DEVELOPMENT OF LIGHT WEIGHT INSULATING BRICKS FROM LOCAL CLAY

A thesis submitted to the Department of Metallurgical Engineering, BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA, in partial fulfilment of the requirements for the degree of Master of Science in Engineering (Metallurgical).

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CERTIFICATE

This is to certify that this work has been carried out by the author under the supervision of Dr. Md. Nasrul Haque, Associate Professor, Department of Metallurgical Engineering, BUET, Dhaka, and it has not been submitted elsewhere for the award of any other degree or diploma.

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ABSTRACT

Employing a simple hand-pressing and sintering process, light weight insulating brick samples were produced from mixtures of kerosine wood sawdust and local Mymensing clay. The various physical, mechanical, and thermal properties were measured. It was observed that bulk density, thermal conductivity and compressive strength of the products were significantly modified by the addition of sawdust. The effect of size of the additive on the thermal conductivity was not appreciable. For an identical insulating property of the products the compressive strength was found to increase with the decrease of the size of the sawdust.

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CHAPTER ONE

INTRODUCTION

Insulating bricks are essential for most of the metallurgical furnaces to reduce heat loss through the wall during operation. As the are porous, they are used only in those furnaces where the material are not in molten condition or the molten material does not come in direct contact of the insulating refractories (e.g. heat treatment furnaces or crucible furnace).

Incorporation of carbon-rich material into clay has been known for sometime to be an effective method of producing light weight insulating bricks (1) , on firing the carbon-rich material burns out and leave both open and closed pore within the clay body. Literature indicates that two general approaches have been followed in the prduction of such bricks :One is to incorporate carbon-rich solid material products and the other is to add liquid organic material. The latter has attracted more attentions in recent years. This is due probably to the ease in access to the organic materials. It has been reported (1) that expanded polystyrene beads can be incorporated into the clay mixtures and the mixture are then fabricated into the products by firing at high temperatures. The incineration of the polystyrene beads results in the formation of small cells in the clay body (2,3). However, this method of fabrication has been found to be less desirable because of several drawbacks. It is generally known that polystyrene produces a pungent odor upon decomposition during firing and that the cost of the polystyrene beads is not economically attractive. As a result, the development of light-weight insulating bricks based on the use of this type of organic material is rather limited. Several recent publications have shown that sawdust particles which are by-products in the sawmilling industry, are an excellent alternative source of organic materials which can be effectively added to the clay grains thus producing light weight and porous bricks (4-9). Sawdust particles are fully combustible when at moderate temperatures (400-500^{0}C) and they produce no undesirable odor upon decomposition during firing.

In Bangladesh Mirpur Ceramic Works and Dhaka Refractories Ltd. produce insulating bricks, but the important properties like thermal condutivity and strength of these bricks are not measured. These properties partly depend on the percentage of porosity and the size of pores in the brick. This research project was under taken to find out the optimum size and percentage of sawdust content in the clay-sawdust system for producing light weight insulating bricks from local clay having a good combination of thermal and mechanical properties.

CHAPTER TWO

LITERATURE REVIEW

2.1 REFRACTORIES

Using the word in its broadest sense, the term refractories embraces all materials used in the constraction of heat resisting containers to afford space for the evolution of gases in combustion processes, holding of molten charges and of solids undergoing heat treatment.

2.1.1 Types of Refractories

From the technical standpoint refractories may be classified as follows-

A. Refractories of the Silica-Alumina Series

1. Fire-clay Refractories
2. Silica Refractories
3. High Alumina Refractories
   a. Diaspore type
   b. Other type

B. Basic Refractories

1. Magnesite Refractories
2. Chrome Refractories
3. Dolomite Refractories

C. Special Refractories

D. Insulating Refractories

2.1.2 Properties of Refractories

The properties of refractories determines their suitability for a particular purpose. The various aspects that are to be considered are discussed below :

2.1.2.1 Chemical and Mineralogical Composition

It is the most important property that governs the stability of refractories under various conditions. Refractories are generally classified on the basis of this property. The nature (e.g. basicity) of refractories determines whether it will be attacked or not. The chemical and mineralogical compositions of raw materials determine the change during production, the phases that are going to be produced. The structural change and phases govern such properties of refractories as thermal conductivity (e.g. Alumina has higher conductivity than magnesia aluminate spinel (10)), resistance to slag action , the fusion point etc.

2.1.2.2 Refractoriness

The usefulness of refractories depends on their refractoriness. Refractoriness should not be confused with fusion point. Refractoriness is markedly affected by the environment. For example fast heating shows high refractoriness of a particular material than under slow heating conditions.

The refractoriness i.e. the temperature at which the material flows under standard condition depends on various factors such as constitution of the refractory, grain size of the constituents, uniformity of the constituent. More the amount of the high melting constituent the higher the refractoriness. On the other hand the greater the tendency to form low melting slag the lower the refractoriness. The larger the grain the higher the refractoriness and vise versa (11). The more the uniformity of constituent higher the refractoriness. The viscosity of low melting slag has a significant effect on refractoriness . The more the viscosity of the low melting component the higher the refractoriness and vise versa.

2.1.2.3 Thermal Expansion

The thermal expansion governs the stresses occurring in the refractory and this has a significant effect on its spalling resistance. Thermal expansion depends solely on the chemical and mineralogical compositions of the given material (12).

To describe the properties of refractories, it is important to know not only the mean coefficient of thermal expansion or its value at a given temperature but also the uniformity of expansion in different temperature regions. The true coefficient of thermal expansion in the different temperature regions is used to describe the uniformity of expansion.

