such as safety, good durability, because of the unique material characteristics of the mica mineral itself such as low thermal conductivity and chemical stability at high temperature. But the mechanical properties of sintered clay-mica product were poorer as compared with sintered pure clay, due to the lack of densification of the clay mixes and the lack of sinterability between the mica flakes and the clay grains. The composite products are to be fabricated mainly from locally available sources and a simple sintering process has been employed. The developed clay composite products containing mica could become a new class of building components as they can be used to replace the existing commercial building products but with contribution to building energy conservation because of their improved thermal insulation value. The technology of the fabrication process developed from the research project could be directly transferred to the manufacturing industry as a new frontier for the production of an innovative and viable building fabric components for the construction industry.

The investigated clay composite products containing glass powders have been found to lower the bulk density and the water saturation coefficient of the composite, this makes the composite with mica to be recommended not only for interior building applications but also for exterior construction applications.

7. GENERAL DISCUSSION

Measurements with the use of a guarded hot-plate showed that the thermal conductivity of the clay-mica composite and the clay-mica-glass composite is in the range of 0.231 – 0.325 $W/m°C$. The thermal conductivity of these clay based composite is found to be considerably lower than the thermal conductivity of several traditional building materials, such as normal-weight concrete with thermal conductivity in the range of of 1.200 – 1.230 $W/m°C$, lightweight concrete with thermal conductivity in the range of 0.550 – 0.560 $W/m°C$(36), solid soda-lime-silica glass with thermal conductivity in the range of 0.900 – 1.100 $W/m°C$.

Chapter 8 CONCLUSION

Three systems of solids, one-component system – clay, two-component system – clay-mica, and three-component system – clay-mica-glass, have been produced.

In the one-component system, the optimum conditions of several important preparation parameters have been identified. These included.

(1) the sintering temperature of 900°C;

(2) the sintering time period of 4 $hours$;

(3) the compaction pressure of 10.0 MPa;

(4) the water content of 4 $\%wt$.

In the clay-mica - two-component system, the investigation also identified the optimum conditions for the preparation of clay-mica composite products: the sintering temperature at 900°C, the sintering time period for 4 $hours$, the compaction pressure at 10.0 MPa, and the water content of 4 $\%wt$. Since the intrinsic density of the phlogopite mica flakes is very low, gradual addition of the mica flakes to clay grains was found to lower the bulk density of the sintered clay-mica composite solids quite effectively. And also because of the high thermal insulation value of the mica flakes, addition of the mica flakes to clay grains was obtained to lower the thermal conductivity of the sintered clay-mica composite solids. Addition of mica flakes to clay grains was also found to produce a few undesirable material characteristics of the composite products, such as the degrees of the cold water and boiling water absorption, water saturation coefficient all increased as the mica content in the clay-mica composite increased. The flexural strength and compressive strength decreased as the mica content increased. This is probably due to the lack of sinterability between the mica flakes and the clay grains. The clay-mica composite solids are much lighter than the pure clay. The display of lower flexural strength and compressive strength and high water absorption for the clay-mica composite products may render this type of products to be less desirable as exterior components for load-bearing or cladding elements in the design of building envelope. However, this type of products would be more suitable for interior building applications, such as for wall partitioning, roofing deck or subfloor structure to provide some degree of thermal insulation without the addition of external mass insulators.

In the clay-mica-glass - three-component system, The material characteristic of the sintered clay-mica-glass composite was different as compared with the sintered clay-mica composite. The significant modification of the properties of the sintered clay-mica-glass composite products probably is attributed to the following facts. When the sintering temperature was above the melting point of the glass about 900°C. The glass powders would melt and spread out to cover both the mica flakes and the clay grains. At the same time both mica flakes and clay grains would undergo a dehydration process at the elevated temperature. The released water vapor trapped in the interior matrix. As a result, the entrapped water vapor developed a strong vapor pressure which caused the molten glass to expand in the continuous heating process. Upon sudden cooling the liquid glass becomes solidified, thus resulting in a volume expansion. When glass was added into the clay-mica mixture, large volume expansion has been developed. This accounts for the decrease of bulk density and increase of the water absorption in the three-component composite products. The clay-mica-glass composites have low bulk density and low water saturation coefficient. This type of product is suggested to be used as cladding components for building envelope exterior construction applications. It would also be suitable for interior building applications comparable to the clay-mica composite products. The investigation shows that sintered clay products including: pure clay, clay-mica composite, clay-mica-glass composite prepared at different temperatures and with different compaction pressures were capable to withstand environmental temperature changes within the range of $-12°C$ and $+10°C$ without catastrophic failure. These new composites were able to withstand the environment temperature change.

Chapter 9 RECOMMENDATION FOR FURTHER WORK

In this project, only the physical properties, the mechanical properties, the durability and the thermal conductivity have been investigated. The variations of these properties were correlated with the product fabrication parameters, such as the composition, the sintering temperature, the sintering time, the compaction pressure and the water content. The internal microstructure of the sintered clay products as a result of the addition of the natural mica flakes and of the ground glass powders has not been examined. It is recommended in a future study to include this aspect of the investigation as it may provide further valuable information in the fabrication process. It is also recommended to carry out a cost analysis. Such analysis may provide some guidance for determining the adequacy of pricing and distribution policies. Investigate how the mica affect other different types of clay is also recommended.

FIGURES

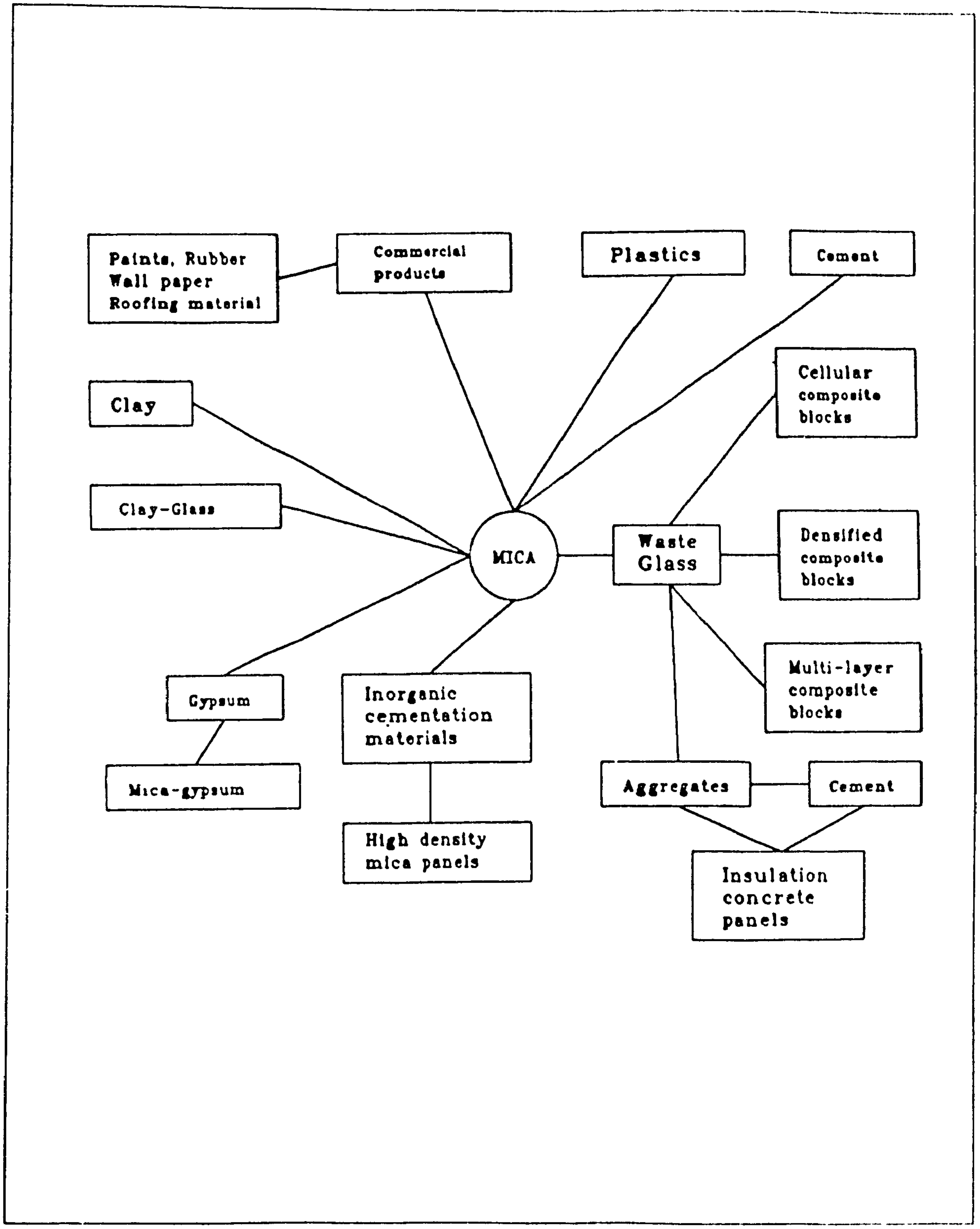

Figure 1 A block diagram on the utilization of natural mica mineral for product research and development

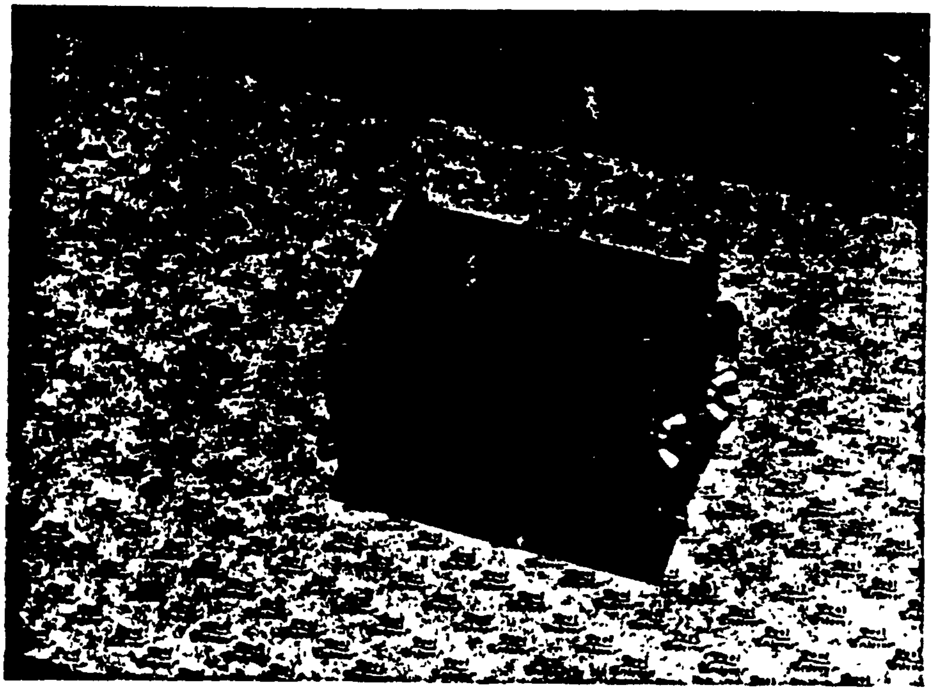

Figure 2 A photograph of the rectangular steel compression mold

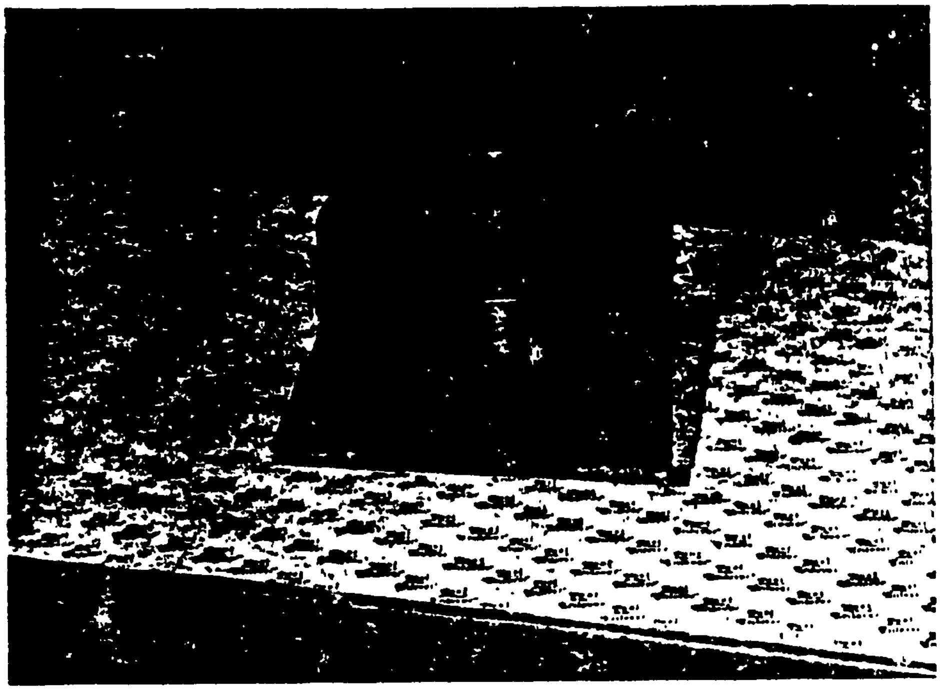

Figure 3 A photograph of the round steel compression mold

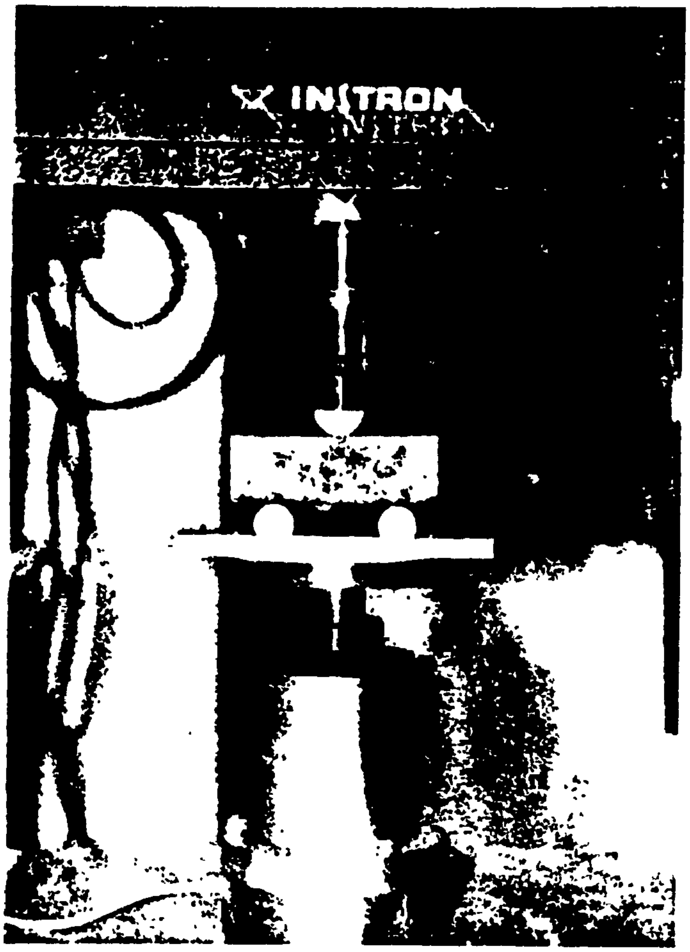

Figure 4 Arrangement for flexural strength test

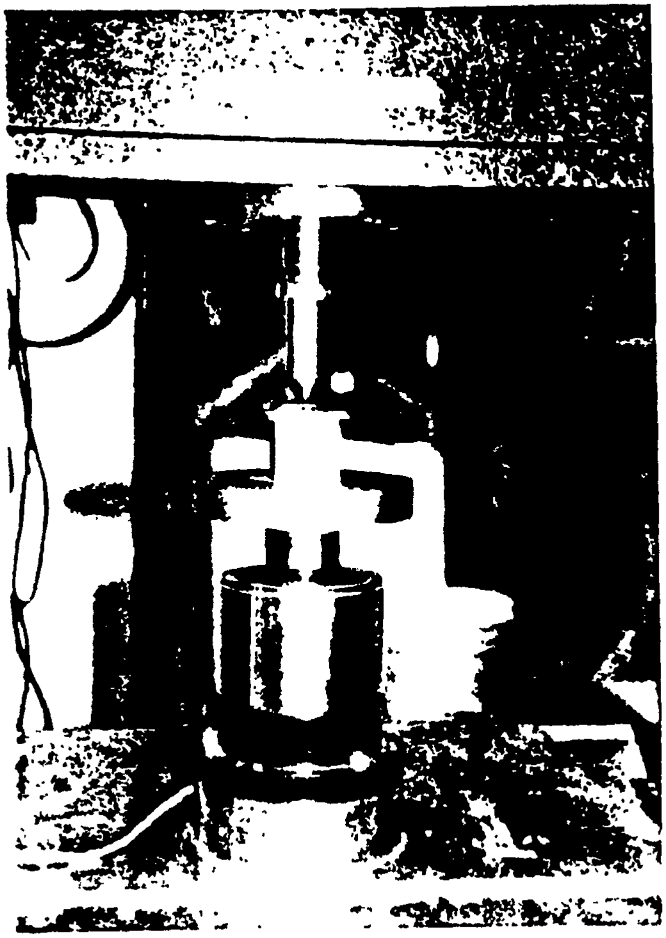

Figure 5 Arrangement for compressive strength test

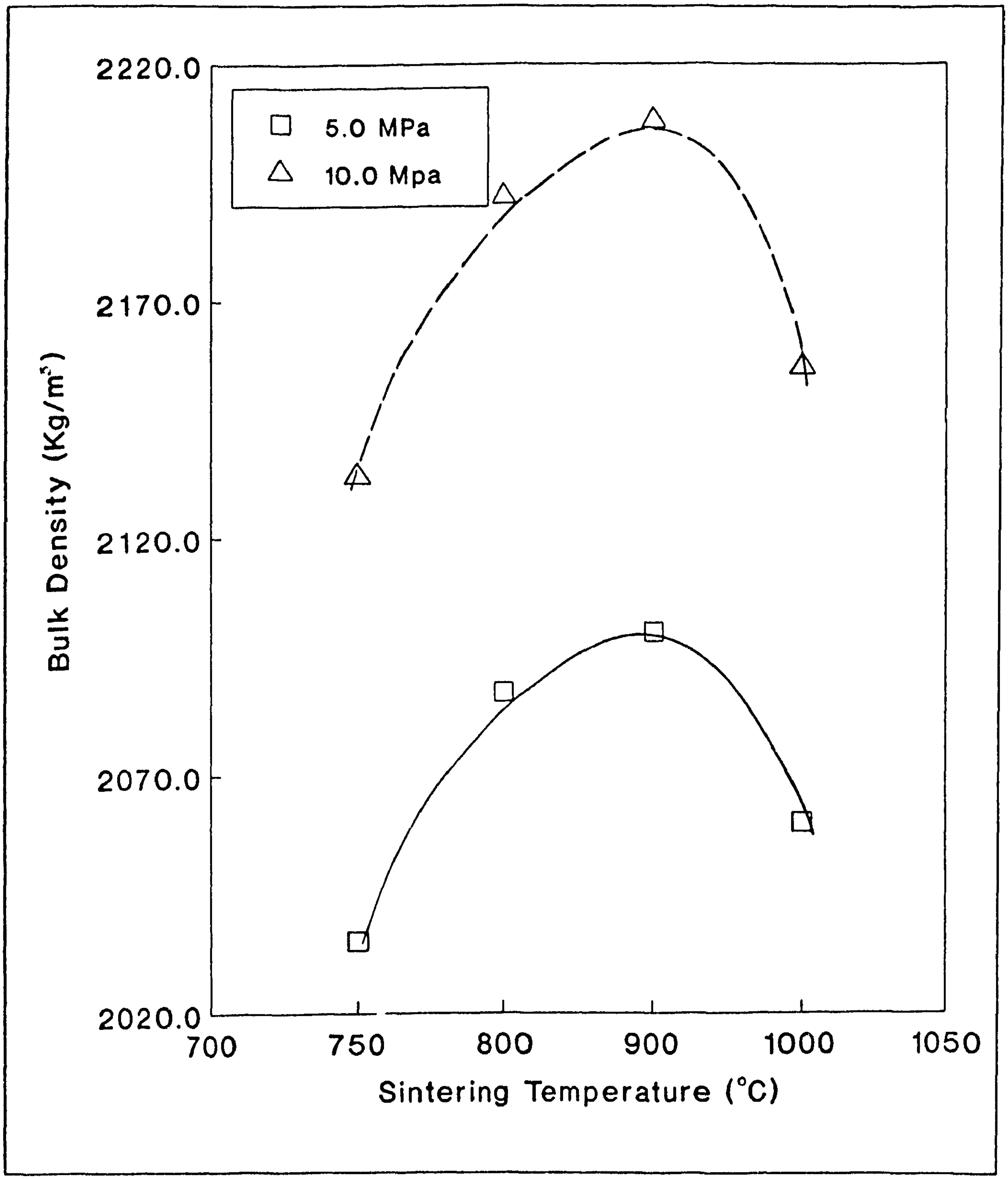

Figure 6 Variation of bulk density of sintered clay product as a function of sintering temperature for specimens prepared at 5.0 MPa and 10 0 MPa compaction pressures

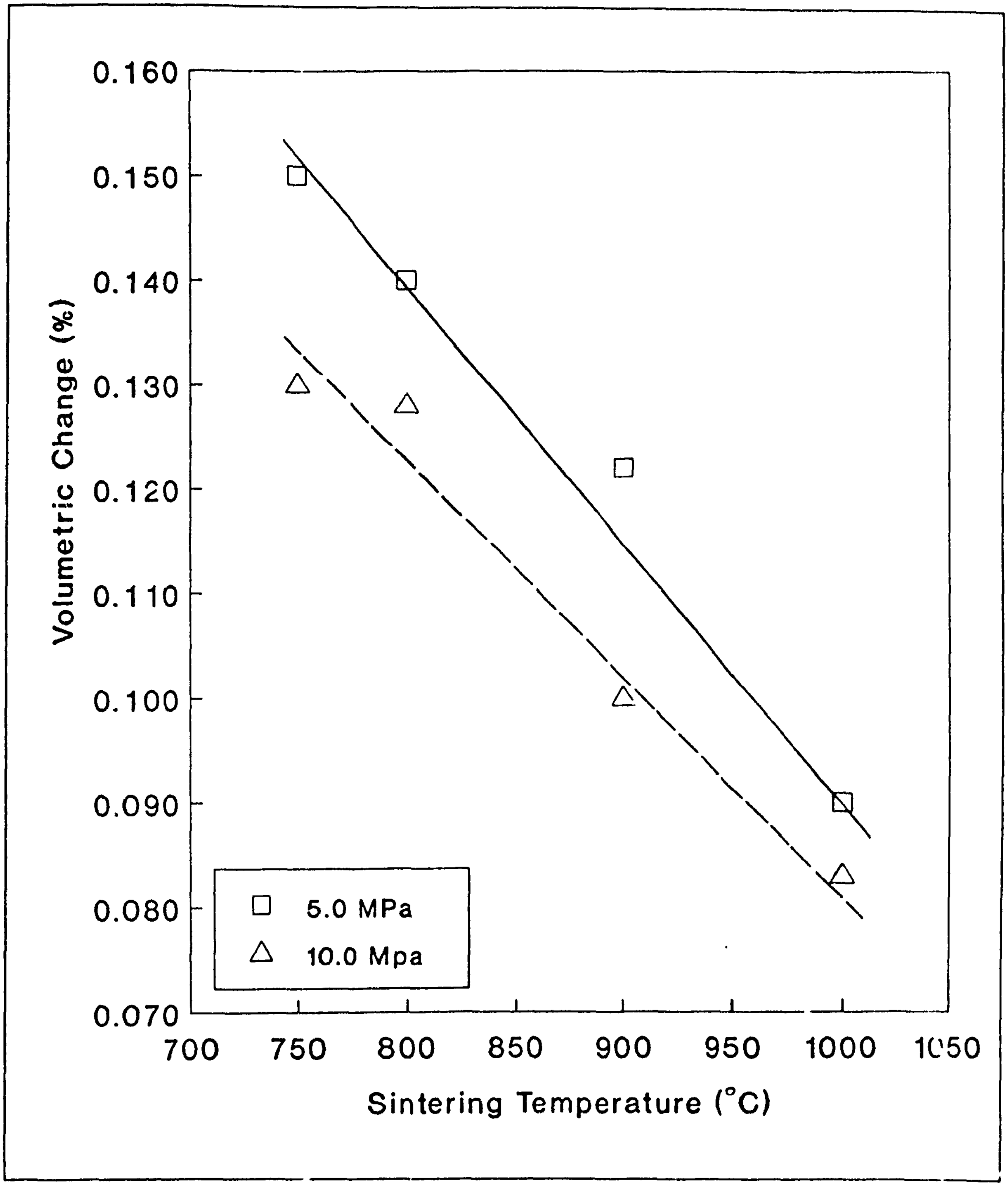

Figure 7 Variation of volumetric change of sintered clay product as a function of sintering temperature for specimens prepared at 5 0 MPa and 10 0 MPa compaction pressures