The Table below shows the thermal expansion of typical refractories :

Table 2.1

Type of refractories	mean thermal expansion coefficient over temperature range 20 -1000 ^{0}C
Kaolin	(4.5 - 5.6)x10^{-6}
Mullite (70 % Al_2O_3)	(5.5 -5.8) x 10^{-6}
Mullite -Corundum (80-90% Al_2O_3)	(7 - 7.5) x 10^{-6}

2.1.2.4. Spalling Resistance

ASTM defines spalling as the breaking or cracking of refractory brick in service to such an extent that pieces are separated or fall away, leaving a new surface of brick exposed. Spalling results from any of the following causes :

1. A temperature gradient, created by uneven heating or cooling, that is sufficient to set up stresses of such magnitude as to cause failure.

2. Compression in a structure of refractories due to expansion of the whole from a rise of temperature, sufficient to cause shear failures.

3. Variation in coefficient of thermal expansion between the surface layer and the body of the brick, due to surface slag penetration or to a structural change in service, great enough to shear off the surface layer.

The first type is most important. Cracks form parallel to the heated surface. With time the cracks widen into crevics and the heated area breaks off. The first layer to spall is followed by a second one and then by a third, and so on until the lining is completely destroyed. Some times the spalling areas particularly in roof, attain tremendous size. Densification of the heated surface through sintering and additional shrinkage intensifies the tendency to spall .

Spalling depends on the heating and cooling rate, temperature gradient and the thermal diffusivity .

The higher the rate of heating and cooling the lower the spalling resistance. The spalling resistance decreases with increasing temperature gradient while it increases with increasing thermal diffusivity. The spalling resistance is also governed by the size and shape of the article. The size of the article determines the absolute value of the relative shear and consequently the magnitude of the stress created at the wall .

2.2 LIGHT WEIGHT HEAT INSULATING REFRACTORIES

Light weight heat insulating refractories are used in heating units to reduce the consumption of fuel.

Losses associated with thermal processes in the brick work is traceable to the accumulation of heat by the solid brick work and to the radiation by the surface of the furnace in to the surrounding atmosphere. These two types of losses sometimes total 24-45% of the fuel consumption (13).

At the beginning of the firing a large amount of heat is lost through accumulation. As the brickwork heats up, this losses decline to zero; losses to the surrounding medium depend on the types of bricks and the thickness of the wall. The lower the accumulation heat losses and the losses to the surrounding, the more quickly the furnace (with cyclic operating condition) can be heated up and less the consumption of fuel. The amount of heat accumulation by the brick work can be reduced by decreasing its thermal conductivity and heat capacity. By reducing losses into the surrounding atmosphere, external insulation may also increase the heat accumulated through a rise in temperature in the brick work. This shortcoming can be removed by using refractory heat insulating material in brick work zone heated to high temperatures. This reduces the heat losses both through accumulation and radiation into the surrounding atmosphere.

The volumetric heat capacity of a material is reduced when its bulk density is reduced (i.e. the porosity is increased). The thermal conductivity of refractories is a fuction of the thermal conductivity of crystalline and vitreous components, the size, interarrangement, number and type of contact of the grains, porosity, and the size and the arrangement of the pores (14).

The thermal conductivity of light weight refractories decreases as the porosity is increased and varies more or less linearly with the bulk density (14). The thermal conductivity is reduced as the size of the pores is increased (14).

2.2.1. PRODUCTION OF LIGHT WEIGHT INSULATING BRICKS

2.2.1.1 Methods of Production

Two methods are employed for the production of light weight insulating bricks.

1) Burning additives methods : In this method combustible additives are used . These are carbonaceous materials and burn during firing leaving porosity which acts as a barrier to the flow of heat . Vacuum pore is more effective in resisting the flow of heat .

Burning additives method is simpler than Gas method as Gas method requires extra equipments .

2) Gas method : In this method a moulding suspension forms numerous small bubbles . Foam former or chemicals are used to produce gas bubbles in this method.

2.2.1.2. Raw Material

The raw materials used for the production of light weight insulating bricks depend on the method of production and the types of product.

For the burning additive method the raw materials are :

a) additives - wood savings (preferably decayed), lignin (a waste product from hydrolysis), small coke, cowdung, sawdust anthracite and combination of these are used as combustible additives. The burning time and temperature of additives depend on the type, amount and size of additives.

b) binder - molasses, paris plaster, plastic refractories etc. are used as binder in the green product. Paris plaster forms calcium silicate reducing conductivity and produces pore, by relieving sulfur dioxide gas, which further reduce the thermal conductivity. But if the calcium oxide remains free in the finished product it absorbs water and detoriates the product.

c) main raw materials - various types of clay (such as chammote, kaolin) having significant amount of silica and alumina and small amount of some basic oxides.

2.2.1.3 Description of Methods of Production

Burning additive method : The flow sheet for the production of light weight chammote products in this method is shown below -

Production Cycle

Clay	Chamotte	Combustible substance
Crushing (toothed rollers or planners)	Course crushing (jaw crusher)	Drying
Drying	Grinding	
Grinding (centrifugal mill)		
Screening (mesh)	Screening (mesh)	Screening (mesh)

Weight or Volume proportioning

Tempering (runners)

Further tempering or moistening (twin - shaft mixer)

Densification of mixer and making of billets (vacuum auger press)

Drying (tunnel dryer)

Firing

Grinding

Packing

The amount of additives is usually 30-40% by weight and for the parts with a bulk density of 1 gm/cc it is 70-76% by volume (savings and lignin).