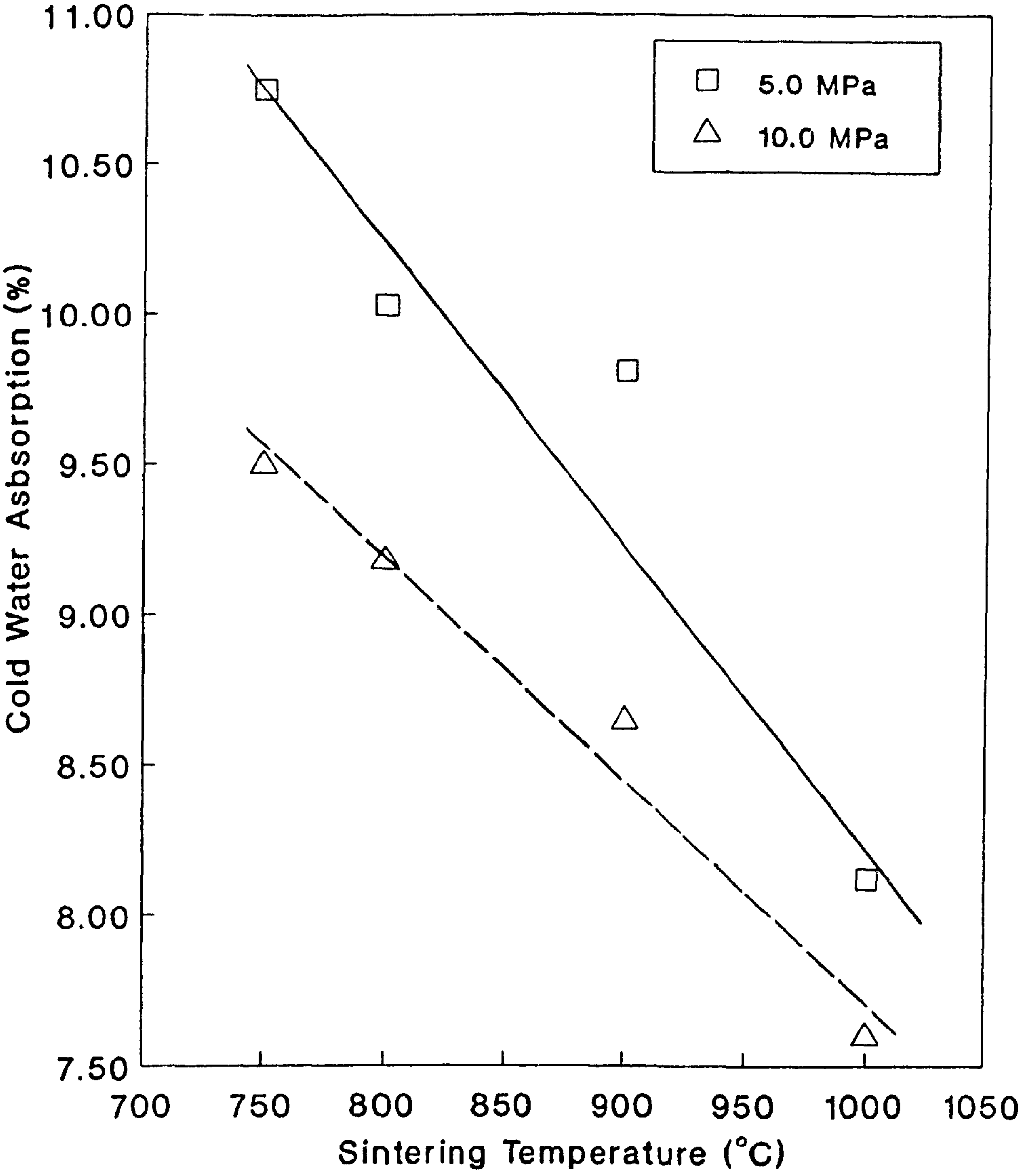

Figure 8 Variation of cold water absorption of sintered clay product as a function of sintering temperature for specimens prepared at 5.0 MPa and 10.0 MPa compaction pressures

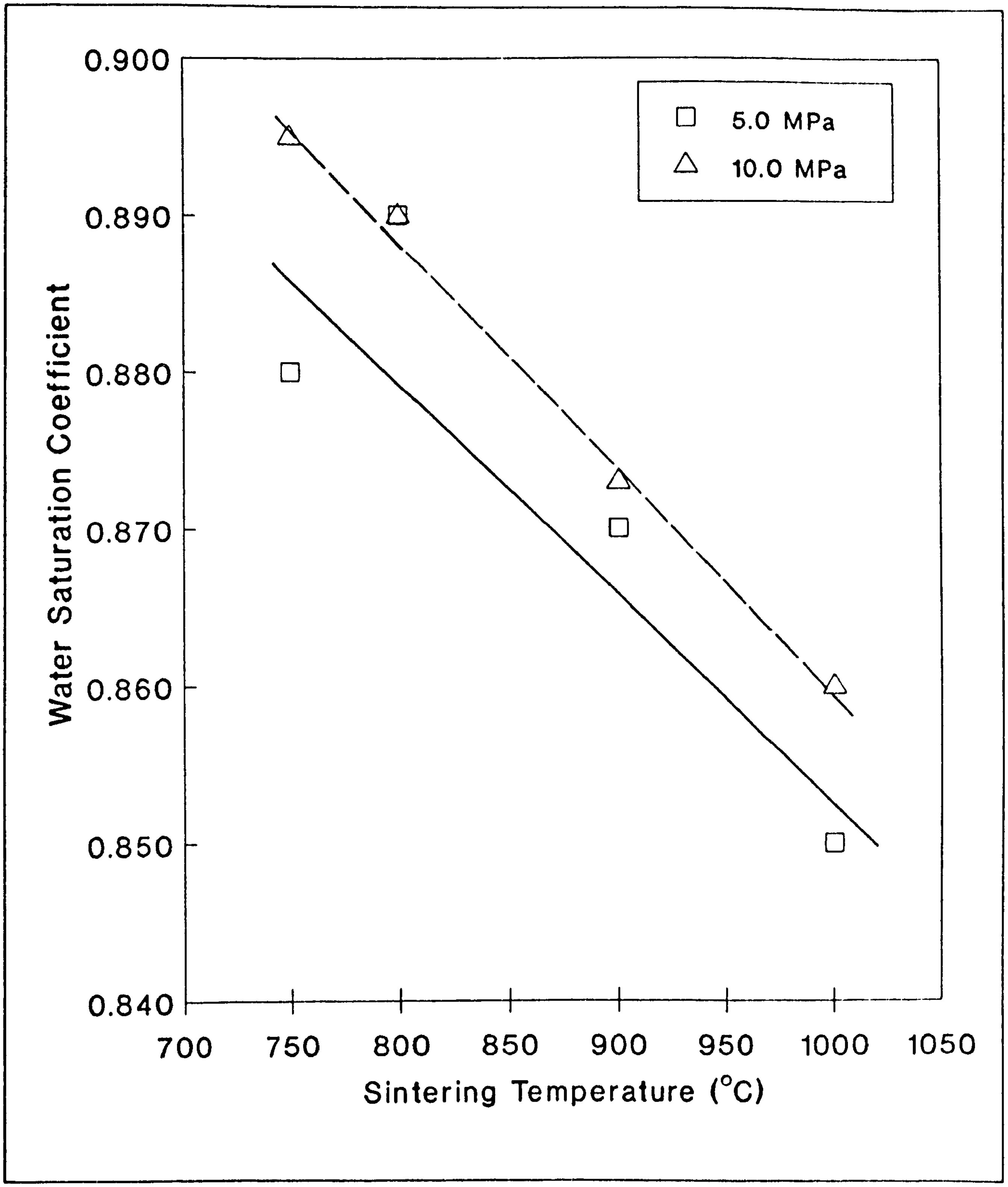

Figure 9 Variation of water saturation coefficient of sintered clay product as a function of sintering temperature for specimens prepared at 5 0 MPa and 10 0 MPa compaction pressures

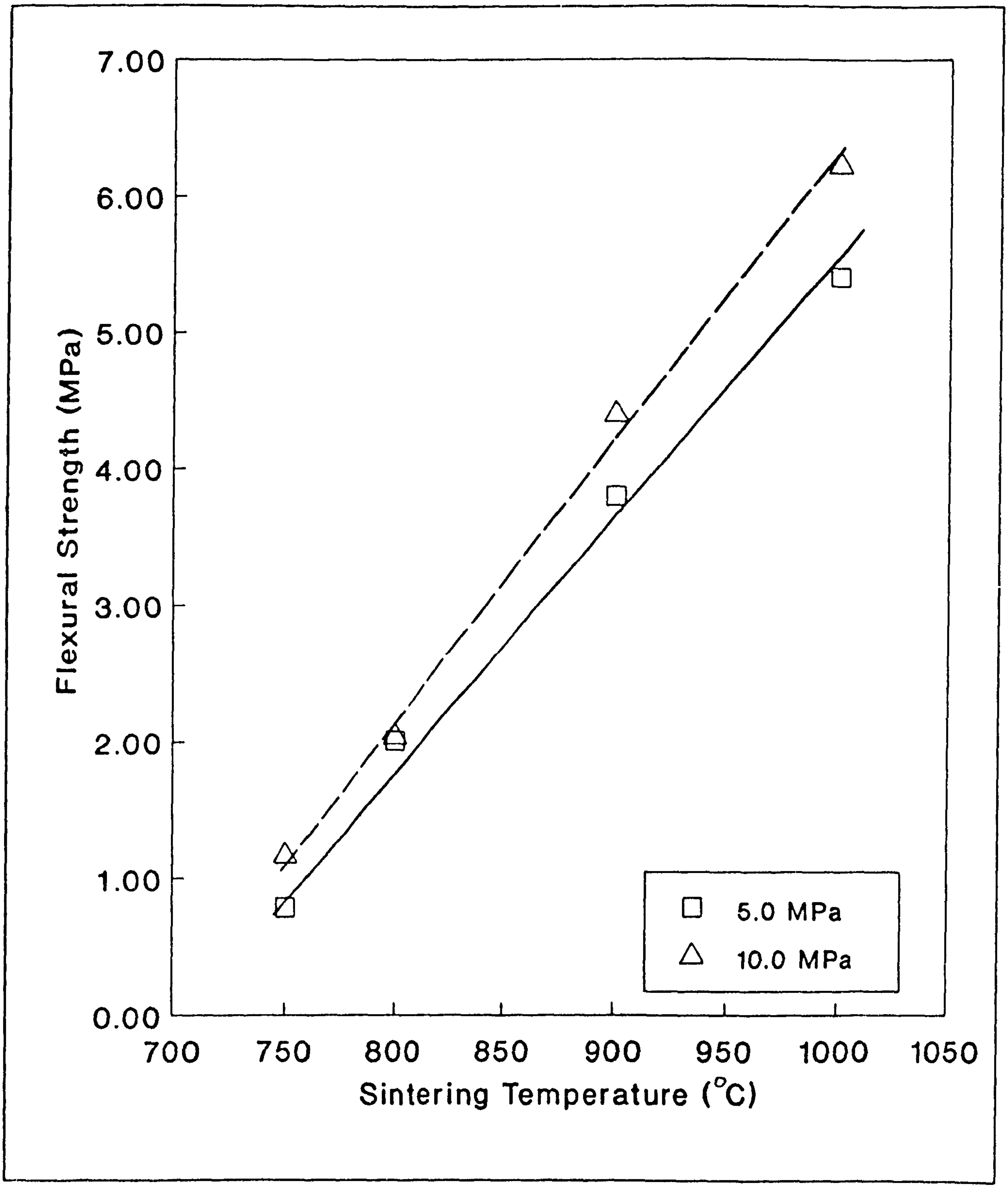

Figure 10 Variation of flexural strength of sintered clay product as a function of sintering temperature for specimens prepared at 5.0 MPa and 10.0 MPa compaction pressures

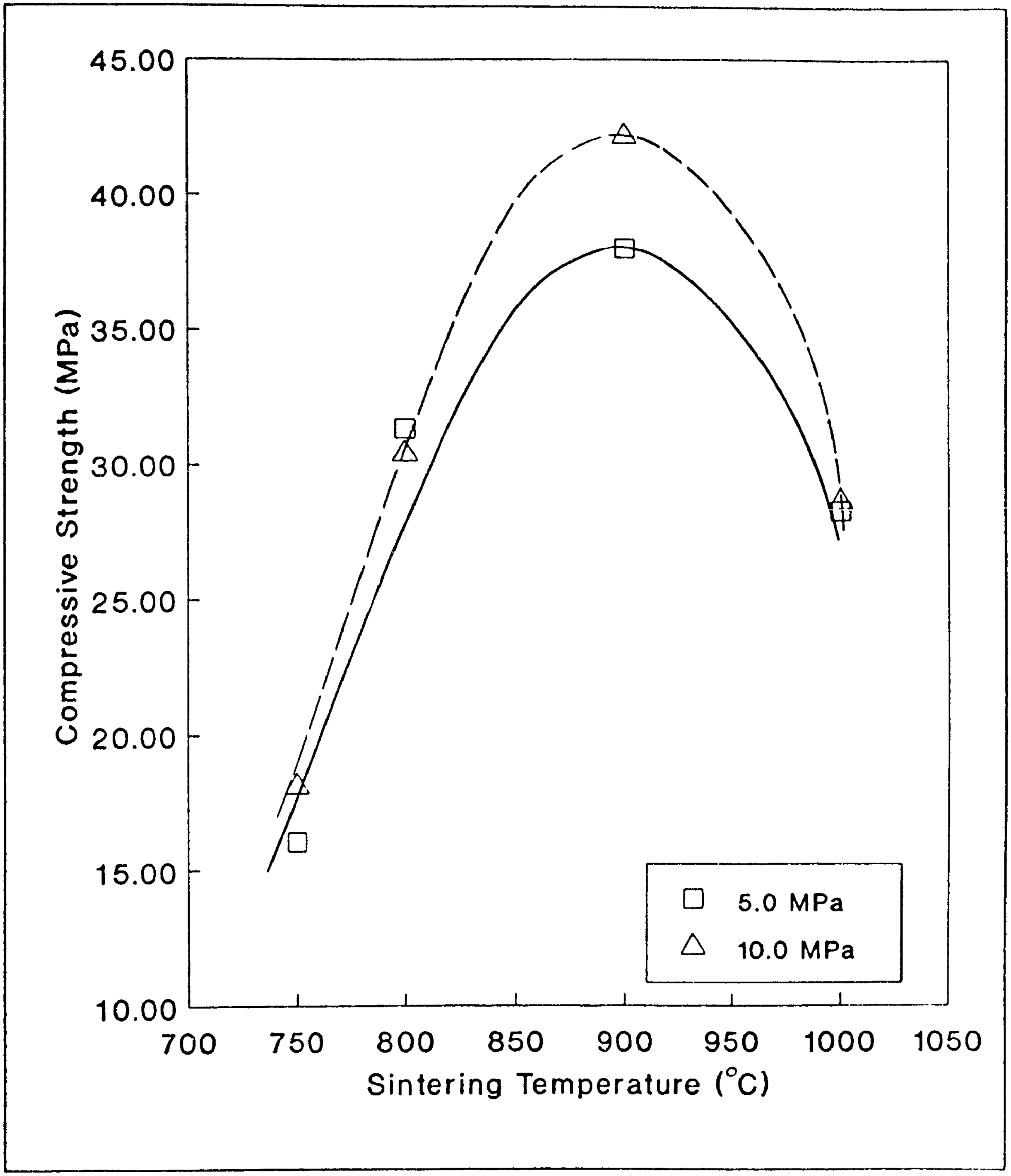

Figure 11 Variation of compressive strength of sintered clay product as a function of sintering temperature for specimens prepared at 5 0 MPa and 10 0 MPa compaction pressures

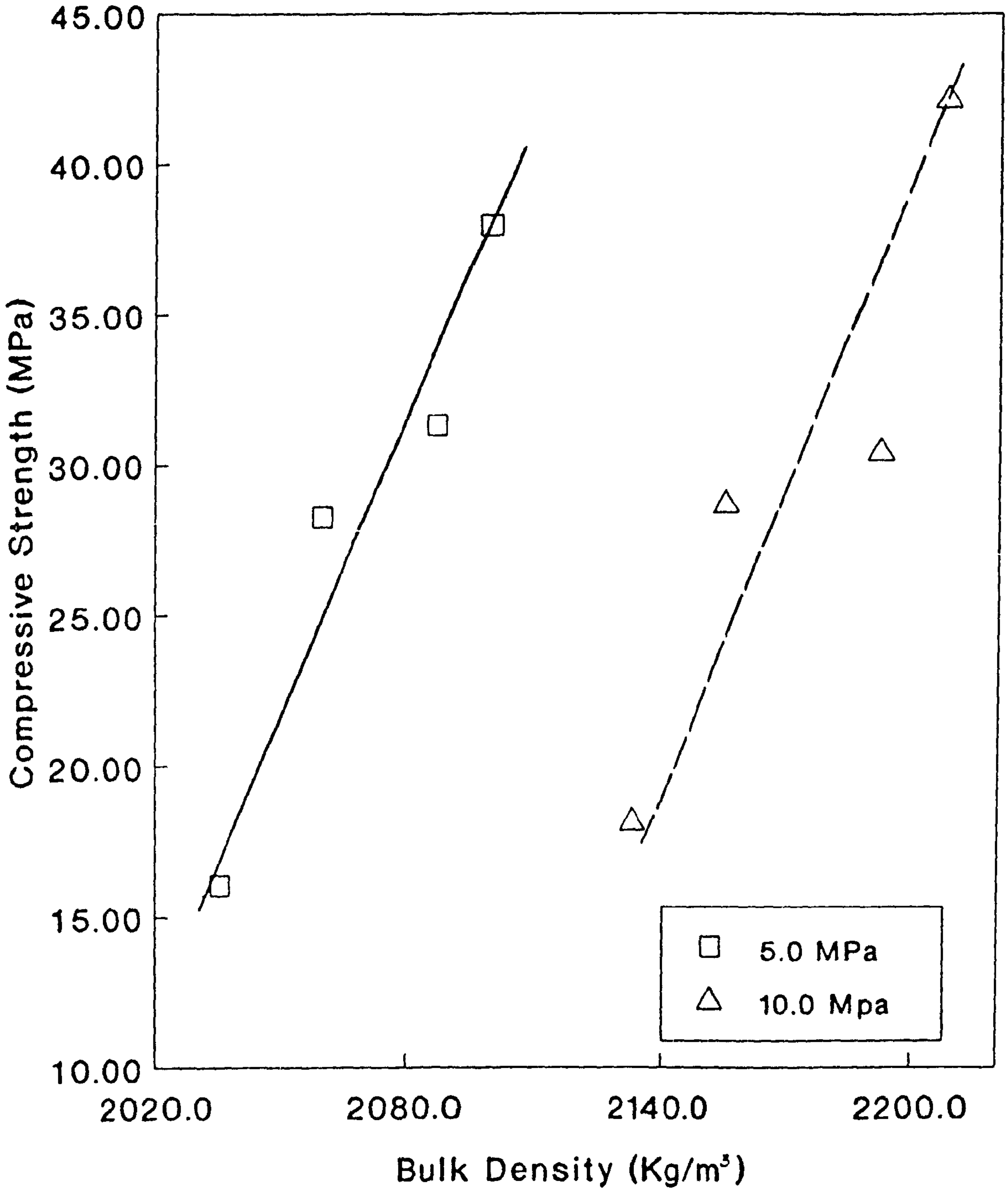

Figure 12 Correlation between compressive strength and bulk density of sintered clay products for specimens prepared at 5.0 MPa and 10.0 MPa compaction pressures

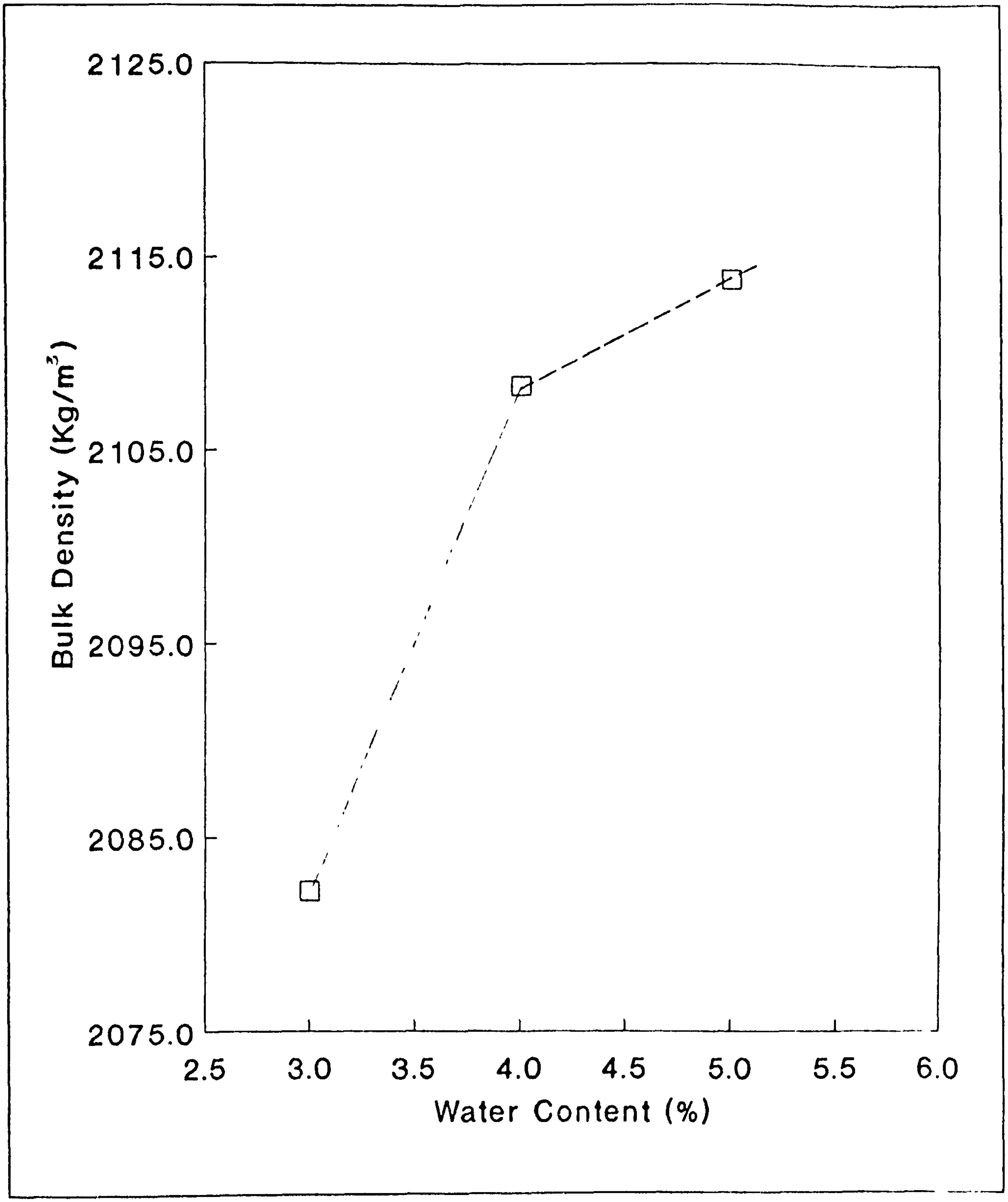

Figure 13 Variation of bulk density of sintered clay products as a function of water content for specimens prepared at a sintering temperature of 900°C and compaction pressure of 5.0 MPa (The line shows only the trend)

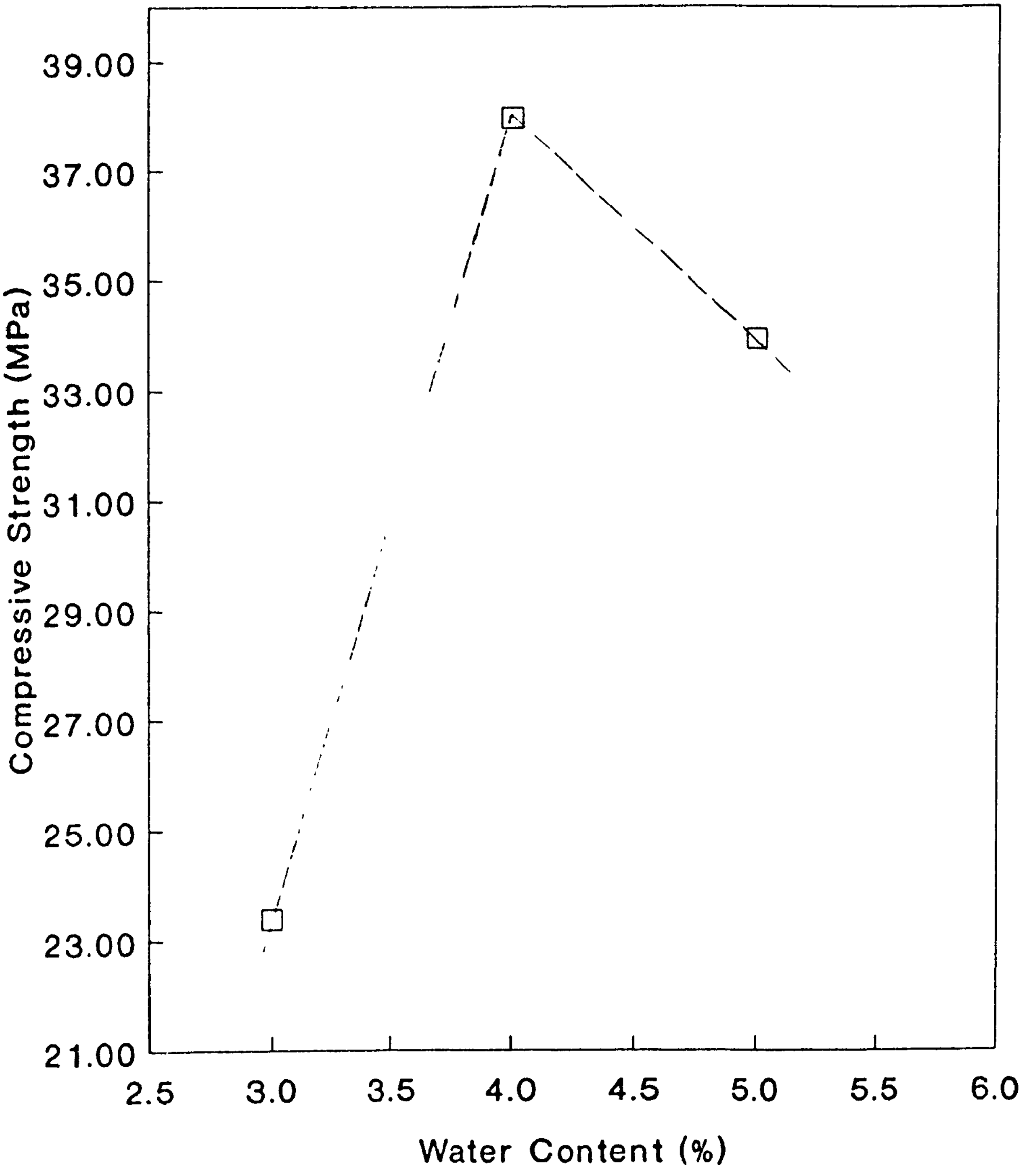

Figure 14 Variation of compressive strength of sintered clay products as a function of water content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 5.0 MPa with different water content
(The line shows only the trend.)

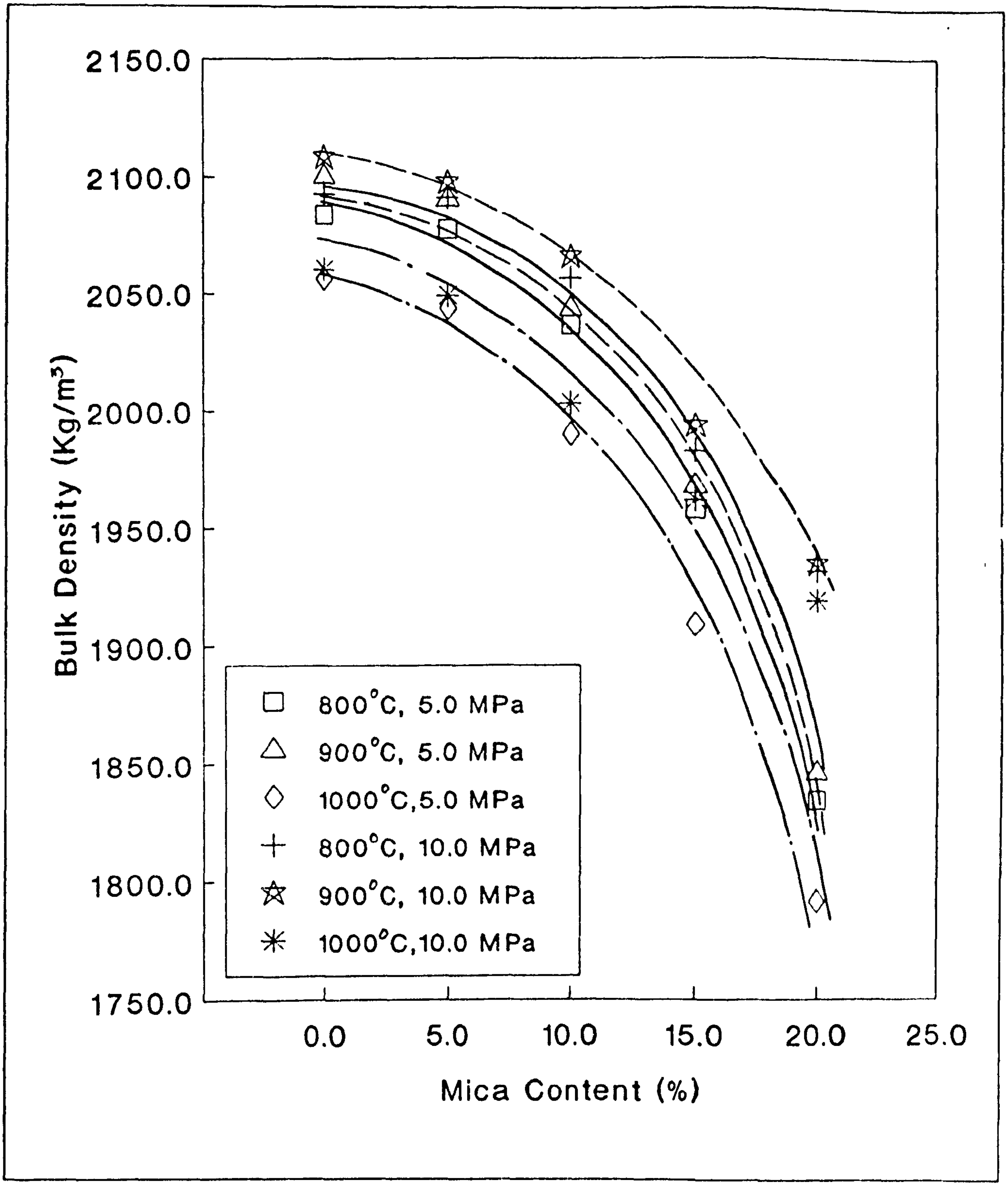

Figure 15 Variation of bulk density of clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800, 900 and 1000°*C* and compaction pressures of 5 0 and 10 0 MPa

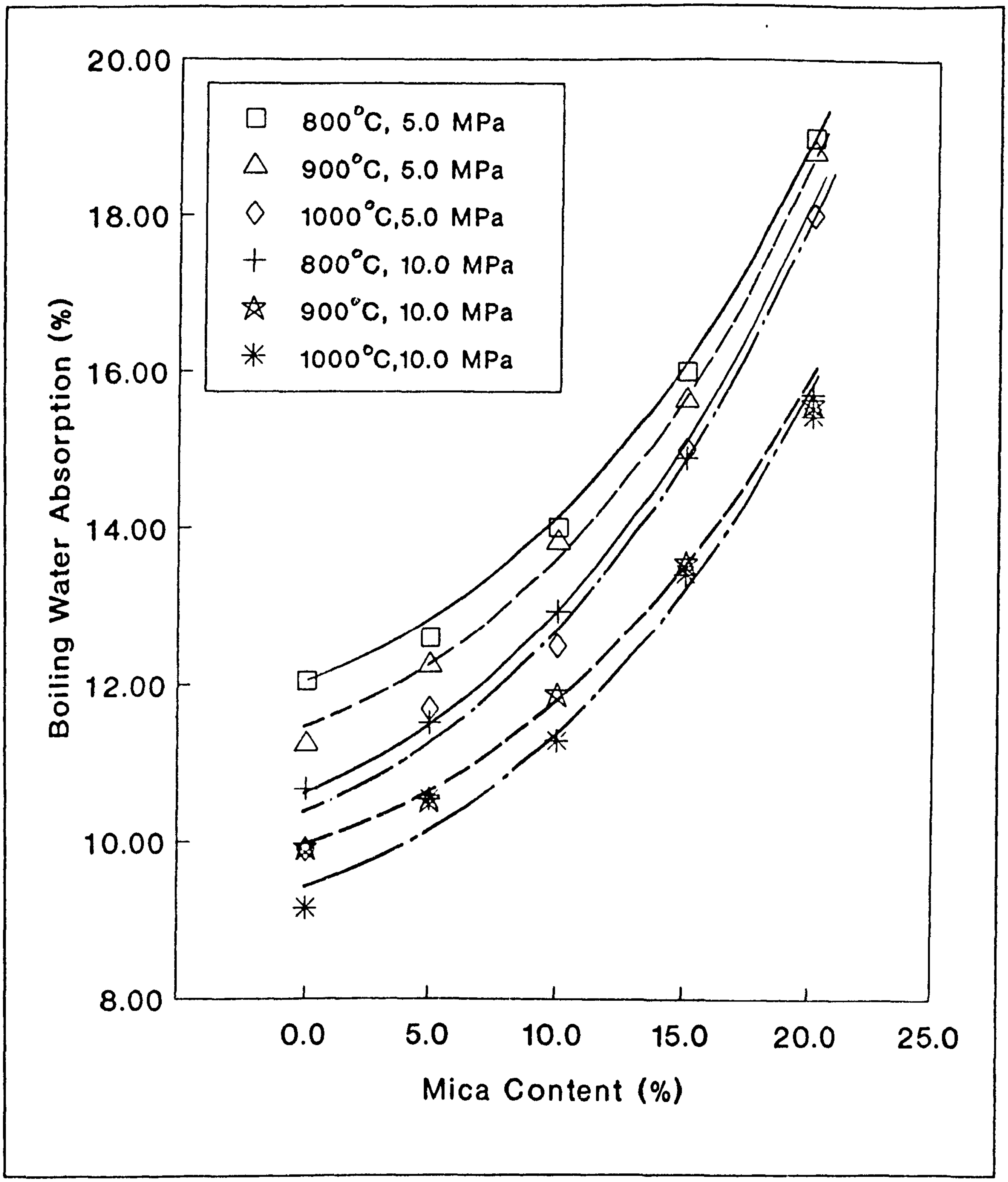

Figure 16 Variation of boiling water absorption of clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800, 900 and 1000°C and compaction pressures of 5.0 and 10.0 MPa

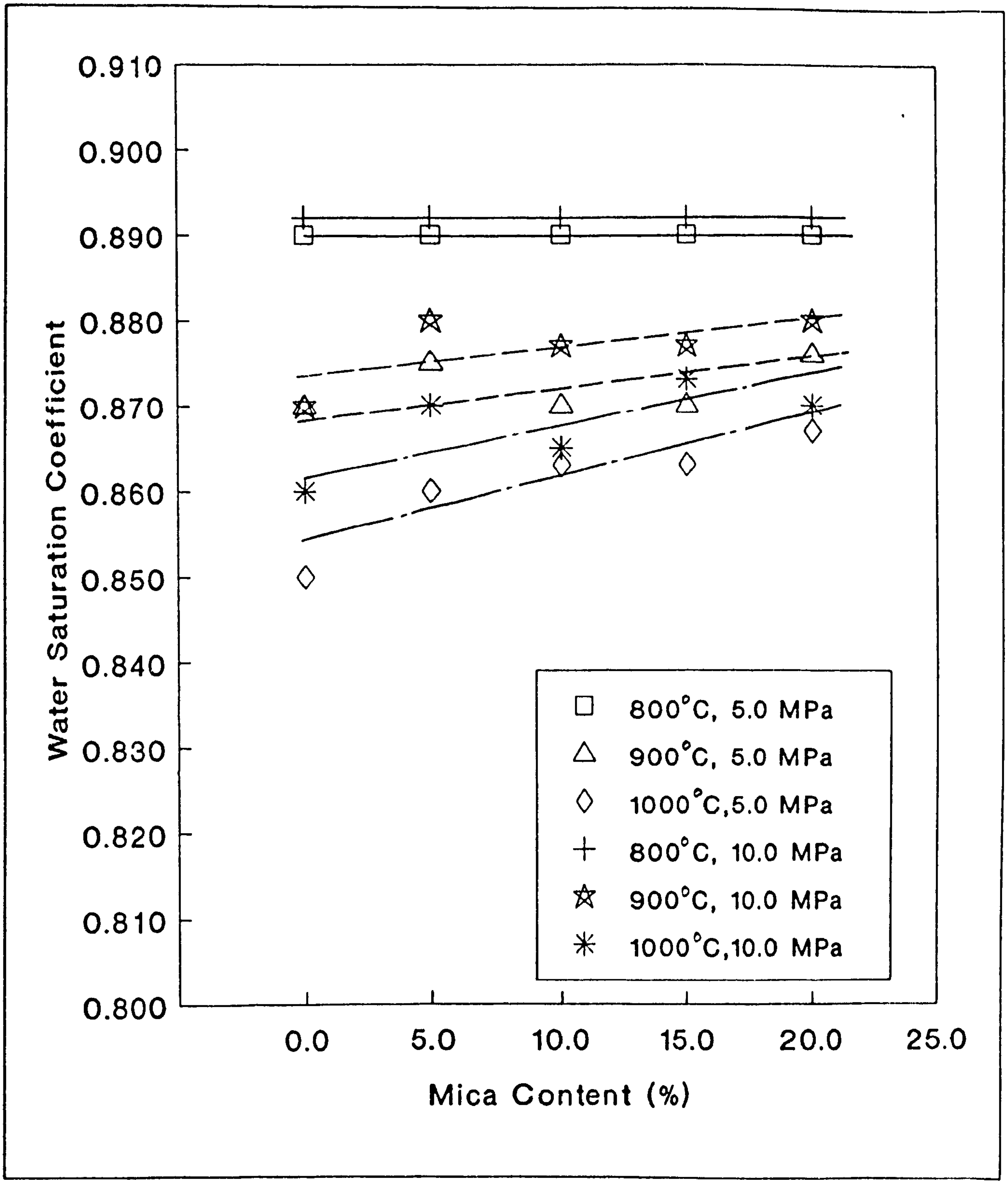

Figure 17 Variation of water saturation coefficient of clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800, 900 and 1000°*C* and compaction pressures of 5.0 and 10 0 MPa

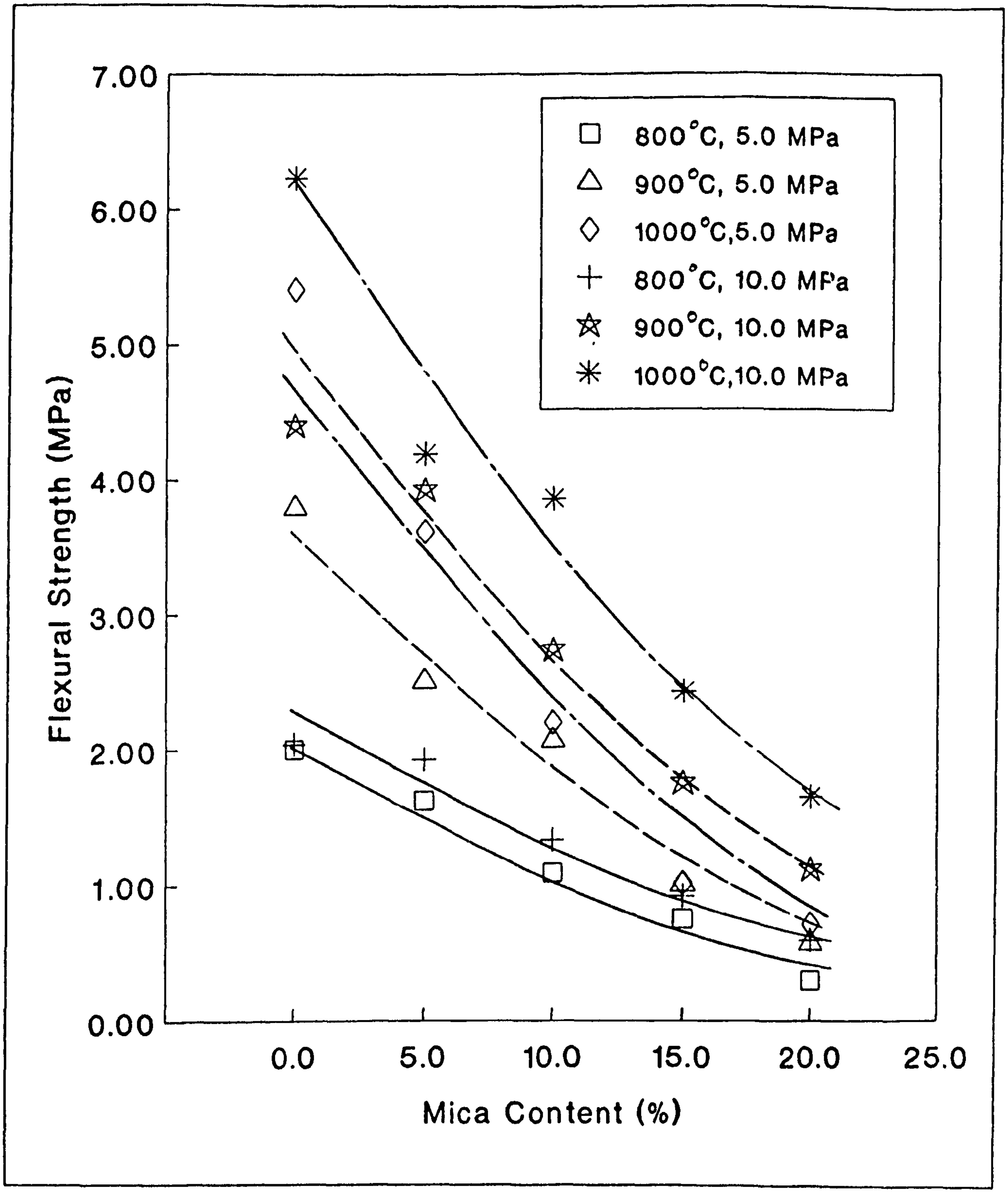

Figure 18 Variation of flexural strength of clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800, 900 and 1000°*C* and compaction pressures of 5.0 and 10.0 MPa

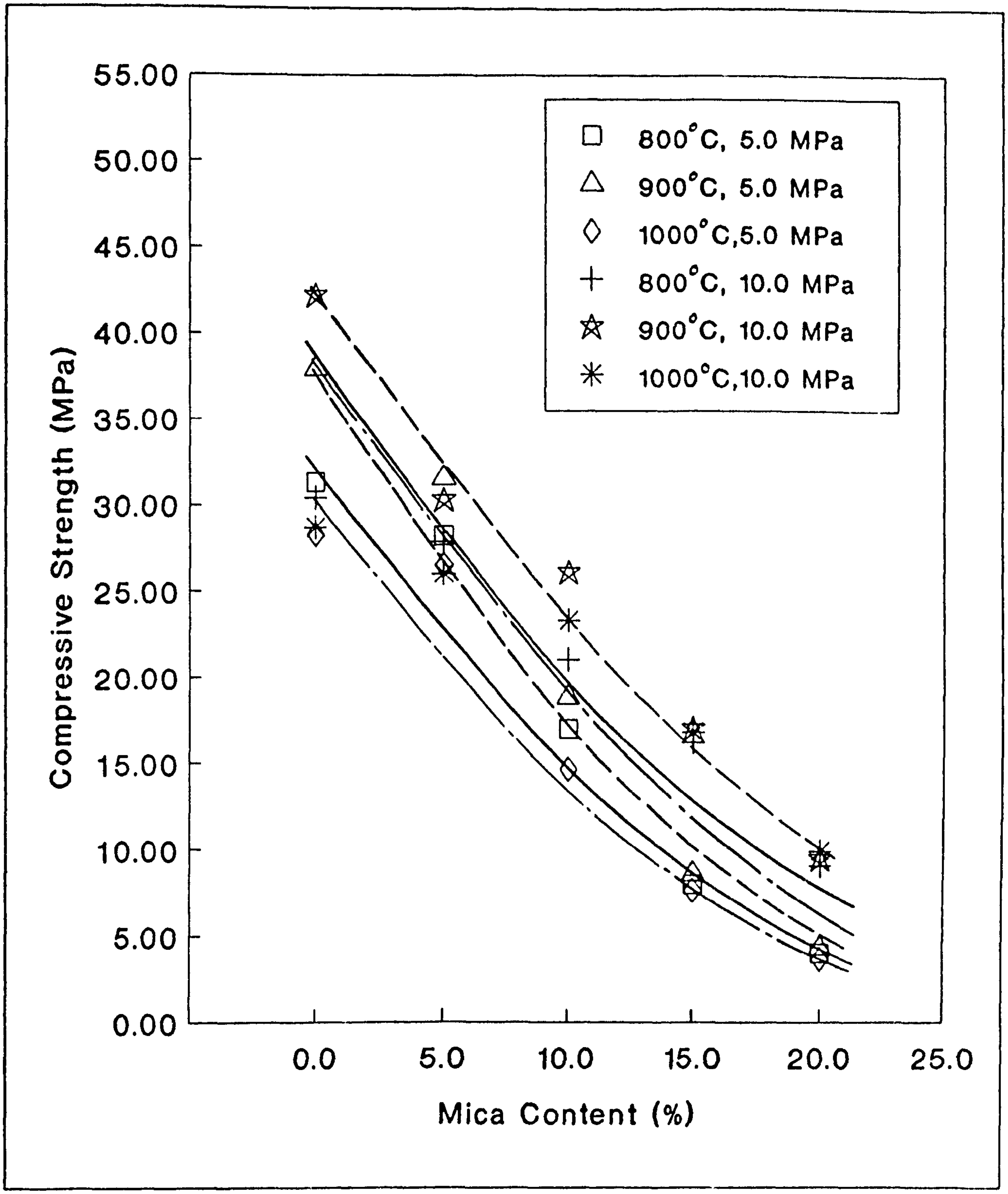

Figure 19 Variation of compressive strength of clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800, 900 and 1000°*C* and compaction pressures of 5.0 and 10.0 MPa