To improve the plasticity of the mixture and to improve the strength and resistance of the material during firing, low-ash coke (not more than 20 % by volume) or coal (1/5 to 1/7 of the weight of the savings) screened through a 1.5 to 2.5 mm mesh, are added to the charge . Chammote in the amount of 15 - 25 % by weight are added in the form of grains finer than 2-3 mm (25- 50 % of the particles must be smaller than 0.5 mm). The binding clay is ground until the 0.5mm fraction is at least 70%. The mixturre is tempered in edge runner with light rollers for 3-5 minutes, after it is moistened and then tempered for the same length of time.

The total shrinkage of light products ranges between 8 and 13 % (including drying shrinkage amounting to about half) ; it differs in the length, width and thickness of the parts and is a function of the over-all dimensions. Intricately shaped green ware is allowed to stand until the moisture content just before drying is 17-20%; this takes place in 10-20 days. It is a good idea to heat the green ware just before drying for a length of time (depending on the properties and size of the articles) ranging between 42 and 84 hours . The moisture content of the green ware after drying should not be above 6-10 %. To burn out the carbon the medium must be intensely oxidizing between 500 and 1000^{0}C . The final temperature is 1300 -1350^{0}C with a holding period of 4 hours . Firing lasts 44 -54 hours (ring kilns 60 hours) .

2.2.2 PROPERTIES OF INSULATING REFRACTORIES

2.2.2.1 Bulk Density

Bulk density is the most fundamental property of light weight insulating refractory.

The bulk density depends on the dencity of the constituents in the raw materials and the final product, the moulding pressure, the degree of sintering and amount of porosity . The more dense the raw materials and density of the end products the higher the bulk density. Bulk density increases with the increase of moulding pressure and the degree of sintering whereas the bulk density decreases with increasing porosity.

Bulk density has a marked effect on the thermal conductivity and the strength. Thermal conductivity decreases with the decrease in bulk density whereas the compressive strength increases with the increase in bulk density.

2.2.2.2 Thermal conductivity

Refractories are composed of one or more solid phases together with a pore phase. The resulting thermal conductivity of the body depends on the amounts and arrangements of each phase present as well as their thermal conductivity, their size and shape, number and type of contact beteen grains, the size and arrangement of the pores, the type and amount of gas and ash in the pores.

Since the resulting conductivity of a mixture depends on the arrangement of phases, an understanding of the microstructure is essential in interpreting thermal conductivity data. Three idealized kinds of phase distribution illustrated by kinegery (15) is given in the Figs. 2.1 (a,b and c).

Of these the parallel slab arrangement (Fig. 2.1 a) is not commonly observed , but a continuous major phase with (Fig. 2.1 b) a minor amount of discontinuous second phase is typical of many microstucture. It is the characteristic of the form of porosity normally present. A discontinuous major phase (Fig. 2.1 c) with a minor phase appearing as a continuous boundary material, for example, is typical of the glass bond distribution in many refractories.

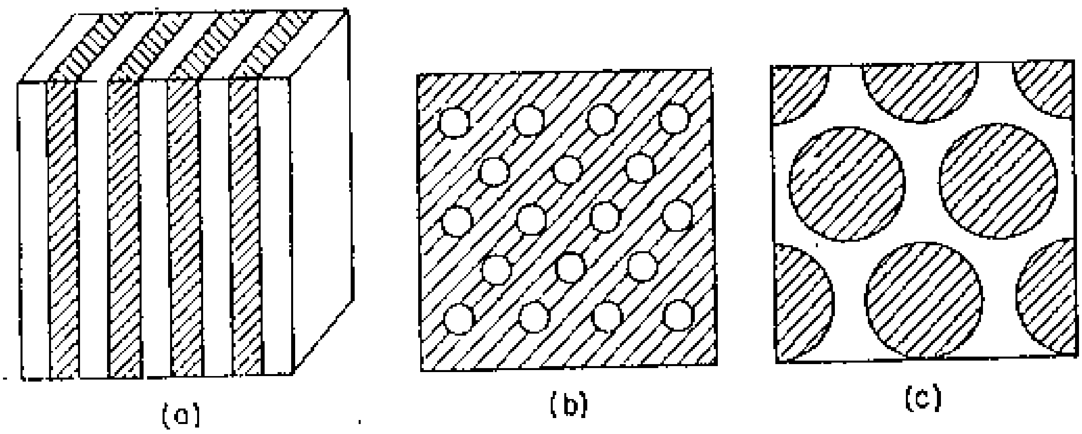


FIG. 2-1 Idealized phase arrangements: (a) parallel slabs, (b) continuous major phase, (c) continuous minor phase.

For the simplest geometry (a series of slab) the thermal conductivity for heat flow parallel to the slabs is given by ,

$$k_m = v_1k_1 + v_2k_2 \quad \text{------------------} \; 2.1$$

where v_1 and v_2 are the volume fraction of each component (equal to the cross- sectional area) and k_1 and k_2 are the thermal conductivity of the two phases respectively. If t_1 and t_2 are the thickness of the slabs respectively then the above equation becomes

$$k_m = t_1k_1 + t_2k_2 \quad \text{----------------} 2.2$$

If $k_1 >> k_2$, then $k_m \simeq t_1 k_1$

For heat flow perpendicular to slabs, the thermal conductivity is given by

$$1/k_m = v_1/k_1 + v_2/k_2 = t_1/k_1 + t_2/k_2 \quad \text{----} 2.3$$

If $k_1 >> k_2$, then $k_m \simeq k_2/v_2$.

More realistic approaches towards the structure of refractories are illustrated in Fig. 2.1 b and 2.1 c. For these structures relationship for the resultant conductivity derived by Maxwell have been discussed in terms of thermal conductivity by Eucken(16). If the continuous phase has a conductivity, k_c, and the dispersed phase has a conductivity, k_d, the resultant conductivity of the mixture is given by

$$k_m = k_c \frac{1 + 2 v_d(1-k_c/k_d)/(2k_c/k_d)}{1 - v_d(1-k_c/k_d)/(k_d+1)} \qquad 2.4$$

When $k_c >> k_d$, the resultant conductivity, then $k_m \simeq k_c[(1-v_d/(1+v_d/2)]$. In contrast, if $k_d >> k_c$ then $k_m \simeq k_c[(1+2v_d)/(1-v_d)]$.