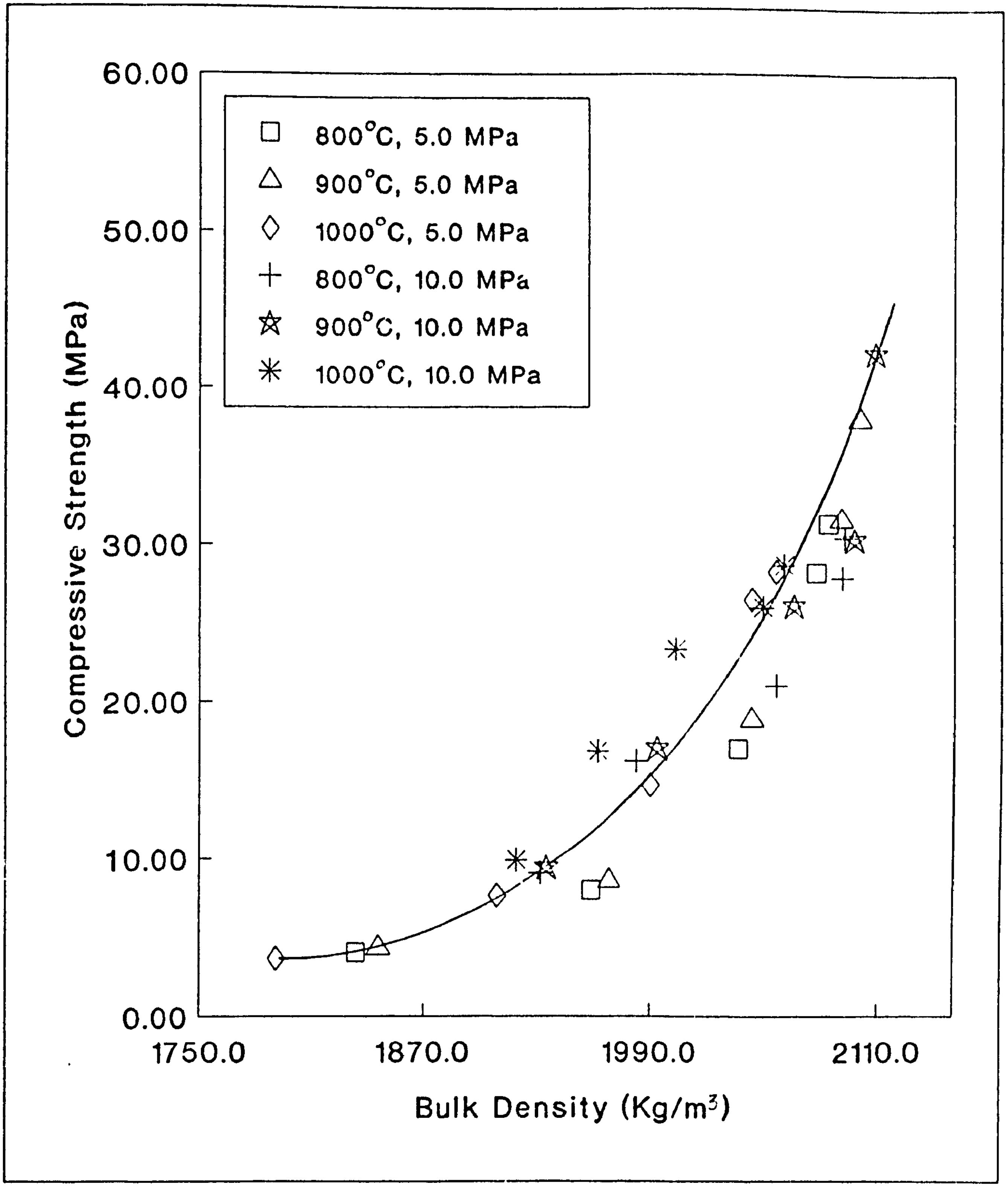

Figure 20 Correlation between compressive strength and bulk density for specimens prepared at the sintering temperature of 800, 900 and 1000°C and compaction pressures of 5.0 and 10.0 MPa

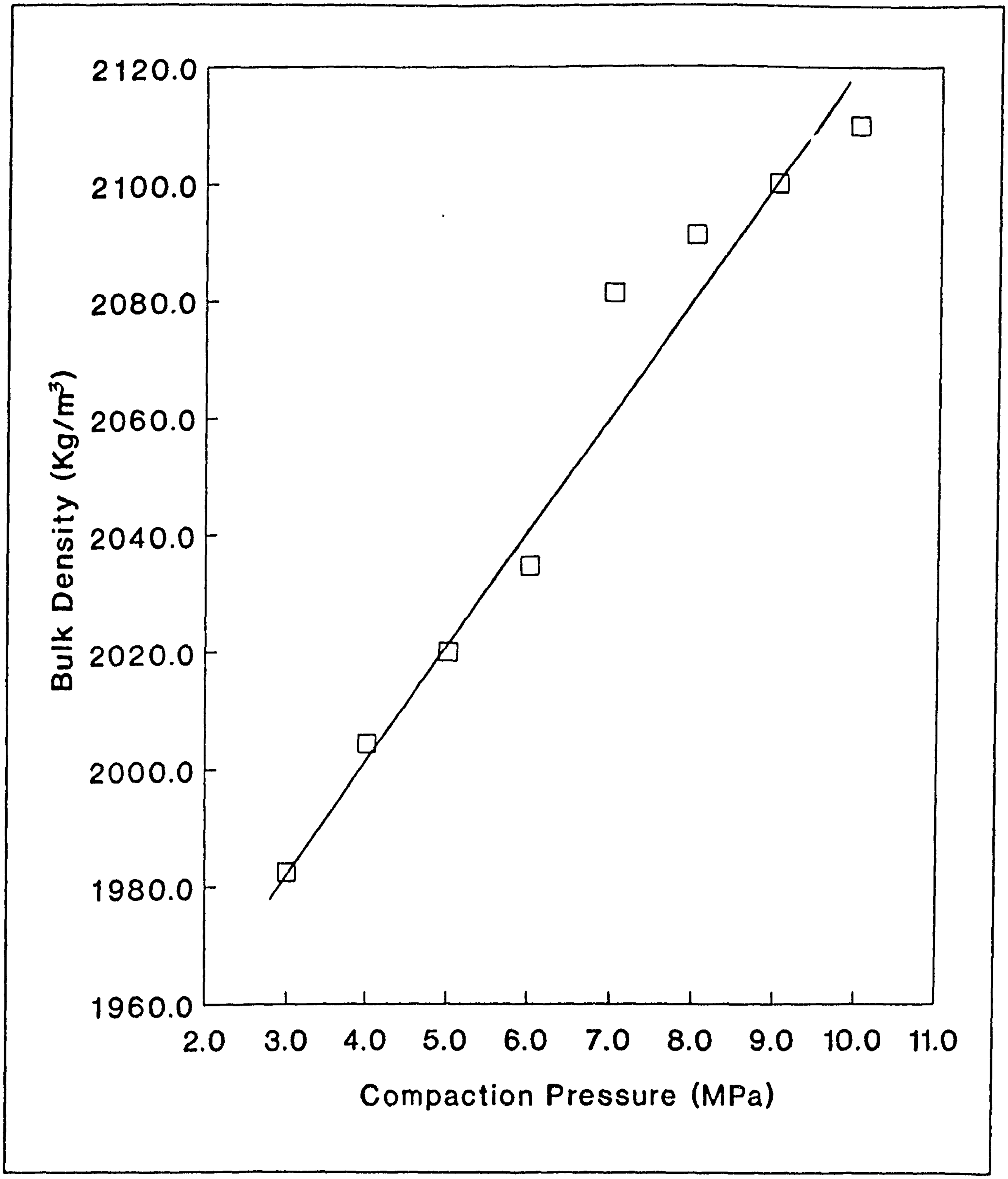

Figure 21 Variation of bulk density of clay-mica composite as a function of compaction pressure for specimens containing 10% mica and sintered at the temperature of 900°*C*

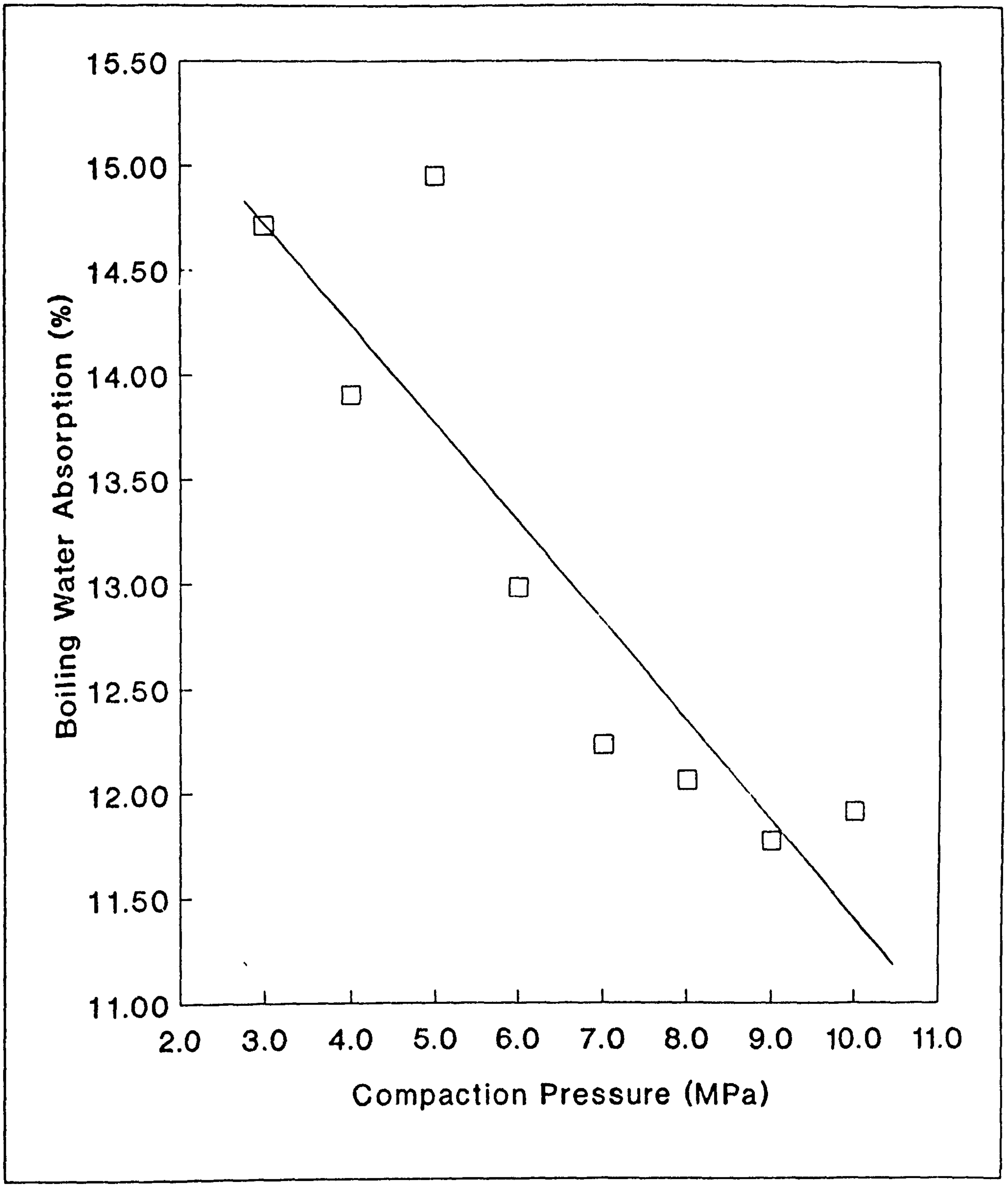

Figure 22 Variation of boiling water absorption of clay-mica composite as a function of compaction pressure for specimens containing 10% mica and sintered at the temperature of 900°*C*

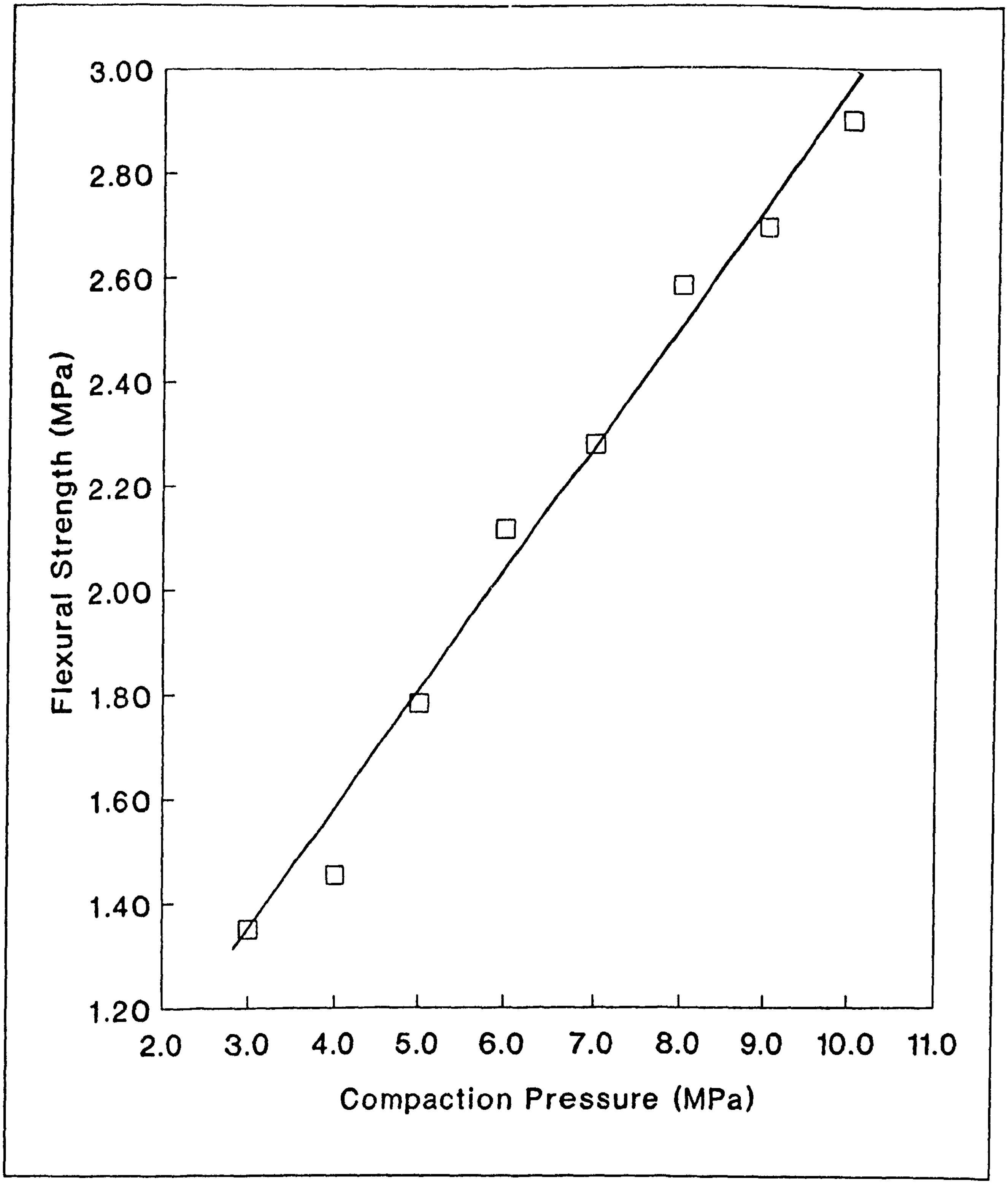

Figure 23 Variation of flexural strength of clay-mica composite as a function of compaction pressure for specimens containing 10% mica and sintered at the temperature of 900°*C*

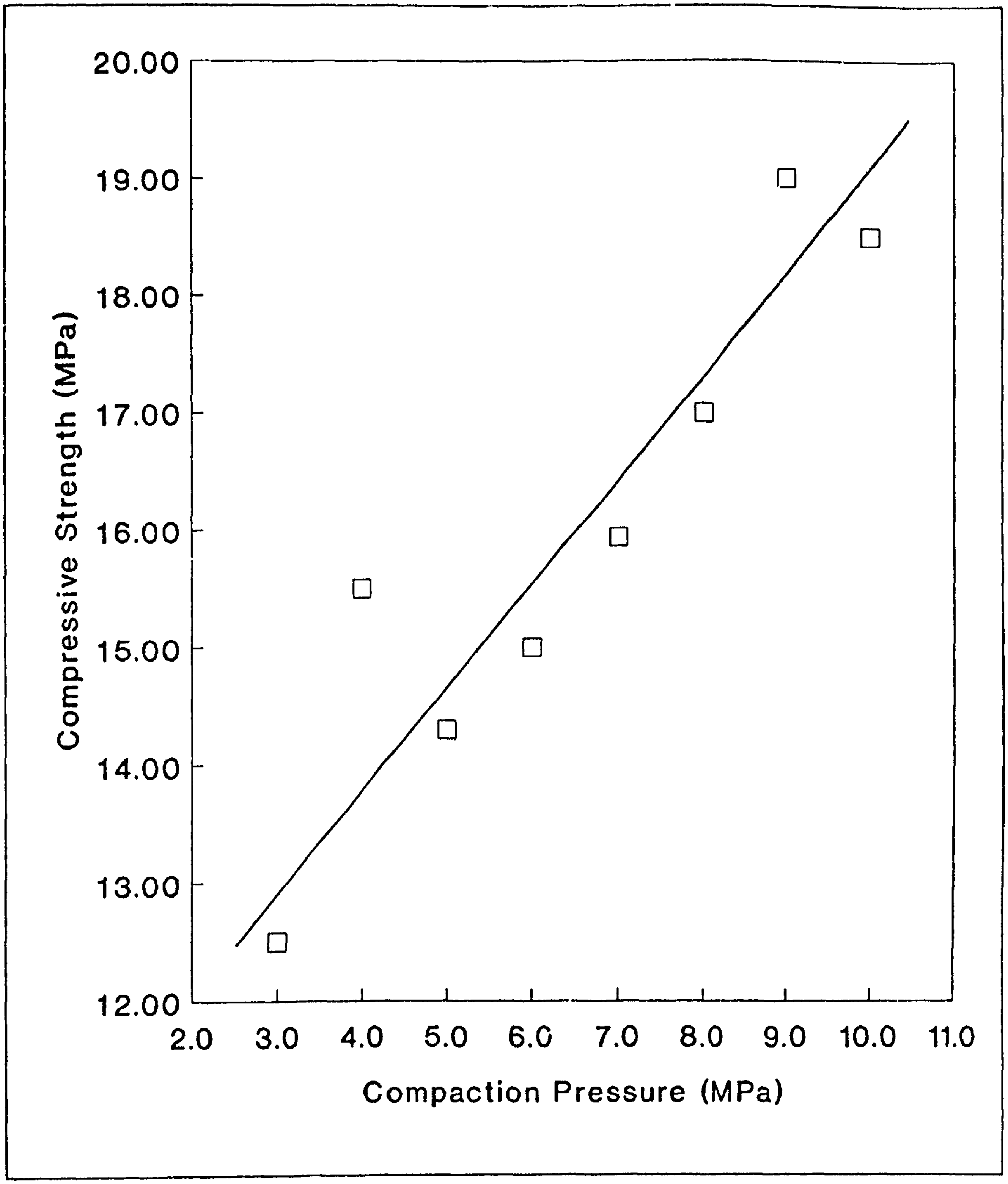

Figure 24 Variation of compressive strength of clay-mica composite as a function of compaction pressure for specimens containing 10% mica and sintered at the temperature of 900°*C*

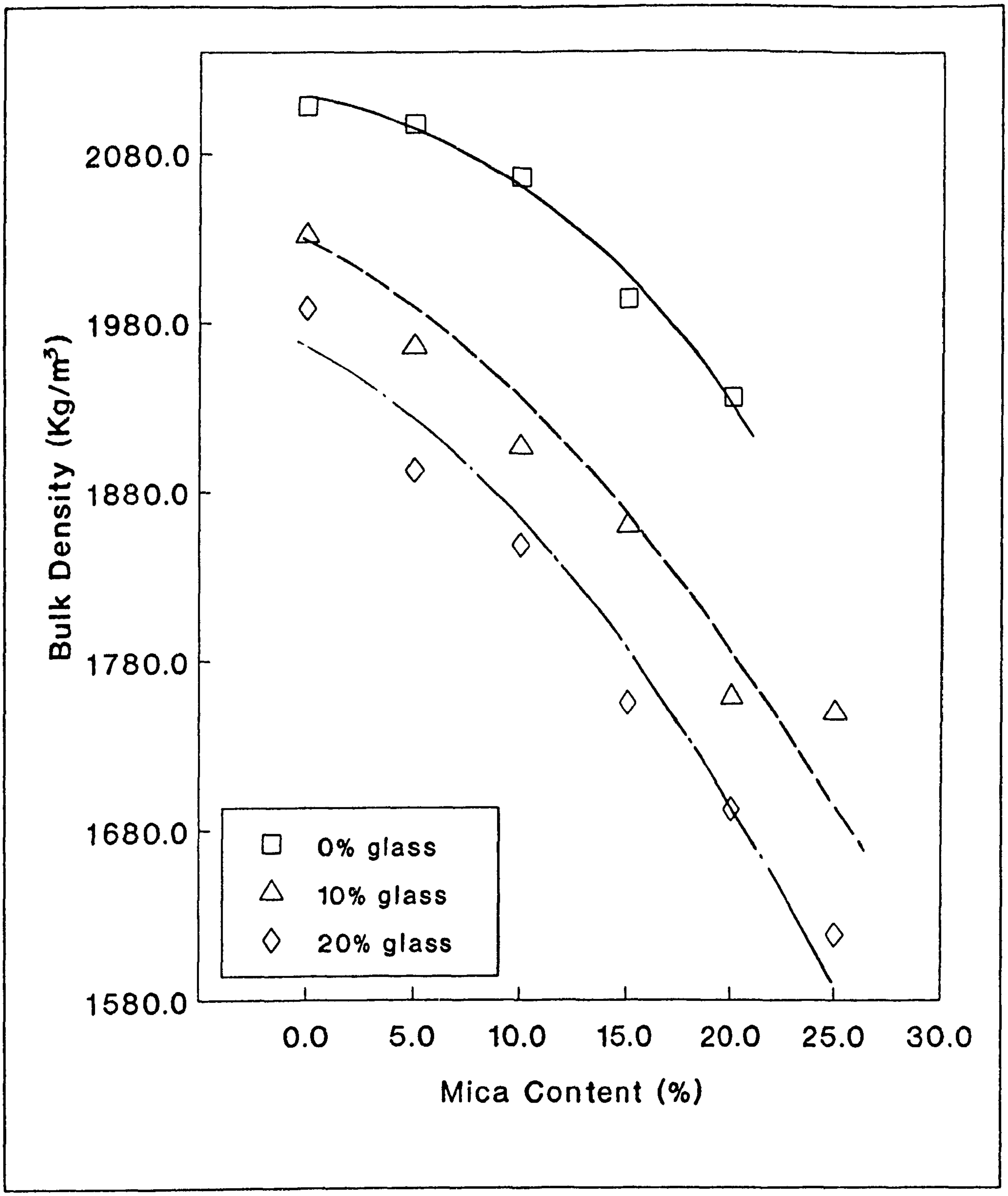

Figure 25 Variation of bulk density of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°C and compaction pressure of 10.0 MPa with specimens containing different glass contents

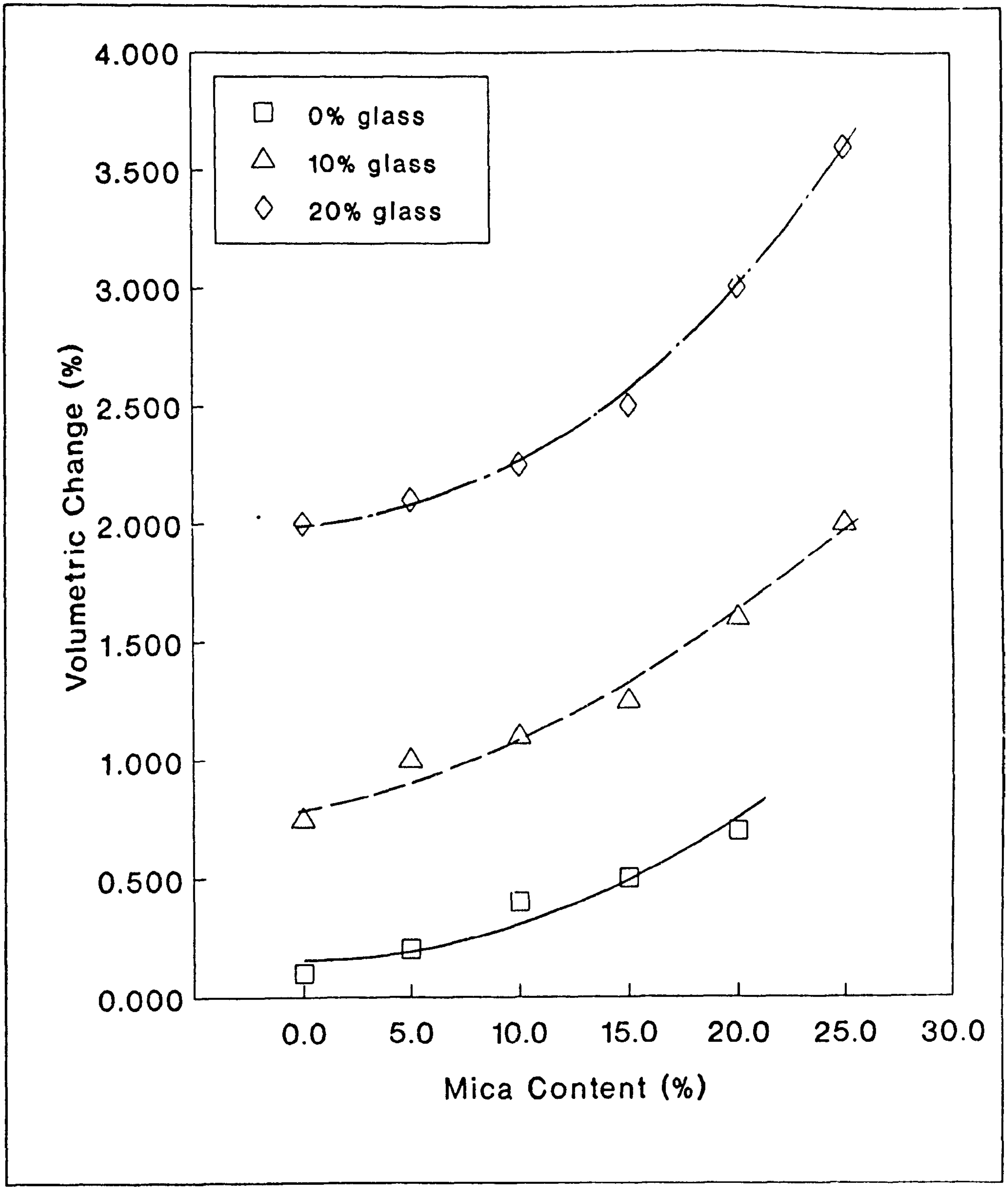

Figure 26 Variation of volumetric change of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents

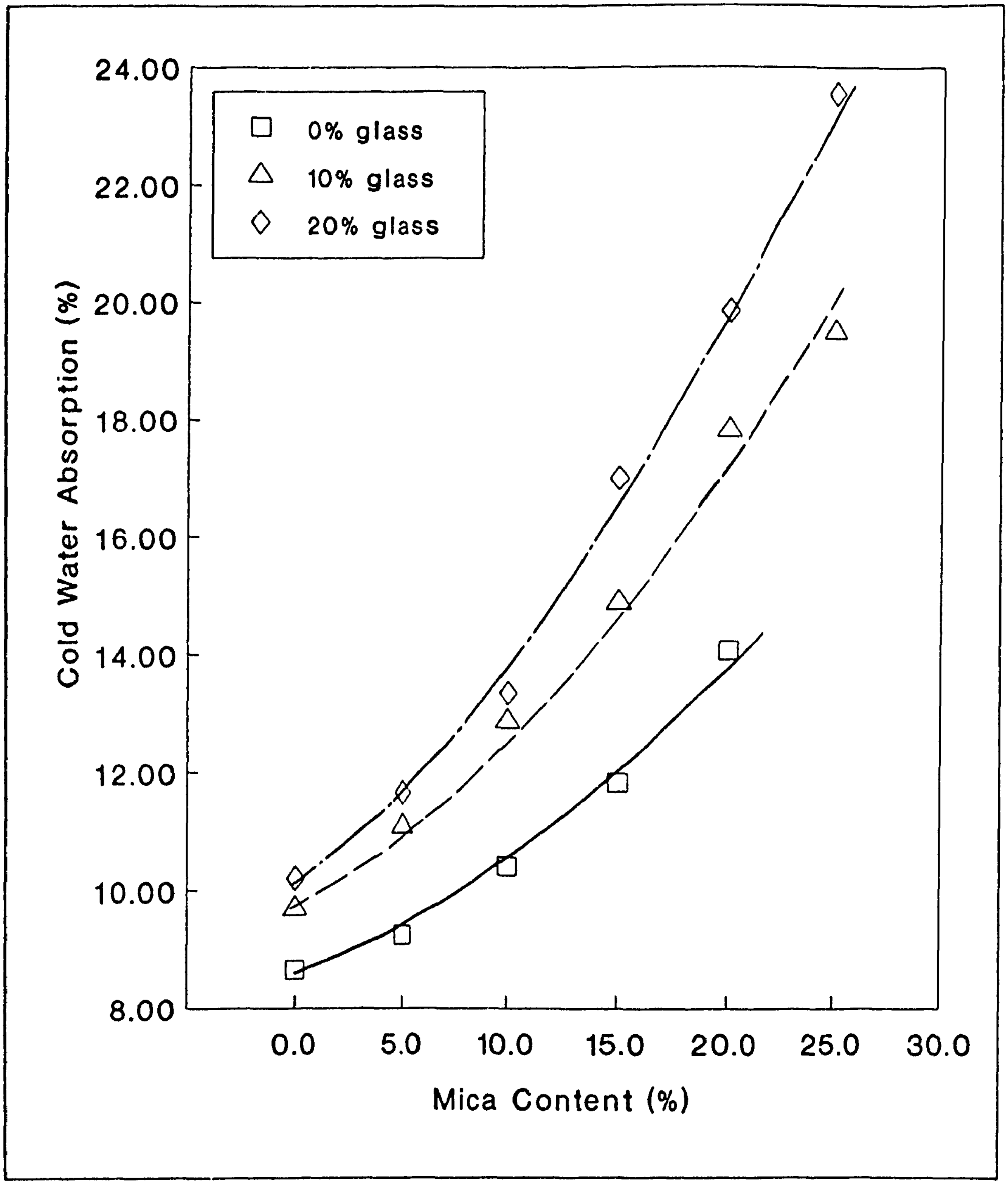

Figure 27 Variation of cold water absorption of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents

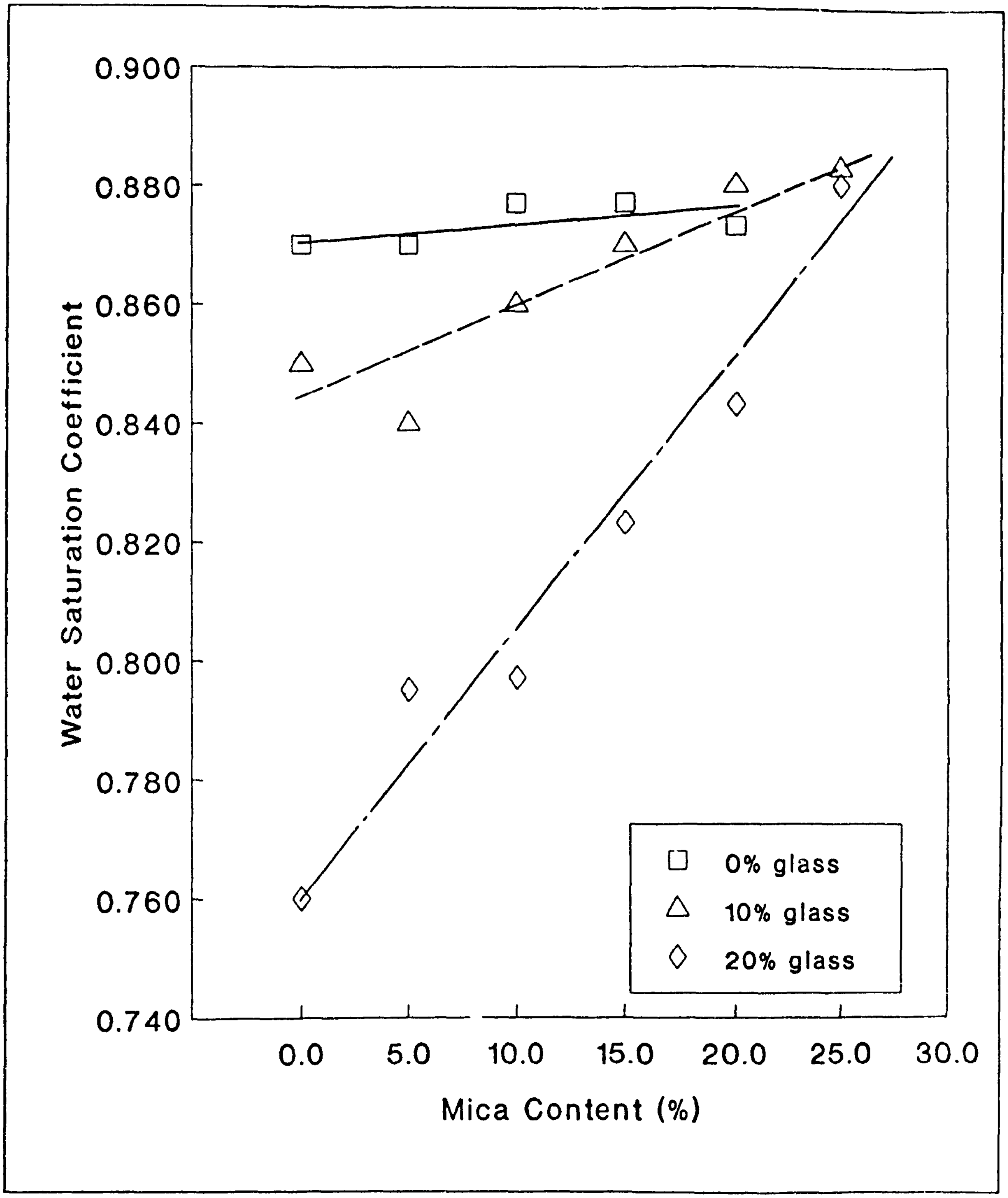

Figure 28 Variation of water saturation coefficient of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents

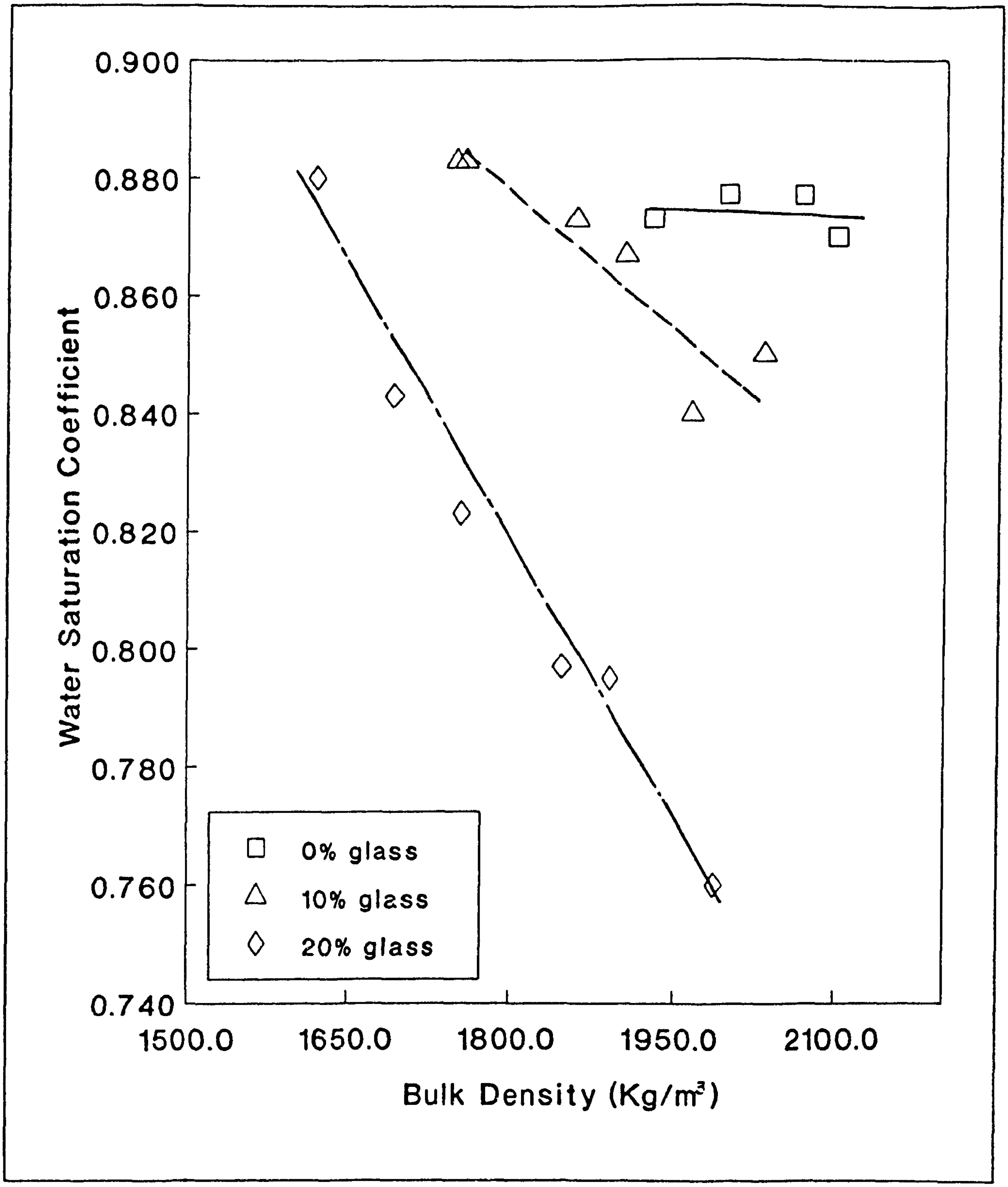

Figure 29 Correlation between water saturation coefficient and bulk density of clay-mica-glass composite for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents

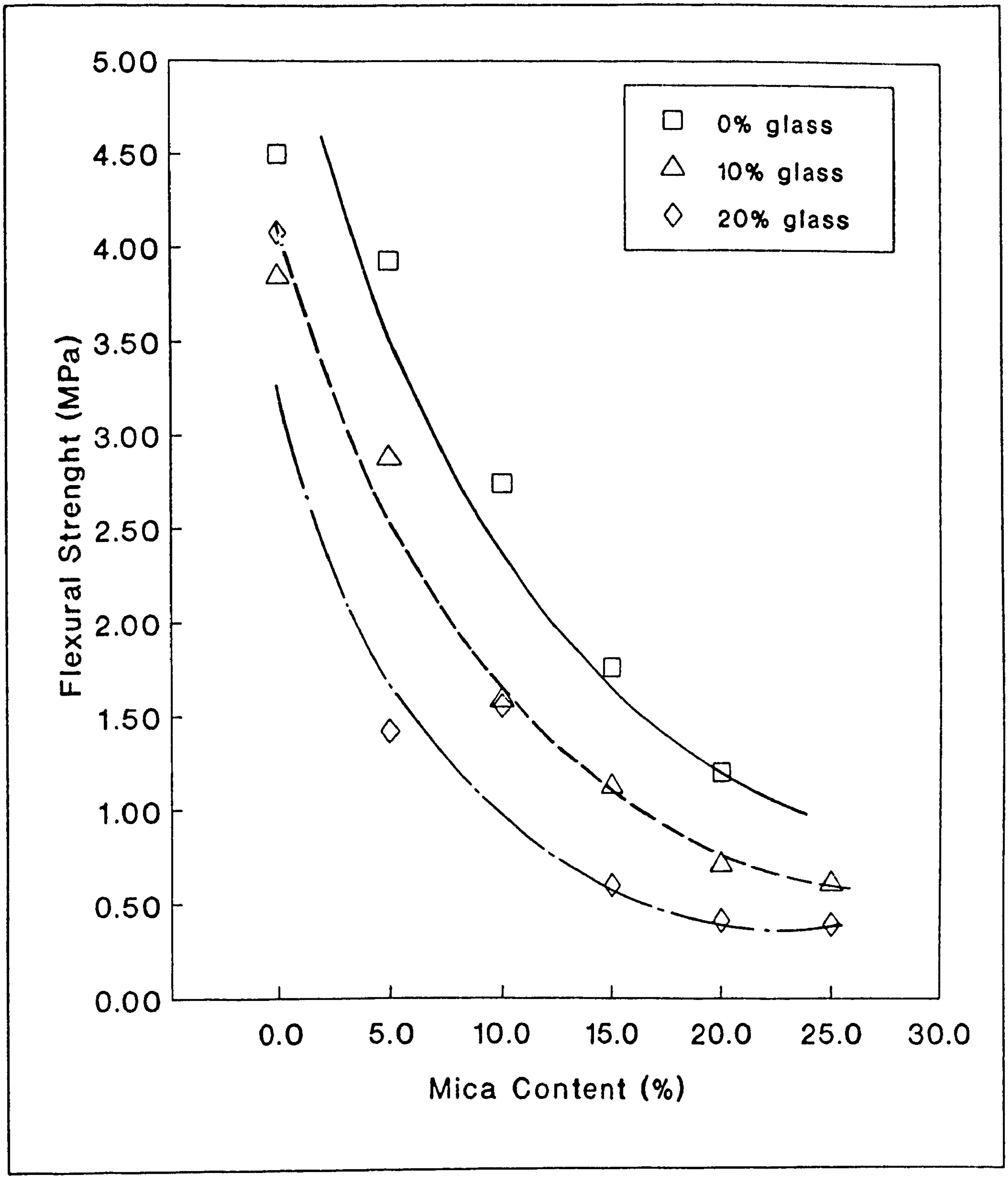

Figure 30 Variation of flexural strength of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10 0 MPa with specimens containing different glass contents

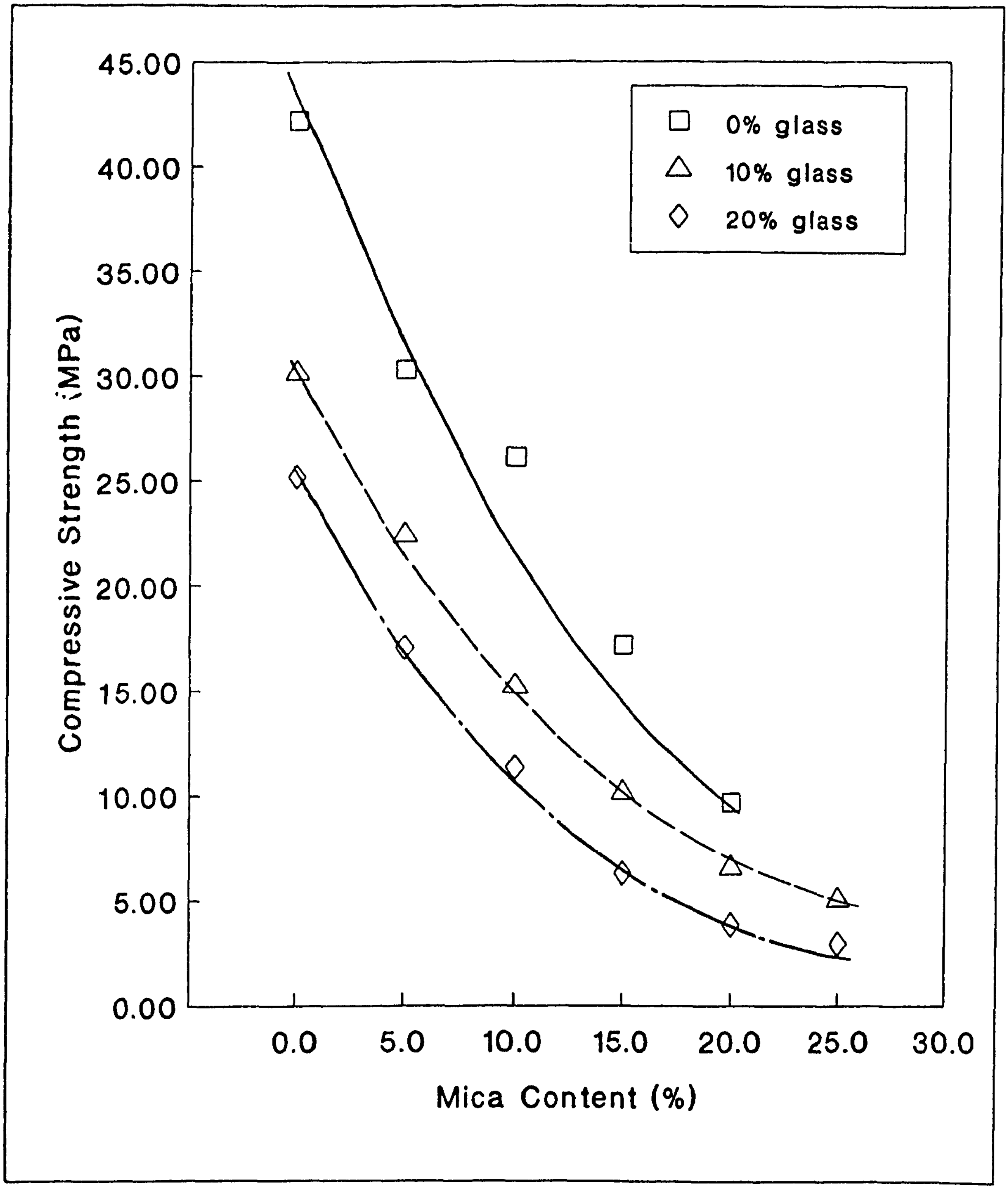

Figure 31 Variation of compressive strength of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents

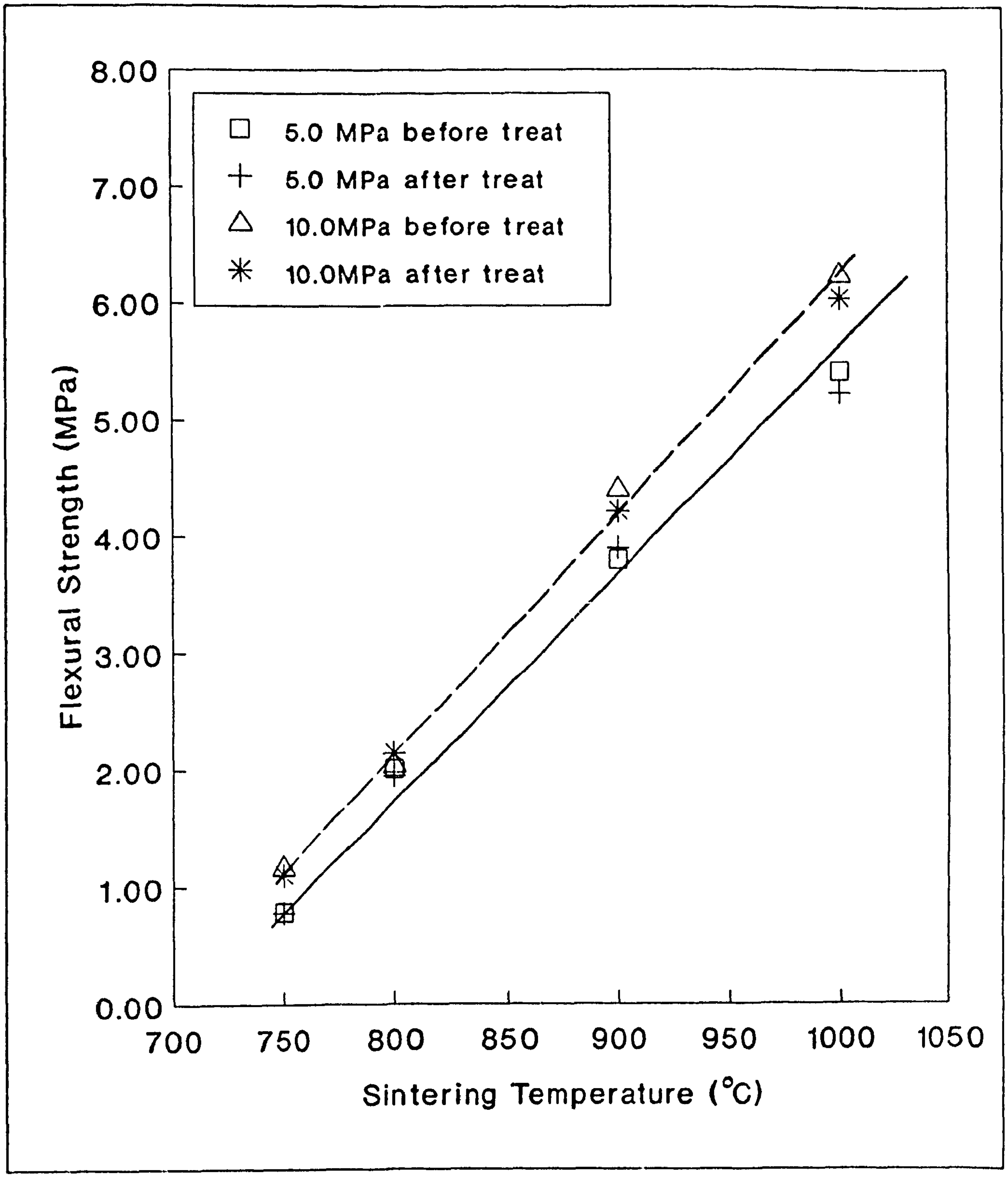

Figure 32 Variation of flexural strength of sintered clay product as a function of sintering temperature for specimens prepared at 5 0 MPa and 10 0 MPa before and after the freezing and thawing treatment