For sintered mixtures of MgO with BeO and for MgO with $MgO-SiO_4$ which for a minor phase dispersed in a continuous major phase, the conductivity changes along a S-shaped curve as illustrated in Fig. 2.2. In most refractories an important constituent is the porosity which is almost always present. One effect of porosity is that even small fractions of porosity strongly reduce the photon mean free path thus severely reduce the thermal conductivity (17). The effect of porosity on the phonon conductivity of refractories has been discussed by Eucken (18) and similar theoretical treatments presented by Russel (19), Riband (20), and Loeb (21) . The Eucken relationship has been given in the equation 2.4, if v_d is taken as volume fraction of porosity. The relationship derived by Russel is given by in equation 2.5.

$$k_m = k_c \frac{v\rho^{0.66} + (k_c/k_p)(1-v\rho^{0.66})}{v\rho^{0.66} - v\rho + (k_c/k_p)(1-v\rho^{0.66}+v\rho)} \qquad 2.5$$

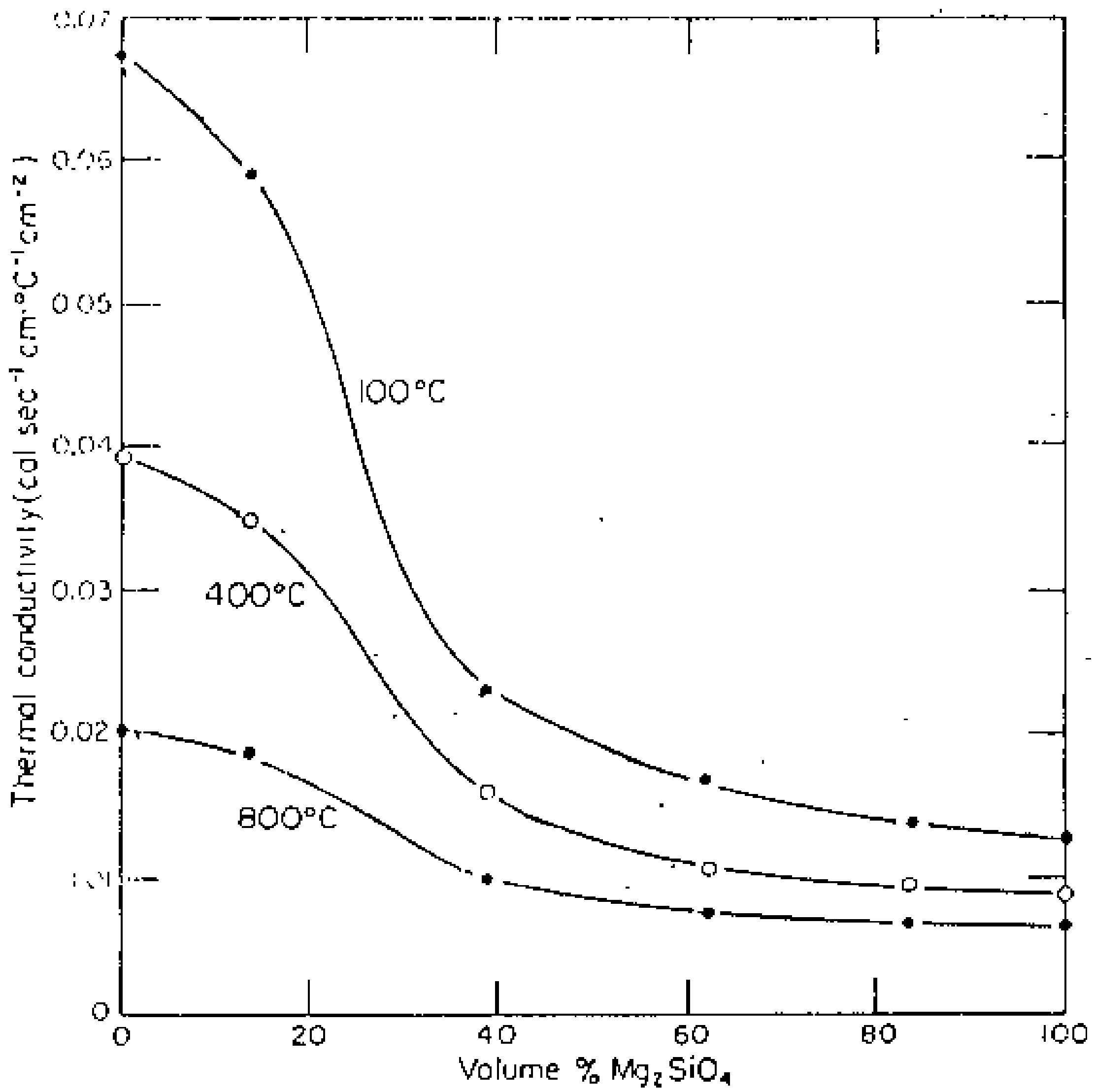


FIG. 2·2 Thermal conductivity in the system $MgO-MgSiO_4$ (Kingery, 1959a).

In general, many workers have found a nearly linear relationship between porosity and thermal conductivity with small pore having more effective insulating power than larger air space at low and intermediate temperatures. A summary of this reports is given by Francl and Kingery (22).