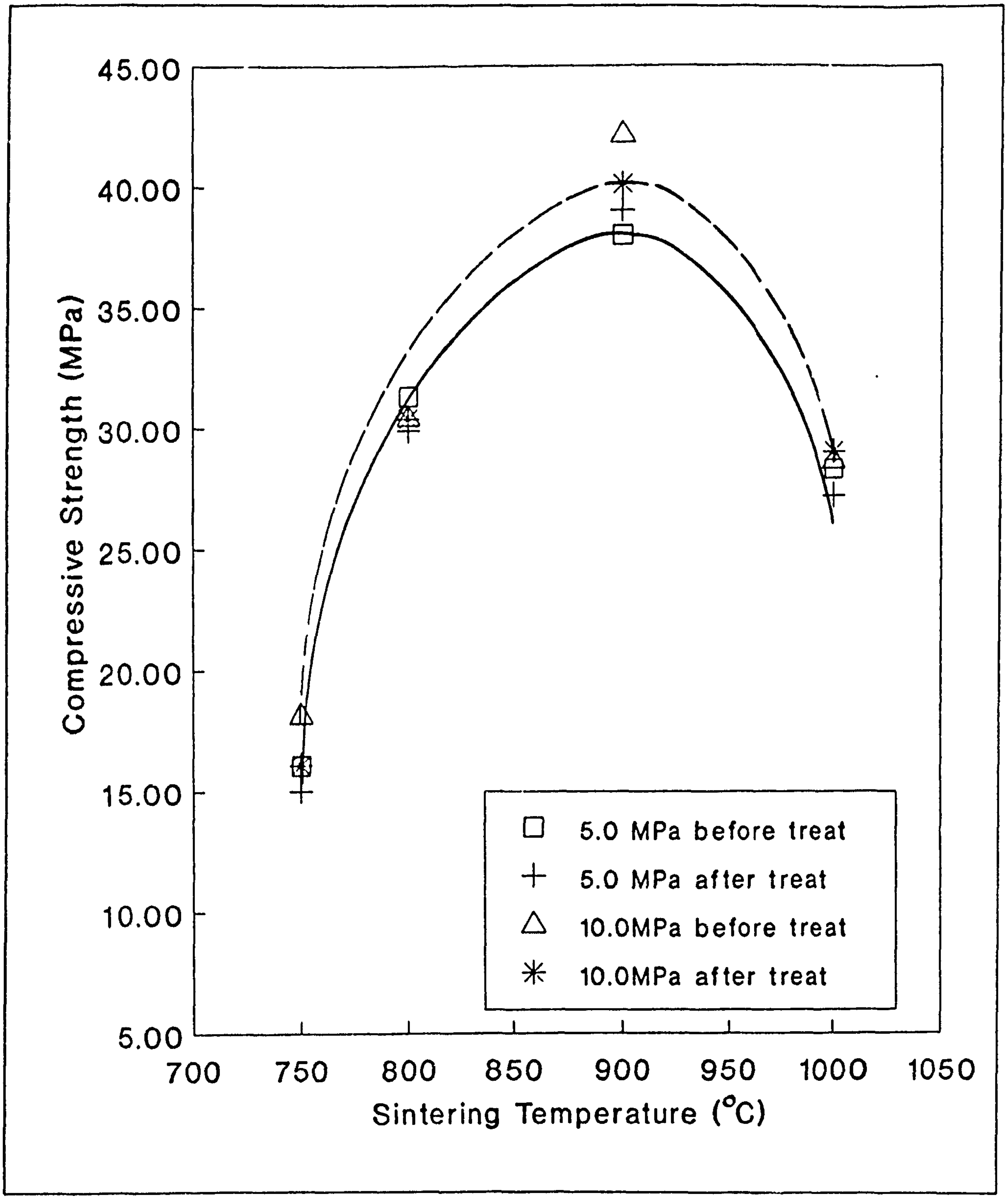

Figure 33 Variation of compressive strength of sintered clay product as a function of sintering temperature for specimens prepared at 5.0 MPa and 10.0 MPa before and after the freezing and thawing treatment

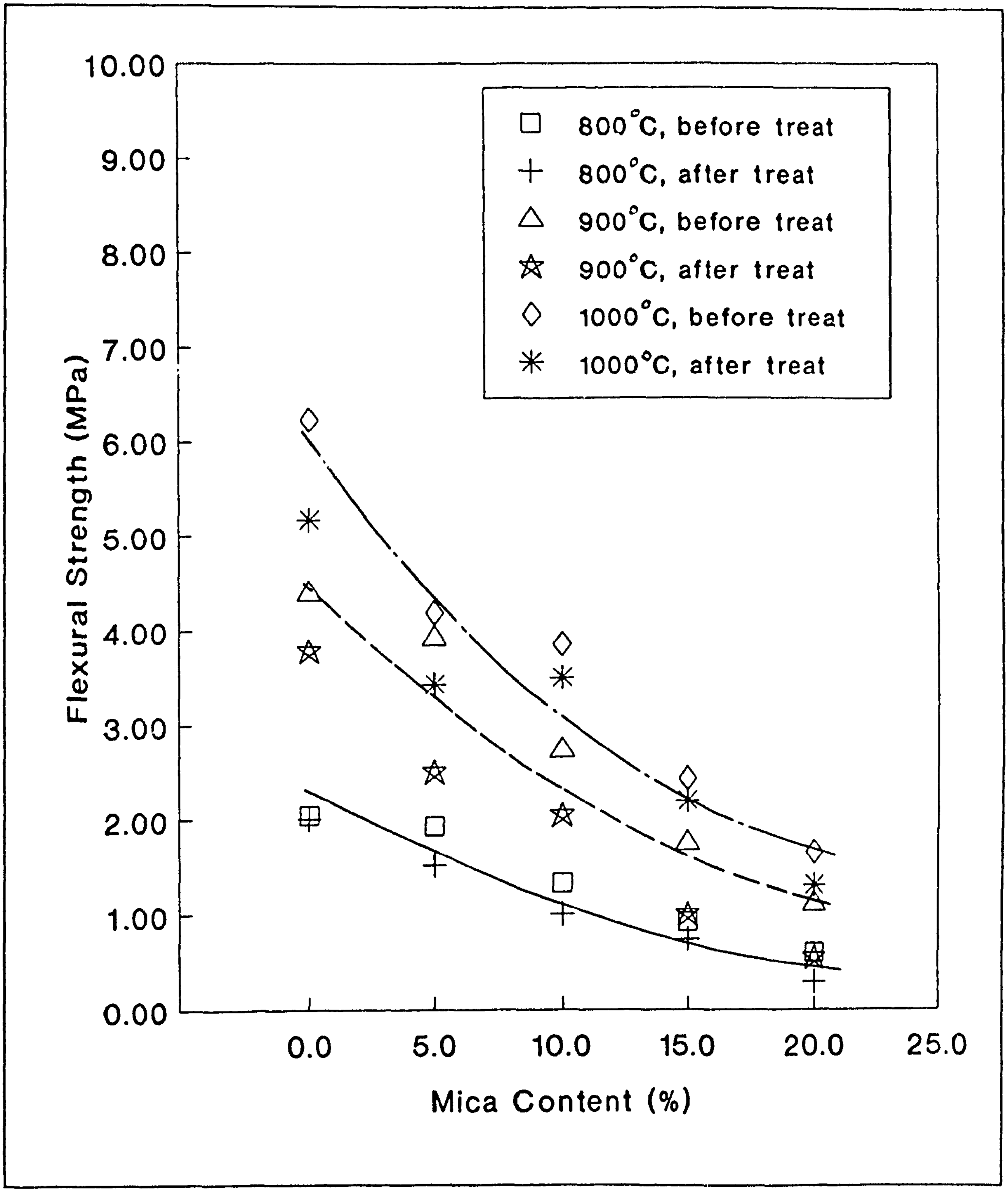

Figure 34 Variation of flexural strength of clay-mica composite as a function of mica content for specimens at the sintering temperature of 800, 900, and 1000°*C* and compaction pressure of 10.0 MPa before and after the freezing and thawing treatment

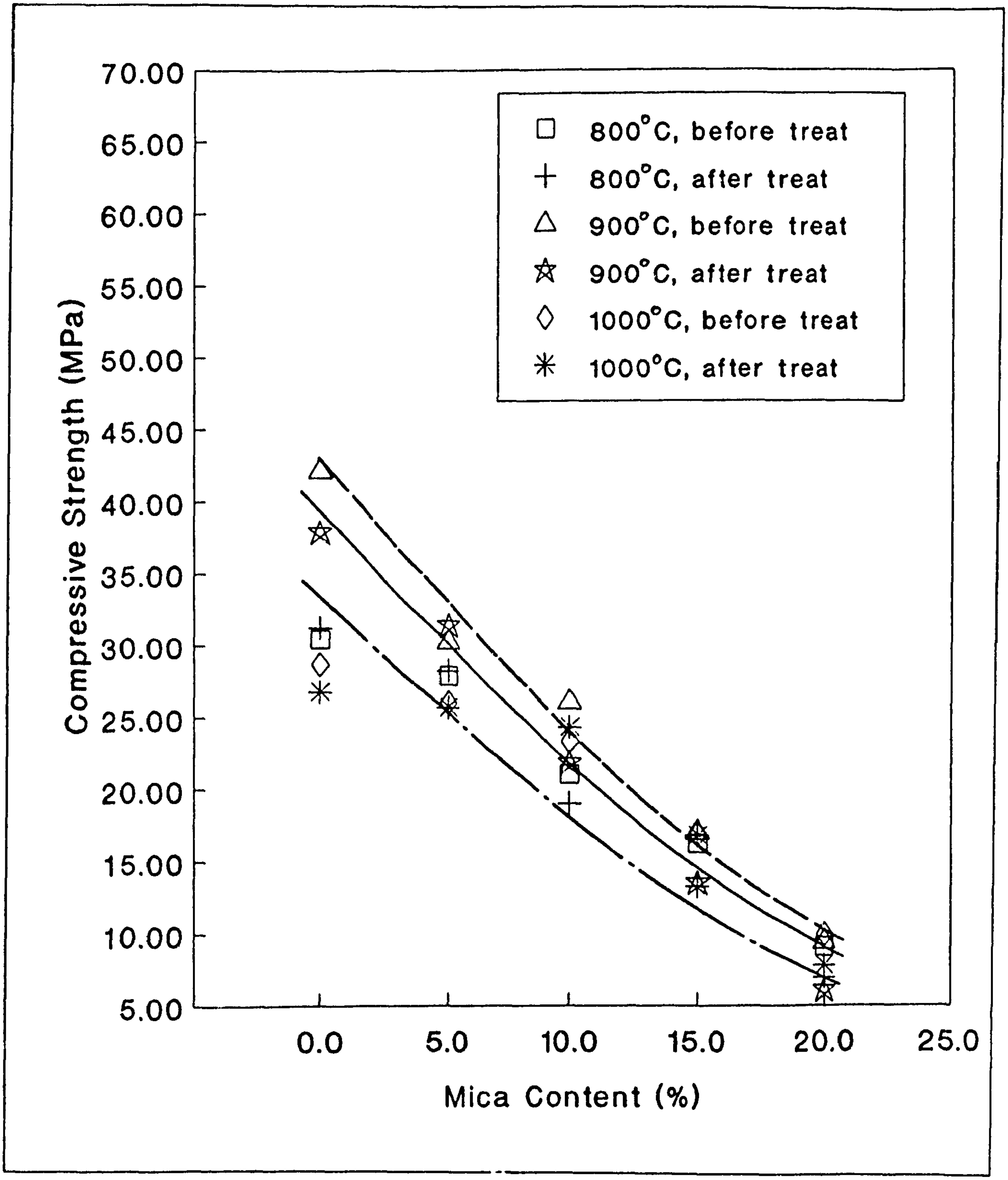

Figure 35 Variation of compressive strength of clay-mica composite as a function of mica content for specimens at the sintering temperature of 800, 900, and 1000°*C* and compaction pressure of 10.0 MPa before and after the freezing and thawing treatment

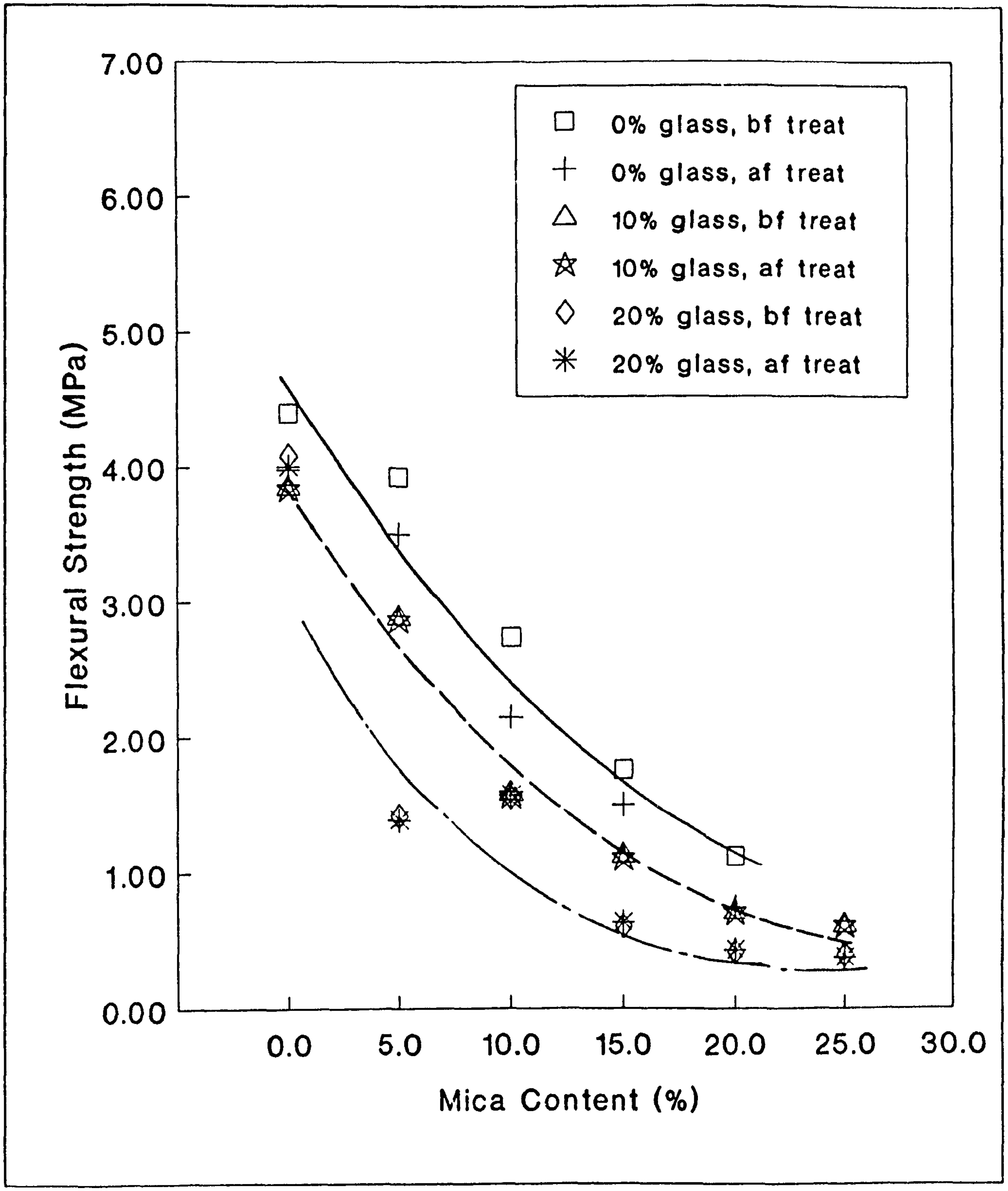

Figure 36 Variation of flexural strength of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°C and compaction pressure of 10.C MPa with specimens containing different glass contents before and after the freezing and thawing treatment

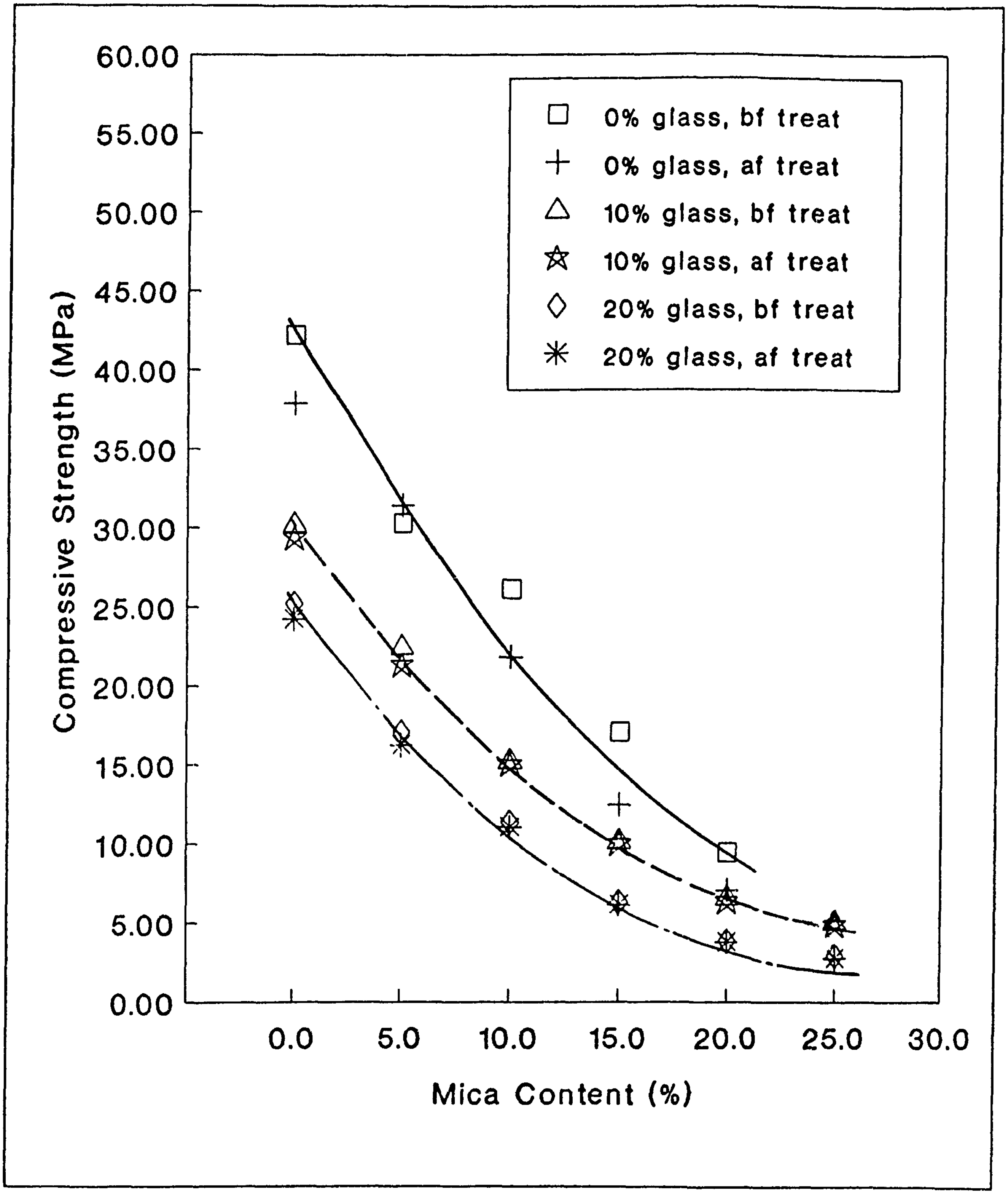

Figure 37 Variation of compressive strength of clay-mica-glass composite as a function of mica content for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different glass contents before and after the freezing and thawing treatment

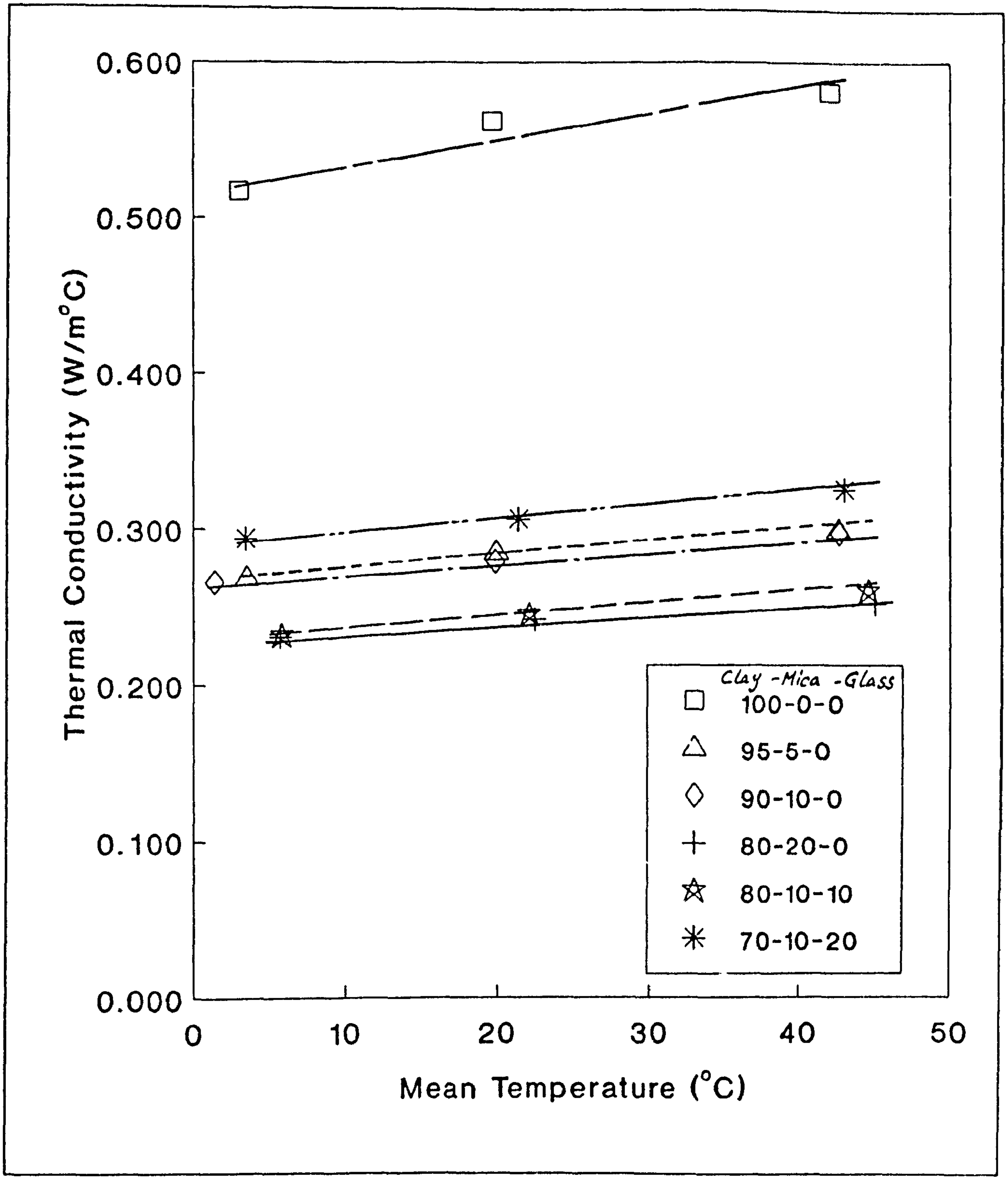

Figure 38 Variation of thermal conductivity of clay, clay-mica and clay-mica-glass composite as a function of mean temperature for specimens prepared at a sintering temperature of 900°*C* and compaction pressure of 10.0 MPa with specimens containing different mica contents and different glass contents

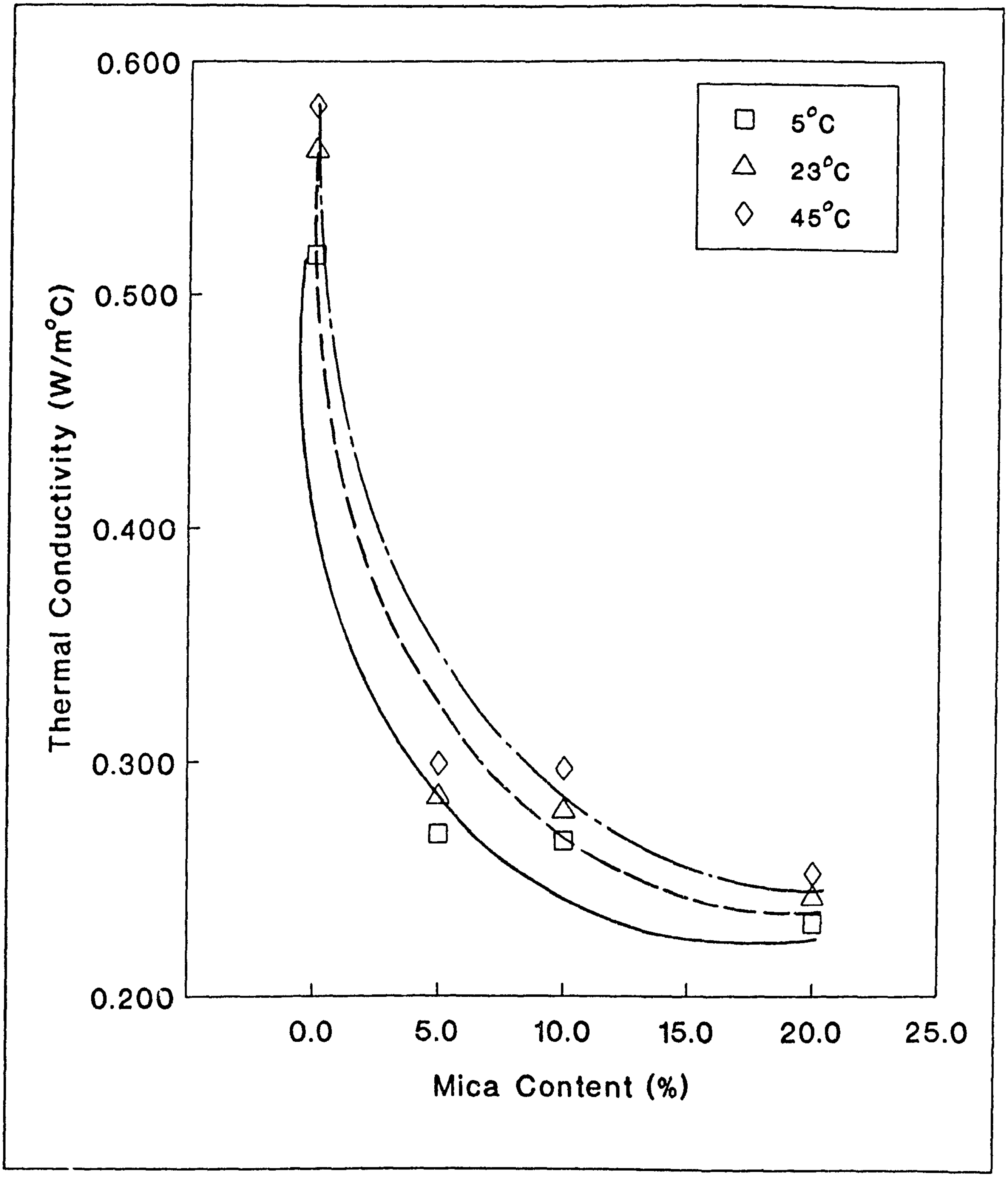

Figure 39 Variation of thermal conductivity of clay-mica composite as a function of mica content for specimens prepared at a sintering temperature or 900°*C* and compaction pressure of 10.0 MPa with specimens at different temperature levels

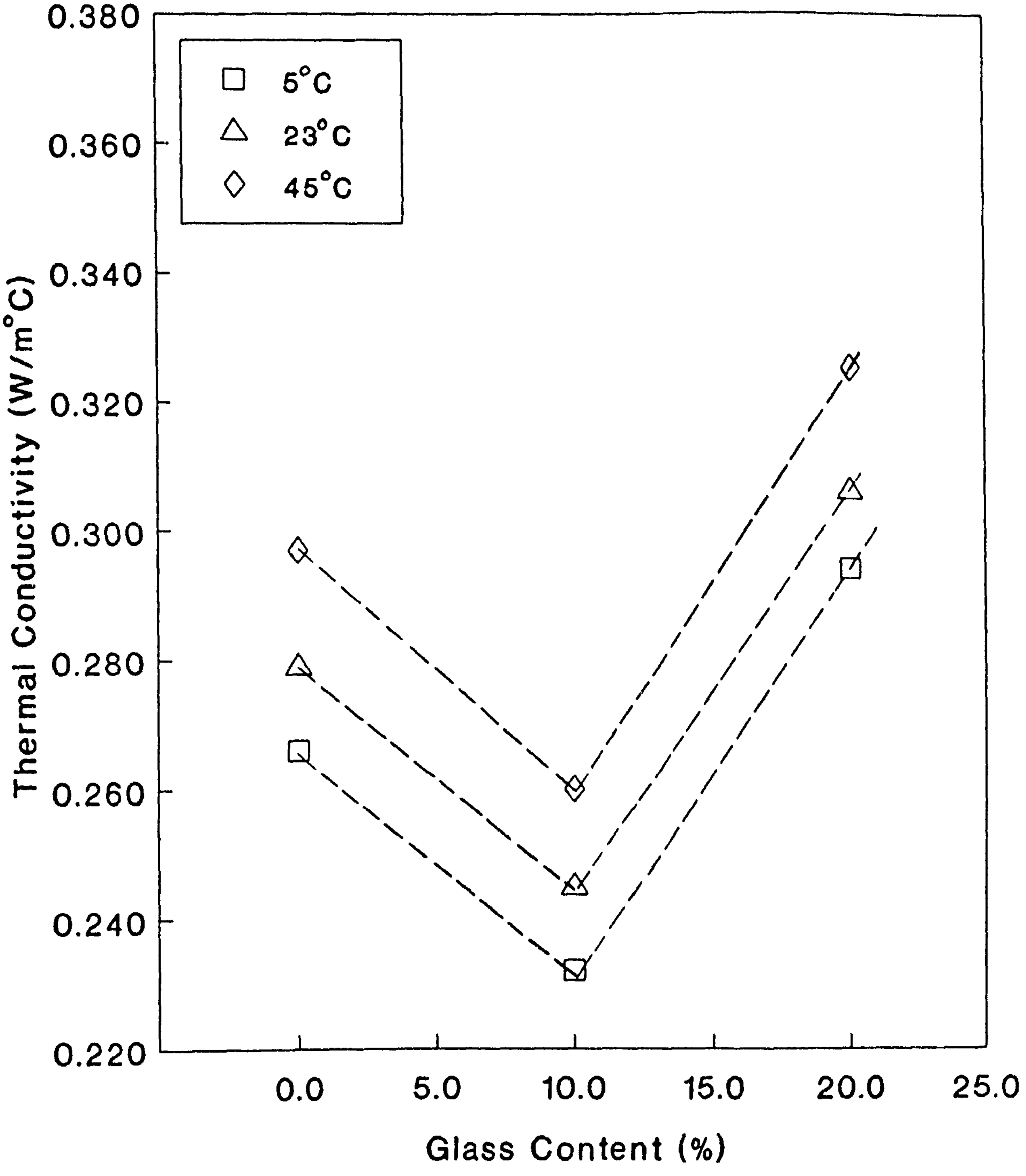

Figure 40 Variation of thermal conductivity of clay-mica-glass composite as a function of glass content for specimens prepared at a sintering temperature of 900°C and compaction pressure of 10.0 MPa with specimens at different temperature levels (Lines shows only trends.)

TABLES

Table 1. Variation of physical properties of sintered clay product as a function of sintering temperature for specimens prepared at $5.0 MPa$ pressure and sintering time period of *4hours*

Sintering Temp. (°C)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
750	2183.8 2120.5 1801.2	2035.2	8.2	0.137 0.172 0.141	0.150	10.4	10.79 10.67 10.79	10.75	0.5	12.13 11.94 12.09	12.05	0.7	0.890 0.880 0.870	0.880	0.9
800	2087.9 2083.6 2090.7	2087.4	0.1	0.163 0.131 0.126	0.140	11.7	10.17 10.30 9.62	10.03	2.9	11.46 11.79 11.02	11.42	2.7	0.890 0.890 0.890	0.890	0.0
900	2042.6 2068.5 2188.9	2100.0	3.0	0.108 0.134 0.124	0.122	8.8	9.86 9.83 9.74	9.81	0.5	11.33 11.27 11.16	11.25	0.6	0.870 0.870 0.870	0.870	0.0
1000	2042.6 2085.4 2051.8	2060.0	0.9	0.077 0.103 0.090	0.090	11.8	7.63 8.25 8.47	8.12	4.4	9.59 9.96 10.14	9.90	2.3	0.850 0.850 0.850	0.850	0.0

Table 2. Variations of mechanical properties of sintered clay product as a function of sintering temperature for specimens prepared at compaction pressure of $5.0MPa$ and sintering time period of $1hours$

Sintering Temperature (°C)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
750	0.86 0.82 0.67	0.78	10.2	15.13 16.19 15.91 16.56 15.82 16.21	16.03	2.2
800	2.15 2.10 1.76	2.00	8.6	30.12 29.26 32.26 32.00 31.81 32.35	31.30	3.8
900	3.62 3.78 3.99	3.79	4.0	35.87 38.43 33.11 35.02 41.73 43.63	37.97	9.8
1000	6.00 5.73 4.50	5.41	12.0	29.02 27.52 27.86 28.68 27.83 28.73	28.28	2.0

Table 3. Variation of physical properties of sintered clay product as a function of sintering temperature for specimens prepared at $10.0 MPa$ pressure and sintering time period of $4 hours$

Sintering Temp. (°C)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
750	2154.0 2112.5 2133.3	2133.3	0.8	0.108 0.139 0.143	0.130	12.0	9.51 9.49 9.49	9.50	0.1	10.70 10.67 10.64	10.67	0.2	0.900 0.890 0.895	0.895	0.5
800	2215.5 2176.1 2185.0	2192.2	0.8	0.149 0.120 0.155	0.128	10.8	9.16 9.18 9.19	9.18	0.1	10.22 10.37 10.30	10.30	0.6	0.890 0.890 0.890	0.890	0.0
900	2220.8 2194.2 2209.4	2208.1	0.5	0.112 0.093 0.095	0.100	8.5	8.66 8.71 8.59	8.65	0.6	9.90 9.96 9.86	9.91	0.4	0.870 8.870 0.880	0.873	0.5
1000	2158.5 2155.3 2154.5	2156.1	0.1	0.076 0.091 0.082	0.083	7.4	7.76 7.50 7.53	7.60	1.5	9.21 9.08 9.15	9.15	0.6	0.860 0.860 0.860	0.860	0.0

Table 4. Variations of mechanical properties of sintered clay product as a function of sintering temperature for specimens prepared at compaction pressure of 10.0 *MPa* and sintering time period of 1*hours*

Sintering Temperature (°C)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
750	1.27 1.17 1.07	1.17	7.0	18.01 16.63 17.37 19.89 18.91 17.91	18.13	5.8
800	1.92 1.88 2.33	2.01	10.0	29.78 31.08 26.36 31.97 25.00 35.73	30.13	13.0
900	4.47 3.86 4.87	4.40	9.3	47.91 41.17 49.31 37.89 37.13 39.55	42.17	11.3
1000	6.11 5.71 6.58	6.23	6.0	27.43 25.61 31.25 29.49 28.07 30.17	28.67	6.5

Table 5. Variation of physical properties of sintered clay product as a function of water content for specimens prepared at a sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 5.0*MPa*

Water Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
3.0	2080.2 2082.2 2084.2	2082.2	0.1	0.107 0.091 0.102	0.100	6.7	8.00 8.50 8.55	8.35	3.0	11.33 11.27 11.16	11.25	0.2	0.780 0.770 0.770	0.773	0.6
4.0	2042.6 2068.5 2188.9	2100.0	3.0	0.108 0.134 0.124	0.122	8.8	8.00 8.20 8.40	8.2	2.0	10.52 10.54 10.56	10.54	0.2	0.870 0.870 0.870	0.870	0.00
5.0	2120.8 2090.8 2130.0	2113.8	0.8	0.157 0.133 0.133	0.141	8.0	8.09 8.15 8.15	8.13	0.3	9.70 9.90 9.65	9.75	1.1	0.865 0.850 0.865	0.860	0.8

Table 6. Variations of mechanical properties of sintered clay product as a function of water content for specimens prepared at a sintering temperature of 900°C for a sintering time period of 1*hours* and compaction pressure of 5.0 *MPa*

Water Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
3.0	2.78 2.79 2.80	2.79	0.3	22.78 23.72 24.16 22.85 23.86 22.86	23.37	2.4
4.0	3.62 3.78 3.99	3.79	4.0	28.72 35.58 33.73 34.43 43.17 42.19	37.97	9.7
5.0	5.86 5.90 5.86	5.87	0.3	34.81 32.83 34.57 33.43 35.01 32.93	33.93	2.6

Table 7. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800°C for a sintering time period of *4hours* and compaction pressure of *5.0MPa*

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2087.9 2083.6 2090.7	2083.4	0.1	0.131 0.136 0.153	0.140	6.7	10.79 10.67 10.79	10.75	0.5	12.13 11.94 12.09	12.05	0.7	0.890 0.890 0.890	0.890	0.0
5	2081.3 2075.7 2074.6	2077.2	0.1	0.365 0.401 0.392	0.386	4.0	10.76 10.83 10.80	10.80	0.3	12.38 12.17 13.25	12.60	3.7	0.885 0.895 0.890	0.890	0.5
10	2039.0 1978.2 2091.4	2036.2	2.3	0.702 0.733 0.704	0.713	2.0	12.45 12.02 11.91	12.13	1.9	13.89 14.31 13.92	14.01	1.6	0.880 0.890 0.900	0.890	0.9
15	1966.2 1967.6 1940.2	1958.0	0.6	0.963 1.000 0.998	0.987	1.7	13.92 13.41 14.67	14.00	3.7	16.15 16.37 15.48	16.00	2.4	0.890 0.890 0.890	0.890	0.0
20	1810.7 1864.8 1827.4	1834.3	1.2	1.097 1.123 1.143	1.121	1.7	17.48 17.82 16.39	17.23	3.5	19.18 19.57 18.25	19.00	2.9	0.880 0.890 0.900	0.890	0.9

Table 8. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800°C for a sintering time period of *4hours* and compaction pressure of 5.0 *MPa*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	2.15 2.10 1.76	2.00	8.6	30.11 28.97 33.56 30.70 31.02 33.11	31.31	5.1
5	1.71 1.58 1.58	1.62	3.8	26.27 27.89 30.72 28.21 26.91 29.13	28.2	5.2
10	1.11 0.99 1.17	1.09	6.8	15.06 14.28 17.31 16.00 20.12 19.16	17.00	12.4
15	0.80 0.72 0.73	0 75	4.7	9.17 8.31 7.26 6.89 8.22 8.12	8.00	9.3
20	0.32 0.25 0.32	0.30	11.1	3.72 4.28 4.62 3.38 3.75 4.23	4.00	10.1

Table 9. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 5.0 *MPa*

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2042.6	2100.0	3.0	0.113	0.122	7.3	9.86	9.81	0.5	11.33	11.25	0.6	0.870	0.870	0.0
	2068.5			0.119			9.83			11.27			0.870		
	2188.9			0.134			9.74			11.16			0.870		
5	2085.3	2090.2	0.2	0.361	0.375	3.9	9.70	9.80	0.8	12.53	12.26	2.4	0.865	0.875	1.2
	2093.6			0.369			9.80			12.39			0.870		
	2093.3			0.395			9.90			11.85			0.890		
10	2084.4	2043.5	1.4	0.703	0.681	2.8	11.98	11.98	0.1	13.83	13.83	0.1	0.870	0.870	1.0
	2022.7			0.683			11.96			13.85			0.880		
	2022.7			0.657			12.00			13.82			0.860		
15	1968.9	1968.0	0.1	0.852	0.980	12.8	13.74	13.74	0.6	15.62	15.65	1.0	0.870	0.870	0.0
	1968.0			0.937			13.64			15.49			0.870		
	1967.1			1.151			13.84			15.85			0.870		
20	1843.8	1846.3	0.9	1.181	1.093	5.7	16.98	16.65	1.4	18.82	18.82	0.5	0.880	0.876	0.5
	1867.0			1.057			16.49			18.70			0.880		
	1828.2			1.041			16.49			18.94			0.870		

Table 10. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time of 1*hours* and compaction pressure of 5.0 *MPa*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	3.62 3.78 3.99	3.79	4.1	36.82 37.48 34.26 33.90 43.00 42.36	37.97	9.1
5	2.67 2.72 2.56	2.52	7.4	30.95 32.23 31.16 32.02 33.11 31.07	31.59	1.7
10	2.06 2.12 2.05	2.08	1.5	19.31 18.11 17.87 18.87 19.93 18.87	18.89	3.1
15	1.03 1.07 0.91	1.01	5.4	7.31 9.12 9.89 8.21 9.13 7.89	8.61	10.1
20	0.56 0.56 0.62	0.58	4.9	4.56 3.61 3.75 4.73 5.12 4.10	4.31	12.0

Table 11. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 1000°C for a sintering time period of *4hours* and compaction pressure of 5.0 MPa

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2058.5 2055.3 2054.5	2056.1	0.1	0.071 0.094 0.105	0.09	4.2	7.63 8.25 8.47	8.12	4.4	9.59 9.96 10.14	9.90	2.3	0.850 0.850 0.850	0.850	0.0
5	2062.7 2042.7 2025.2	2043.5	0.7	0.338 0.382 0.363	0.361	5.0	9.42 9.92 9.94	9.76	2.5	11.59 11.48 11.99	11.69	1.9	0.850 0.860 0.870	0.860	0.9
10	1995.1 1990.3 1984.7	1990.0	0.2	0.558 0.621 0.612	0.597	4.5	11.66 11.29 11.55	11.50	1.3	10.28 13.02 14.20	12.50	10.0	0.860 0.865 0.870	0.865	0.5
15	1908.9 1910.6 1907.3	1908.9	0.1	0.927 0.971 1.021	0.973	3.9	13.15 13.66 13.39	13.40	1.6	16.00 14.97 14.03	15.00	5.4	0.850 0.870 0.870	0.863	1.1
20	1797.3 1785.7 1791.1	1791.4	0.3	0.962 1.151 1.136	1.083	7.9	16.16 16.36 16.08	16.20	0.7	17.71 19.25 17.07	18.01	5.1	0.860 0.870 0.870	0.867	0.5

Table 12. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 1000°C for a sintering time of 1*hours* and compaction pressure of 5.0 *MPa*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	6.00 5.23 4.99	5.41	8.0	31.27 29.45 24.52 27.89 30.76 25.79	28.28	8.8
5	3.67 3.56 3.61	3.61	1.2	24.28 25.31 26.21 27.45 27.33 28.36	26.49	5.2
10	2.04 2.36 2.20	2.20	5.9	12.65 13.41 14.07 15.31 16.22 16.33	14.67	9.5
15	0.95 1.05 1.05	1.02	4.5	7.31 6.87 7.52 7.96 8.36 7.85	7.65	6.2
20	0.66 0.72 0.75	0.71	5.2	3.21 3.63 3.91 3.38 3.72 3.96	3.61	7.5

Table 13. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800°C for a sintering time period of *4hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2015.5	2092.2	3.4	0.123	0.128	6.0	9.51	9.50	0.1	10.70	10.67	0.2	0.892	0.892	0.0
	2076.1			0.139			9.50			10.67			0.892		
	2185.0			0.122			9.49			10.64			0.892		
5	2085.3	2090.7	0.2	0.201	0.193	3.6	10.40	10.34	0.6	11.55	11.52	0.5	0.890	0.892	0.2
	2093.6			0.194			10.25			11.44			0.892		
	2093.3			0.184			10.36			11.58			0.894		
10	2097.6	2056.3	1.4	0.489	0.507	3.1	11.59	11.54	0.7	12.89	12.94	0.3	0.889	0.892	0.3
	2036.5			0.505			11.43			12.95			0.895		
	2034.8			0.527			11.61			12.98			0.892		
15	1985.2	1982.6	0.1	0.798	0.794	2.1	12.64	13.09	2.5	14.90	14.90	1.0	0.890	0.892	0.3
	1981.8			0.772			13.37			15.09			0.890		
	1980.8			0.812			13.26			14.71			0.896		
20	1928.7	1931.9	0.2	0.892	0.903	1.0	14.79	15.20	2.0	15.62	15.72	1.4	0.890	0.892	0.2
	1930.3			0.914			15.28			15.53			0.893		
	1936.7			0.903			15.52			16.02			0.893		

Table 14. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800°C for a sintering time period of 1 *hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	1.92 1.88 2.33	2.013	10.0	31.27 29.59 35.17 31.53 28.96 26.00	30.13	9.2
5	1.92 1.80 2.06	1.93	5.5	30.59 28.67 23.71 21.33 30.13 29.70	27.86	9.9
10	1.16 1.28 1.26	1.33	6.7	23.97 22.41 18.67 18.32 19.65 23.10	21.02	10.6
15	0.87 1.02 0.89	0.92	7.2	16.26 11.08 17.16 17.30 16.17 16.43	16.23	6.5
20	0.67 0.59 0.53	0.60	9.6	9.14 9.01 9.37 9.21 9.36 8.10	9.08	3.6

Table 15. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2120.8	2108.1	0.5	0.112	0.100	3.6	8.66	8.65	0.6	9.90	9.91	0.4	0.870	0.870	0.0
	2094.2			0.103			8.71			9.96			0.870		
	2109.4			0.085			8.59			9.86			0.870		
5	2103.4	2097.2	0.2	0.164	0.179	6.6	9.19	9.24	0.4	10.52	10.52	0.0	0.880	0.880	0.0
	2091.1			0.193			9.28			10.52			0.880		
	2097.1			0.180			9.26			10.53			0.880		
10	2084.4	2065.5	0.8	0.445	0.463	4.5	10.30	10.40	0.9	11.82	11.87	0.8	0.870	0.877	0.5
	2044.2			0.492			10.52			12.00			0.880		
	2067.9			0.452			10.39			11.79			0.880		
15	1992.3	1993.5	0.4	0.708	0.723	2.4	11.83	11.83	0.3	13.38	13.55	0.9	0.880	0.877	0.5
	2004.9			0.714			11.87			13.68			0.880		
	1983.3			0.747			11.78			13.59			0.870		
20	1960.2	1935.0	1.0	0.871	0.887	1.5	13.97	14.07	0.5	14.80	15.60	4.0	0.880	0.880	0.0
	1912.3			0.903			14.15			16.32			0.880		
	1932.5			0.887			14.08			15.68			0.880		

Table 16. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of $900°C$ for a sintering time period of $1 hours$ and compaction pressure of $10.0\ MPa$