At low temperature the porosity has a low thermal conductivity as compared to any solid phases present and a nearly linear decrease in conductivity with increasing porosity is found for dispersed pores in a solid. However, in addition to true conduction raddition accross pores contributes to heat transfer at high temperature.

If the material surrounding the pores is opaque, an effective radiation conductivity of a pore can be defined when the temperature gradient is small since the radiant energy transfer across a pore is proportional to the temperature difference between pore surfaces,

$$q = n^2 \sigma \ e_{eff} A (T_1^4 - T_2^4) \quad \text{-------} \ 2.5$$

In this eq. $(T_1^4 - T_2^4)$ can be factored, so that,

$$q = 4n^2 \sigma \ e_{eff} A T_m^3 \ \Delta T. \quad \text{-------} \ 2.6$$

Considering heat transfer accross a flat cavity, with parallel sides and thickness d_p, and effective conductivity is defined by,

$$q = k_{eff}(r) \ A(\Delta T/d_p) \quad \text{--------} \ 2.7$$

An effective conductivity is thus defined which gives the proper heat flux when inserted in the normal thermal conductivity relations,

$$k_{eff} = 4d_p n^2 \sigma e T_{meff}^3 \quad \text{---------} \ 2.8$$

Consequently the effect of radiation on pore conductivity is proportional to the pore size and to the third power of temperature . Pores of larger size contribute to increasingly high conductivity at high temperatures, while small size porosity remains a good barrier to heat flow (37). The calculated conductivity of different size pores over a wide temperature range as calculated by Kingery etal (23) is illustrated in Fig. 2.3.

In contrast to solids in which the main effect of the presence of porosity is to decrease the conductivity nearly in proportion to the fraction of porosity, powders and fibrous materials have much lower conductivity even though the volume fraction solids may be considerable. This results from the fact that the pore phase is continuous, there being no sintering between solid-solid contacts. Under this conditions, the resulting conductivity is largely determined by the effective conductivity of the pore phase (24). For gas systems having different conductivities from air, the effective conductivity of the overall system increase in proportion to the conductivity of the gas phase present,and also depends on the gas pressure as found by the various investigators (25), (26), (27).

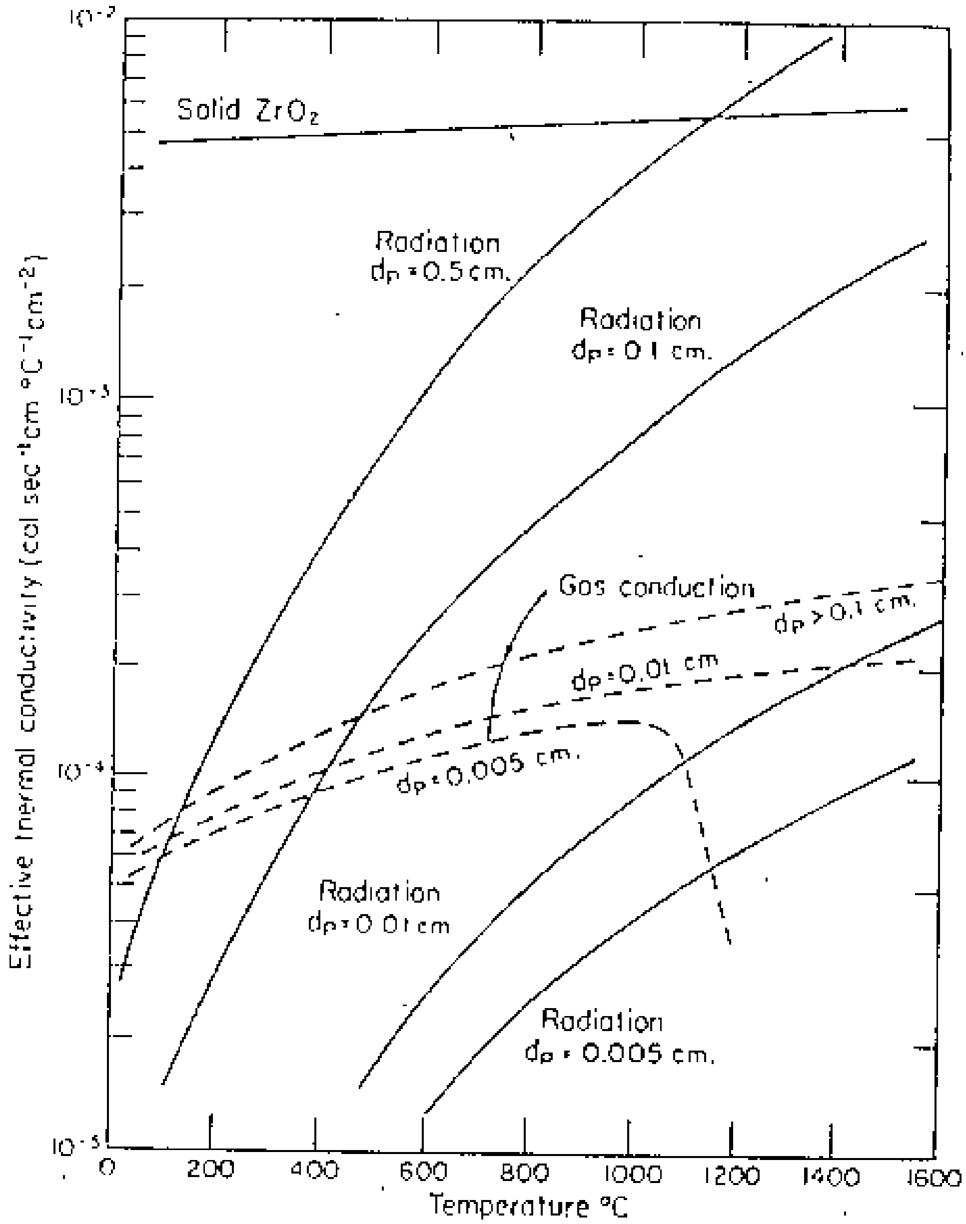


FIG. 2-3 Effective thermal conductivity of pore spaces for conduction and radiation heat transfer.