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	1.17 3.86 1.87	1.10	9.1	17.53 16.21 40.17 38.89 39.72 40.53	12.18	8.0
5	3.99 1.10 3.67	3.92	1.7	32.07 31.71 32.98 32.76 26.31 25.76	30.27	10.0
10	2.85 2.80 2.56	2.71	4.6	27.11 25.97 23.86 22.81 28.72 27.98	26.08	8.1
15	1.69 1.82 1.76	1.76	3.0	16.57 18.03 15.19 16.37 18.11 17.58	17.03	6.5
20	1.11 1.05 1.19	1.12	5.1	8.27 9.23 8.96 9.11 9.97 11.09	9.41	9.1

Table 17. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of *1000°C* for a sintering time period of *4hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2058.5 2055.3 2066.5	2060.1	0.2	0.078 0.073 0.098	0.083	4.9	7.76 7.50 7.53	7.60	1.5	9.21 9.08 9.15	9.15	0.6	0.860 0.860 0.860	0.860	0.0
5	2060.6 2061.2 2025.2	2049.0	0.8	0.149 0.171 0.166	0.162	5.8	9.22 9.54 8.82	9.19	3.2	10.60 10.70 10.31	10.54	1.6	0.870 0.890 0.850	0.870	1.9
10	1995.1 1990.3 2023.6	2003.0	0.7	0.358 0.388 0.391	0.379	3.9	9.73 9.74 9.75	9.74	0.1	11.22 11.32 11.33	11.29	0.4	0.870 0.865 0.860	0.865	0.5
15	1956.0 1964.5 1964.5	1961.7	0.2	0.691 0.721 0.700	0.704	1.8	11.67 11.70 11.65	11.67	0.2	13.43 13.34 13.46	13.41	0.4	0.870 0.870 0.880	0.873	0.5
20	1906.4 1928.6 1922.7	1919.2	0.5	0.851 0.884 0.869	0.868	1.6	13.62 13.32 13.19	13.38	1.3	15.66 15.39 15.28	15.44	1.0	0.870 0.870 0.870	0.870	0.0

Table 18. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 1000°C for a sintering time period of 1*hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	6.11 5.71 6.58	6.23	6.0	27.22 25.82 28.97 31.79 30.01 28.25	28.68	6.7
5	3.96 3.77 1.81	1.19	11.1	21.37 25.62 21.17 25.66 28.17 28.07	26.01	6.1
10	1.00 3.89 3.67	3.85	3.6	23.57 22.76 21.32 22.68 23.11 23.12	23.31	2.1
15	2.10 2.51 2.39	2.13	2.2	17.23 16.55 17.17 18.15 15.93 16.07	16.85	1.5
20	1.66 1.72 1.58	1.65	3.5	9.27 9.85 10.20 9.32 9.89 10.93	9.91	5.7

Table 19. Variation of physical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of 7$hours$ and compaction pressure of 10.0 MPa

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2109.6 2121.2 2069.5	2100.1	1.1	0.084 0.090 0.105	0.093	9.5	8.58 8.73 8.49	8.60	1.2	9.86 9.83 10.01	9.90	0.8	0.870 0.870 0.870	0.870	0.0
5	2096.5 2086.2 2118.2	2100.3	0.6	0.182 0.170 0.152	0.168	7.3	9.10 9.26 8.64	9.00	2.9	10.51 10.52 10.53	10.52	0.1	0.870 0.870 0.870	0.870	0.0
10	2084.6 2044.0 2077.2	2068.6	0.9	0.458 0.400 0.363	0.407	9.6	10.20 10.55 10.60	10.45	1.7	12.02 11.85 11.83	11.90	0.7	0.870 0.880 0.880	0.877	0.5
15	1993.5 2004.1 2002.4	2000.0	0.2	0.627 0.734 0.706	0.689	6.6	11.88 11.75 11.92	11.85	0.6	13.75 13.60 13.75	13.70	0.5	0.870 0.880 0.880	0.877	0.5
20	1961.2 1932.3 1898.0	1930.5	1.3	0.829 0.897 0.899	0.875	3.7	14.15 14.07 14.08	14.10	0.3	15.73 15.68 15.69	15.70	0.1	0.870 0.870 0.880	0.873	0.5

Table 20. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of 7$hours$ and compaction pressure of 10.0MPa

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	4.67 4.44 4.39	4.50	2.7	45.31 46.80 39.23 40.07 41.03 40.73	42.20	6.7
5	3.67 4.07 4.04	3.93	4.6	32.44 31.35 28.01 29.51 29.71 30.78	30.30	4.7
10	2.57 2.81 2.84	2.74	4.4	26.11 27.03 24.34 25.66 27.15 26.31	26.10	3.6
15	1.76 1.68 1.84	1.76	3.7	18.92 17.54 15.37 16.93 16.41 17.61	17.13	6.4
20	1.11 1.21 1.28	1.20	5.8	8.73 9.06 9.07 9.86 10.18 11.00	9.65	8.1

Table 21. Variation of physical properties of sintered clay-mica composite as a function of compaction pressure for specimens containing 10% mica and sintered at the temperature of 900°C for a sintering time of *4hours*

Comp. Pressure (*MPa*)	Physical Properties														
	BD (*Kg/m³*)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
3.0	1980.2 1982.6 1984.4	1982.4	0.1	0.754 0.792 0.758	0.768	2.2	12.02 13.00 12.63	12.55	3.2	15.03 14.23 14.87	14.71	2.3	0.870 0.866 0.873	0.870	0.3
4.0	2000.1 2003.5 2009.3	2004.3	0.2	0.717 0.728 0.745	0.730	1.6	12.00 11.35 12.08	11.81	2.8	14.00 13.75 13.95	13.90	0.8	0.860 0.860 0.860	0.860	0.0
5.0	2035.2 2010.4 2014.4	2020.0	0.5	0.703 0.683 0.657	0.681	2.8	10.98 11.23 11.06	11.09	0.9	15.20 14.65 15.00	14.95	1.5	0.866 0.860 0.853	0.860	0.6
6.0	2032.8 2040.4 2030.6	2034.6	0.2	0.631 0.664 0.634	0.643	2.3	11.23 11.05 11.05	11.11	0.8	13.14 12.68 13.12	12.98	1.6	0.863 0.856 0.860	0.860	0.3
7.0	2080.1 2085.5 2078.3	2081.3	0.1	0.592 0.617 0.597	0.602	1.8	10.98 10.45 10.52	10.65	2.2	12.05 12.53 12.11	12.23	1.7	0.870 0.870 0.870	0.870	0.0
8.0	2085.2 2100.2 2088.2	2091.2	0.3	0.563 0.587 0.563	0.571	2.0	10.83 10.32 10.35	10.50	2.2	11.94 12.11 12.13	12.06	0.7	0.873 0.866 0.870	0.870	0.3
9.0	2105.0 2100.0 2095.0	2100.0	0.2	0.517 0.531 0.551	0.533	2.6	10.45 10.13 10.02	10.20	1.8	11.57 11.89 11.85	11.77	1.2	0.870 0.870 0.870	0.870	0.0
10.0	2118.2 2102.8 2109.0	2110.0	0.3	0.445 0.492 0.452	0.463	4.5	10.61 10.33 10.77	10.57	1.7	11.78 12.03 11.92	11.91	0.9	0.860 0.860 0.860	0.860	0.0

Table 22. Variation of mechanical properties of sintered clay-mica composite as a function of compaction pressure for specimen containing 10 % mica and sintered at the temperature of 900°*C* for a sintering time period of 4*hours*

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
3.0	1.32 1.37 1.36	1.35	1.6	11.78 12.68 13.17 12.29 12.08 13.00	12.50	4.0
4.0	1.48 1.42 1.46	1.45	1.7	16.22 15.30 14.81 15.59 15.02 16.06	15.50	3.3
5.0	1.72 1.82 1.80	1.78	2.4	14.34 14.78 11.67 13.53 13.98 14.50	14.30	3.0
6.0	2.11 2.12 2.12	2.12	0.2	15.47 15.17 14.03 14.43 15.19 15.71	15.00	3.9
7.0	2.26 2.30 2.28	2.28	0.7	16.02 15.24 15.97 16.43 15.69 16.29	15.91	2.5
8.0	2.57 2.60 2.57	2.58	0.5	17.66 17.16 16.47 16.61 16.83 17.27	17.00	2.4
9.0	2.71 2.67 2.70	2.69	0.5	18.73 18.99 19.85 19.23 18.66 18.54	19.00	2.1
10.0	2.75 3.01 2.95	2.90	3.7	18.96 18.31 18.03 18.17 18.98 18.22	18.50	1.9

Table 23. Variation of physical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 10.0*MPa* with specimen containing 10% glass

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	2043.6 2027.0 2025.4	2032.0	0.4	0.70 0.78 0.77	0.75	4.7	9.57 9.89 9.65	9.70	1.4	11.30 11.59 11.39	11.43	1.1	0.850 0.850 0.850	0.850	0.0
5	1974.0 1972.4 1951.7	1966.0	0.5	0.96 0.98 1.06	1.00	4.3	10.99 11.17 11.14	11.10	0.7	13.24 13.33 15.02	13.28	5.9	0.830 0.840 0.850	0.840	1.0
10	1927.1 1895.1 1897.3	1906.5	0.8	1.16 0.96 1.18	1.10	9.0	12.48 13.15 13.01	12.88	2.2	14.94 15.49 15.19	15.21	1.5	0.870 0.860 0.880	0.860	1.0
15	1868.6 1860.7 1849.8	1859.7	0.4	1.34 1.19 1.22	1.25	5.2	14.75 15.08 14.87	14.90	0.9	16.25 17.40 17.15	16.93	2.9	0.870 0.870 0.870	0.870	0.0
20	1783.4 1786.1 1787.6	1758.7	0.1	1.62 1.61 1.57	1.60	1.4	18.20 17.34 17.96	17.83	2.0	20.19 20.01 19.88	20.03	0.6	0.890 0.860 0.880	0.876	1.4
25	1754.8 1750.5 1743.4	1749.6	0.3	1.88 2.10 2.02	2.00	4.5	19.14 19.59 19.78	19.50	1.4	21.79 22.56 21.94	22.10	1.5	0.880 0.870 0.900	0.883	1.4

Table 24. Variations of mechanical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of $900°C$ for a sintering time period of $1 hours$ and compaction pressure of $10.0 MPa$ with specimens containing 10% glass

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	4.06 3.49 4.00	3.85	6.6	33.70 32.17 28.15 29.76 30.78 26.58	30.19	7.9
5	2.90 2.90 2.86	2.89	0.8	22.27 21.51 22.04 22.76 22.82 23.24	22.44	2.5
10	1.72 1.67 1.38	1.59	9.1	15.61 16.11 15.03 14.23 14.96 15.42	15.23	3.9
15	1.09 1.08 1.22	1.13	5.6	10.29 9.81 9.77 10.37 10.04 10.66	10.15	3.1
20	0.76 0.75 0.64	0.72	7.6	5.72 6.24 6.53 7.37 7.09 6.59	6.59	8.2
25	0.65 0.54 0.65	0.61	8.5	5.32 5.80 5.20 4.91 4.87 4.26	5.06	9.3

Table 25. Variation of physical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of 4*hours* and compaction pressure of 10.0*MPa* with specimen containing 20% glass

Mica Content (%)	Physical Properties														
	BD (Kg/m^3)			VC (%)			CWA (%)			BWA (%)			SC		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV	Ind.	Ave.	COV(%)
0	1988.8 1990.5 1985.5	1988.3	0.1	1.92 2.05 2.03	2.00	2.9	10.20 10.30 10.10	10.20	0.8	11.82 11.97 12.25	12.01	1.5	0.750 0.750 0.780	0.760	1.9
5	1893.5 1890.4 1893.5	1892.5	0.1	2.13 2.06 2.11	2.10	1.4	11.51 11.61 11.84	11.65	1.2	13.82 14.83 14.88	14.51	3.4	0.800 0.780 0.800	0.795	1.2
10	1854.0 1848.0 1841.9	1848.0	0.3	2.32 2.13 2.30	2.25	3.8	13.91 13.71 12.44	13.35	4.9	17.18 17.08 15.98	16.75	3.2	0.810 0.800 0.780	0.797	1.6
15	1778.0 1801.1 1685.7	1754.9	2.8	2.64 2.32 2.54	2.50	5.3	17.94 18.19 14.86	17.00	8.9	21.35 21.79 18.53	20.56	7.0	0.840 0.830 0.800	0.823	2.1
20	1692.6 1694.0 1689.6	1692.1	0.1	3.22 2.93 2.85	3.00	5.3	19.87 19.66 20.03	19.85	0.8	22.85 23.64 23.78	23.42	1.7	0.860 0.830 0.840	0.843	1.5
25	1620.0 1617.4 1617.4	1618.3	0.1	3.74 3.56 3.50	3.60	2.8	22.32 24.55 23.77	23.55	3.9	25.65 27.64 25.53	26.27	3.7	0.870 0.890 0.910	0.890	1.8

Table 26. Variations of mechanical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of 1*hours* and compaction pressure of 10.0*MPa* with specimens containing 20% glass

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	4.41 3.85 3.99	4.08	5.8	20.12 22.73 25.67 27.18 27.31 28.16	25.20	11.1
5	1.49 1.54 1.23	1.42	9.6	17.61 18.53 16.67 17.12 16.10 15.91	17.01	5.0
10	1.41 1.48 1.74	1.55	8.6	10.63 10.74 10.58 11.47 12.01 12.55	11.33	6.6
15	0.52 0.59 0.69	0.60	11.6	6.71 5.81 6.12 6.27 6.33 6.47	6.29	4.6
20	0.15 0.12 0.38	0.11	6.9	3.61 3.72 3.80 3.89 3.91 3.96	3.82	3.5
25	0.35 0.39 0.43	0.391	8.4	2.77 2.81 2.89 2.93 3.01 3.17	2.93	1.5

Table 27. Variations of mechanical properties of sintered clay product as a function of sintering temperature for specimens prepared at the compaction pressure of $5.0MPa$ and sintering time period of $1hours$ after the freezing and thawing treatment

Sintering Temp. (°C)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
750	0.77 0.79 0.78	0.78	1.0	14.27 14.15 14.98 15.21 15.66 15.43	15.00	3.3
800	1.93 1.97 1.95	1.95	0.8	29.33 29.51 30.16 30.27 30.98 29.15	29.90	2.1
900	3.90 3.85 3.93	3.89	0.8	39.11 38.16 38.78 39.07 39.58 39.13	39.01	0.9
1000	5.11 5.38 5.12	5.20	2.5	26.98 27.03 27.11 27.27 27.53 27.25	27.20	0.7

Table 28. Variations of mechanical properties of sintered clay product as a function of sintering temperature for specimens prepared at the compaction pressure of $10.0MPa$ and sintering time of $4hours$ after the freezing and thawing treatment

sintering Temp. (°C)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
750	1.08 1.18 1.01	1.10	5.1	15.58 15.97 16.01 16.13 16.11 16.32	16.07	1.7
800	2.11 2.15 2.15	2.14	0.2	30.02 30.17 30.31 30.11 30.78 30.68	30.10	0.9
900	1.22 1.21 1.20	1.21	0.2	39.71 39.96 40.13 40.19 40.22 40.39	40.10	0.5
1000	6.02 6.01 6.03	6.03	0.1	28.62 28.77 28.91 29.07 29.31 29.50	29.03	1.0

Table 29. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 800°C for a sintering time period of 1hours and compaction pressure of 5.0MPa after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	2.01 2.01 2.01	2.01	0.0	31.07 31.11 31.22 31.31 31.18 31.13	31.23	0.1
5	1.53 1.52 1.51	1.52	0.5	27.87 27.99 28.13 28.37 28.31 28.56	28.21	0.8
10	1.01 1.06 0.95	1.01	4.5	16.57 16.81 16.98 17.13 17.22 17.32	17.01	1.5
15	0.71 0.71 0.71	0.71	0.0	8.21 7.18 7.66 7.79 7.92 7.98	7.81	3.0
20	0.29 0.29 0.28	0.29	1.6	3.37 4.44 3.67 3.99 4.12 1.17	3.96	8.8

Table 30. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of $900°C$ for a sintering time period of $4hours$ and compaction pressure of $5.0MPa$ after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	3.77 3.78 3.79	3.78	0.2	38.13 37.29 37.58 37.91 37.99 38.77	37.86	1.2
5	2.51 2.48 2.49	2.50	1.0	30.91 31.12 31.27 31.40 31.58 31.91	31.37	1.1
10	2.04 2.04 2.06	2.05	0.5	17.11 17.35 17.62 17.91 18.07 18.71	17.80	2.9
15	1.02 1.00 0.98	1.00	1.6	8.22 8.31 8.41 8.57 8.73 8.49	8.46	1.9
20	0.53 0.51 0.56	0.51	2.3	3.87 3.92 3.98 4.07 4.13 4.21	4.03	2.9

Table 31. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of $1000^{\circ}C$ for a sintering time period of $4hours$ and compaction pressure of $5.0MPa$ after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	5.11 5.19 5.20	5.18	0.5	26.27 26.51 26.79 26.93 27.02 27.28	26.80	1.2
5	3.15 3.13 3.12	3.13	0.1	25.12 25.31 25.58 25.71 25.99 26.28	25.67	1.5
10	2.19 2.16 2.19	2.18	0.6	13.98 14.17 14.31 14.18 14.72 13.82	14.30	2.1
15	1.01 1.02 1.03	1.02	0.8	7.21 6.10 6.58 6.79 6.98 6.89	6.78	3.9
20	0.71 0.71 0.70	0.71	0.7	3.57 3.62 3.77 3.83 3.91 4.10	3.80	1.7

Table 32. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of $800^{\circ}C$ for a sintering time period of $1 hours$ and compaction pressure of $10.0MPa$ after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	1.92 2.17 2.01	2.01	5.1	29.67 29.87 30.01 30.19 30.37 30.78	30.12	1.2
5	1.80 2.03 1.89	1.91	5.0	26.91 27.08 27.29 27.17 27.63 28.20	27.13	1.5
10	1.11 1.27 1.25	1.32	6.5	21.00 20.29 20.61 20.87 20.98 21.65	20.87	2.0
15	0.86 0.88 0.97	0.90	5.3	15.37 15.69 15.93 16.17 16.31 16.62	16.02	2.6
20	0.56 0.53 0.60	0.56	5.0	9.21 8.43 8.69 8.92 9.01 9.20	8.91	3.1

Table 33. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time of 1*hours* and compaction pressure of 10.0*MPa* after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	1.19 1.23 1.12	1.18	1.1	10.27 10.59 10.96 11.18 11.13 11.69	11.02	1.2
5	3.75 3.72 3.71	3.72	0.5	29.56 29.83 30.27 30.51 30.78 31.27	30.37	1.9
10	2.81 2.35 3.03	2.73	10.1	21.17 21.69 21.81 25.02 25.77 25.78	25.09	2.0
15	1.73 1.65 1.93	1.77	6.7	16.87 17.13 17.21 17.12 17.56 17.19	17.23	1.3
20	1.01 1.13 1.19	1.11	6.7	8.81 8.97 9.21 9.66 9.93 10.15	9.16	5.2

Table 34. Variations of mechanical properties of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 1000°C for a sintering time period of $1 hours$ and compaction pressure of $10.0 MPa$ after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	6.01 6.35 5.75	6.01	4.1	28.08 28.33 28.67 28.92 28.89 29.31	28.70	1.1
5	4.27 4.01 4.62	4.31	5.5	25.21 25.57 25.81 26.12 26.37 26.11	25.87	1.5
10	3.62 3.75 3.58	3.65	2.0	22.31 22.57 22.82 22.97 23.15 23.61	22.96	2.0
15	2.26 2.15 2.29	2.23	2.7	15.57 15.83 15.98 16.27 16.31 16.22	16.03	1.7
20	1.62 1.53 1.16	1.51	4.3	9.09 9.47 9.68 9.86 10.17 10.11	9.73	3.8

Table 35. **Variations of mechanical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *1hours* and compaction pressure of *10.0MPa* with specimens containing 10% glass after the freezing and thawing treatment**

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	3.83 3.98 3.71	3.84	2.9	28.63 28.87 29.05 29.37 29.86 30.11	29.32	1.8
5	2.88 2.65 3.06	2.86	5.9	20.88 20.97 21.14 21.39 21.52 21.66	21.26	1.3
10	1.57 1.78 1.33	1.56	11.8	15.17 14.29 14.76 14.93 15.37 15.36	14.98	2.5
15	1.20 0.91 1.17	1.10	10.5	9.27 9.53 9.71 9.99 10.18 10.90	9.97	5.6
20	0.69 0.73 0.68	0.70	3.1	5.87 5.96 6.12 6.14 6.61 6.92	6.32	5.9
25	0.58 0.76 0.18	0.60	6.2	1.18 1.71 1.82 1.89 1.97 5.17	1.81	1.1

Table 36. Variations of mechanical properties of sintered clay-mica-glass composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 10.0*MPa* with specimens containing 20% glass after the freezing and thawing treatment

Mica Content (%)	Mechanical Properties					
	Flexural Strength (MPa)			Compressive Strength (MPa)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	4.38 3.88 3.75	4.00	6.8	23.67 23.86 24.01 24.28 24.41 24.82	24.18	1.6
5	1.40 1.25 1.52	1.39	7.9	15.83 16.02 16.27 16.45 16.61 16.08	16.21	1.6
10	1.63 1.51 1.56	1.57	2.4	10.42 10.87 10.96 11.18 11.32 11.37	11.02	2.9
15	0.62 0.58 0.69	0.63	7.2	5.89 5.97 6.10 6.22 6.41 6.25	6.14	2.9
20	0.43 0.43 0.43	0.43	0.0	4.07 3.22 3.57 3.71 3.98 3.92	3.75	7.7
25	0.39 0.40 0.34	0.38	7.0	2.41 2.67 2.73 2.86 2.92 2.97	2.76	6.8

Table 37. Variation thermal conductivities of sintered clay-mica composite as a function of mica content for specimens prepared at the sintering temperature of 900°C for a sintering time period of 1*hours* and compaction pressure of 10.0 *MPa*

Mica Content (%)	Mean Temperature (°C)			Thermal Conductivities ($W/m°C$)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	2.836 3.068	2.952	3.9	0.517 0.517	0.517	0.0
	19.503 20.003	19.753	1.3	0.561 0.563	0.562	0.2
	11.872 12.140	12.006	0.3	0.581 0.582	0.581	0.1
5	1.332 1.374	1.353	1.6	0.269 0.269	0.269	0.0
	19.767 19.945	19.856	0.1	0.285 0.284	0.285	0.2
	12.243 12.863	12.553	0.7	0.297 0.301	0.299	0.7
10	3.117 3.169	3.143	0.8	0.269 0.269	0.269	0.0
	19.861 20.005	19.933	0.1	0.284 0.285	0.285	0.2
	12.543 12.567	12.555	0.0	0.298 0.299	0.299	0.2
20	5.668 5.778	5.723	1.0	0.231 0.231	0.231	0.0
	22.423 22.585	22.504	0.1	0.211 0.213	0.212	0.1
	14.769 15.239	15.004	0.5	0.251 0.253	0.252	0.1

Table 38. Variation of thermal conductivities of sintered clay-mica-glass composite with 10% mica content as a function of glass content for specimens prepared at the sintering temperature of 900°C for a sintering time period of *4hours* and compaction pressure of 10.0 *MPa*

Glass Content (%)	Mean Temperature (°C)			Thermal Conductivities (W/m°C)		
	Ind.	Ave.	COV(%)	Ind.	Ave.	COV(%)
0	3.117 3.169	3.143	0.8	0.269 0.269	0.269	0.0
	19.861 20.005	19.933	0.4	0.284 0.285	0.285	0.2
	12.543 12.567	12.555	0.0	0.298 0.299	0.299	0.2
10	5.827 5.857	5.842	0.3	0.232 0.232	0.232	0.0
	21.987 22.217	22.102	0.5	0.244 0.245	0.245	0.2
	11.269 11.833	11.551	0.6	0.258 0.262	0.260	0.8
20	3.354 3.418	3.386	1.0	0.294 0.295	0.294	0.2
	21.276 21.448	21.362	0.4	0.305 0.306	0.306	0.2
	12.653 13.181	12.917	0.6	0.323 0.327	0.325	0.6

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