In polycrystalline and polyphase refractories the conductivity is fixed by the composition of each phase present by the shape and distribution of each phases including the pore phase. When these parameters are known, the overall conductivity can be predicted.

In most polycristalline refractories, which contain a few percentage porosity, the photon contribution to energy transfer does not become significant until very high temperatures are reached.

In multi-phase compositions, the resultant thermal conductivity is stongly dependent on details of the microstructure. An extreme example of this is the effect of small amounts of grain boundary porosity resulting from microstresses; these pores greatly reduce the thermal conductivity even though the porosity is small. For porous and fibrous low density materials, other energy transfer processes are extremely limited and radiation process become particularly important.

2.2.2.3 COPMRESSIVE STRENGTH

The compressive strength of refractories plays an important role in the furnace design. The refractory must be sufficiently strong to carry the weight of the wall. This is more important at high temperature.

Refractory used in lining of industrial furnace are subjected to small loads, usually not exceeding 1 Kg/cm^2 in the wall lining and 4.5 Kg/cm^2 in the roof (28). Thus, high strength for resisting static loads occurring in the lining must be possesed by the refractoriues. In many cases, however, refractories must be able to withstand impact, abrasion and the effect of other mechanical factors.

High compressive strength is an important characteristic, which depends on the quality of the molded mixture, homogeneity of structure and good firing. On account of the simplicity and rapidity with which compressive strength can be calculated, it is one of the principal properties for assessing the quality of refractories. Along with porosity, compressive strength is a reliable index of adherence to establish procedures and of product homogeneity, since in most cases deviation from procedures reduce the strength.

Tests have shown (28) that as the temperature is raised the strength most refractories increases, reaching a peak at 1000-1100^{0}C. Further increase in temperature is accompanied by a sharp declinein strength. But a strength of 1-10 Kg/cm^2, needed for normal service of refractories in furnace, is retained up to the softening point. The reasons for this changes that the plastic deformation occurring at this temperature prevent brittle fracture of the refractory under load. It would be of great interest to the ultimate strength of the refractories at their working temperatures.

2.2.3 MEASUREMENT OF PROPERTIES

2.2.3.1 Test for Bulk density

According to ASTM Standard Method C-134 (29) the bulk density of insulating firebrick can be measured. The procedure is described as follows ----

10 specimens are taken to represent each system. Then the length and width of each specimen are measured to the nearest 0.02 in (0.5 mm). The individual measurement of the two opposite faces of each specimen are recorded. The thickness of the insulating firebrick is determined and recorded in the same manner. The dry specimen are then weighed by a balance having an accuracy +/- 4.5 gm. The average length, width and hight are calculated and the bulk density of each specimen is determined using the appropriate formula bellow ---

$$\text{Bulk Density, lb/cu.ft} = \frac{(\text{wt in lb})\,(1728)}{(\text{length})\,(\text{width})\,(\text{thickness})\,(\text{all in in.})}$$

$$\text{Bulk Density, kg/cu. m} = \frac{\text{wt in kg}}{(\text{length})\,(\text{width})\,(\text{thickness})\,(\text{all in m})}$$

2.2.3.2 Test for Cold crushing Strength

ASTM Method C 93 (30) describes the determination of Cold crushing strength of insulating refractory. The procedure is described partly as follows---

A standard mechanical or hydraulic compression machine (sensitivity 20 lbf and range 0-15000 lbf). The specimen`s dimension is 4.5 by 4.5 by 2.5/3 in. The load bearing surfaces should be approximately parallel. The specimen is placed on the plane surface of the spherical bearing block which have an area greater than that of the largest faces of the specimen.

The load is applied to the 4.5 by 4.5 in surface of the specimen. The bearing block is placed on the top of the test specimen and it is so placed that the center of sphere is in allingment with the vertical axis of the specimen. The cold crushing strength of the specimen are measured using the following formula -----

$$S = W / A$$

where :

S =cold crushing strength, psi (or MPa)

W = total maximum load at 3% deformation or visible failure, whichever is smaller, lbf (or N), and

A = average of the gross area of the two 4.5 by 4.5 in. (114 by 114 mm) faces of the specimen, $in.^2$ (mm^2).

2.2.3.3 Test for Thermal conductivity

According to ASTM Method C 201 (31) the thermal conductivity can be measured.

An alternative method for the test of thermal conductivity is Lees and Choorlton`s Method (32). The method is described as follows ----

Theory -- The thermal conductivity of a bad conductor like rubber, ebonite, glass, refractory etc. can be measured by this method. In measuring the conductivity of such poor conductor, a thin layer or slab of the material is used. The difficulty arises in maintaining the face at uniform temperature and in measuring that temperature. Lees and chorlton overcome this difficulty by placing a good conductor. such as brass or copper, of exactly the same diameter as the experimental slab on each side of the poor conductor. In Fig. 2.4 let S be the disc of poor conductor, B and A be the thick metallic discs each on either side of S. C is a steam chamber from which heat passes to B, S and A.

When steam is passed through C, A is warmed by the heat conducted by S. When the rate of flow of heat through S equals the heat loss from A by radiation and convection then steady state will be reached.

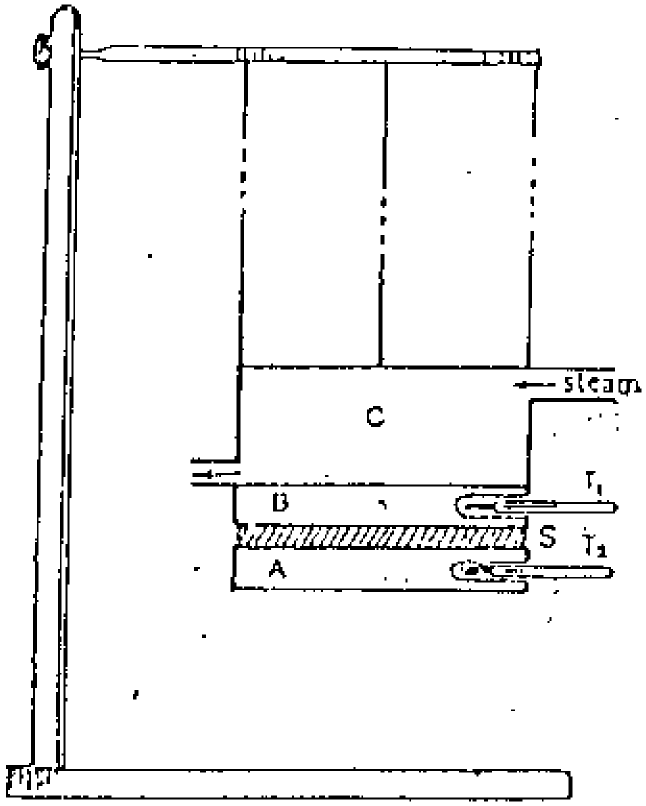


FIG.2.4 LEES APPARATUS.

If T_1 = temperature of B in the steady state.

T_2 = temperature of A in the steady state.

A = cross-sectional area of S.

K = thermal conductivity of S.

d = thickness of the slab S.

then the quantity of heat conducted per second through S is

$$Q = \frac{K A (T_1 - T_2)}{d} \qquad \text{---------- } 2.9$$

In the steady state this heat Q is radiated per second from A. If m and s be the mass and specific heat of A and dT/dt be its cooling rate at temperature T_2, then the heat loss (radiated per second from A is

$$Q = ms\,(dT/dt) \qquad \text{---------- } 2.10$$

dT/dt is determined by performing a subsidiary experiment. From 2.9 and 2.10 the thermal conductivity of S is

$$K = \frac{ms\,(dT/dt)}{A\,(T_1 - T_2)} \qquad \text{---------- } 2.11$$

Description of the Apparatus : The experimental arranangement of the apparatus is shown in Fig. 2.4. A brass disc A of about 10 cm in diameter is supported by means of strings from a large ring on a retort stand. The experimental material in the form of a thin slab (S) and having the same diameter as A, is placed on A. A steam chamber consists of two parts - the top part is a hollow brass cylinder C of the same diameter as S, having side tubes for entry and exit of steam while the bottom part is a thick metal plate having the same surface area as that of S. The surface of A and B are nickel plated to obtain uniform and good emmisivity. The thermometers T_1 and T_2 are introduced into two holes drilled in the base B and in A.

The whole system suspended horizontally from a stand by means of three threads attached to three small hooks provided symmetrically along the circumference of A.

By determining the value of m, dT/dt, d, A, T_1 and T_2, the value of K is measured from the eqn. 2.11.

CHAPTER THREE

EXPERIMENTAL PROCEDURE

3.1 RAW MATERIALS

The raw materials used for the manufacture of the specimens of light weight insulating bricks for this work were clay, sawdust, and molasses.

3.1.1 Clay

Dried and crushed Mymensing clay was procured from Mirpur ceramic works Ltd. This clay was dried at 100^{0}C to constant weight for chemical and mineralogical analysis.The chemical and mineralogical compositions were determined by standard chemical analysis procedure (33) and by X-ray diffraction respectively. The moisture content and grain fineness number of clay were determined according to the procedure described in ASTM C-92 (34).The chemical and mineralogical compositions, moisture content and grain fineness number are shown in Table 3.1. The X-ray diffraction pattern of the Mymensing clay is shown in Fig. 3.0 .

3.1.2 Sawdust

Sawdust of kerosene wood was procured from a local sawmill and was dried in the sun. Then the dried sawdust was sized by Taylor Sieve Analyzer. Five deferent sizes (1.68 mm--595 micron, 595 --420 micron, 420---250 micron, 250--- 149micron and less than 149 micron)

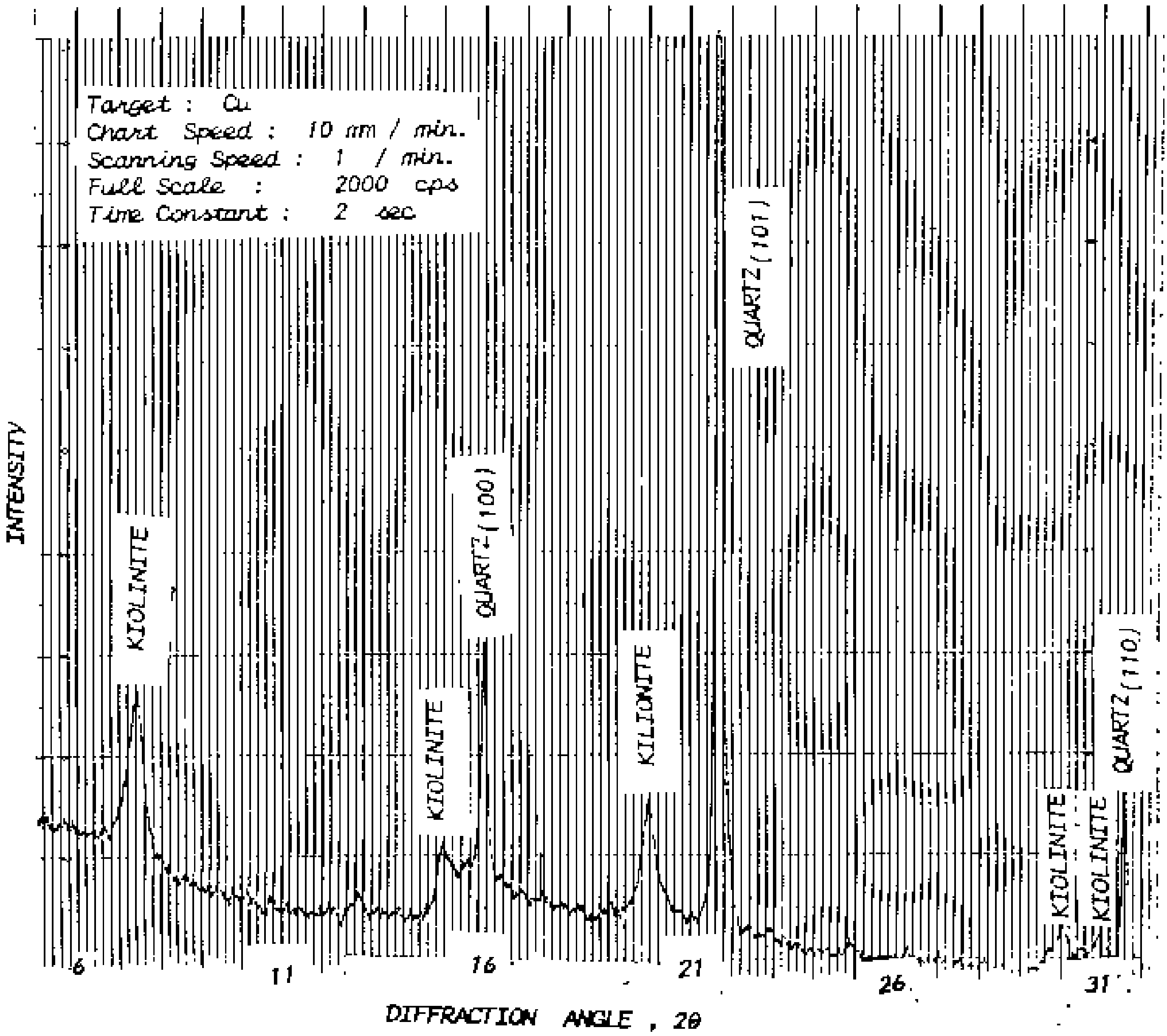


FIG. 3.0 X-RAY DIFFRACTION PATTERN OF M/MENSING CLAY

Table - 3.1 : Properties of clay

Chemical composition --	SiO_2 - 66.5%, Al_2O_3-25.5%, FeO - 5.5%, CaO -0.85% .
Phase -	Quartz (SiO_2) Kiolinite (Al_2O_3.2 SiO_2 $2H_2O$)
Moisture content --	2.23%
A.F.S Fineness No. --	160.88

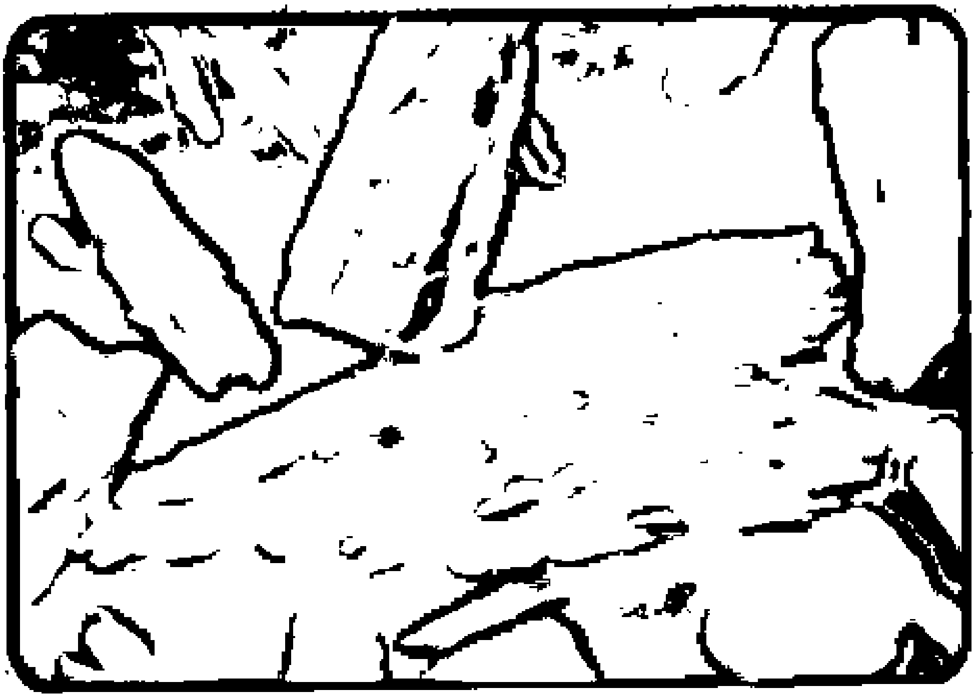
of sawdust were taken for the production of specimens The shapes of various size sawdust are shown in Fig. 3.1(a-e). Both the elongated and irregular round particles are found in them. Coarse size is found to contain greater amount of elongated particles whereas finer size is found to contain lesser amount of them. The sun dried sawdust was dried at 110^{0}C to a constant weight and finally burned at 800^{0}C and was found to contain moisture and ash 12.2% and 1.05% respectively.

3.1.3 Molasses

Molasses was collected from local market and used as a binder in the green product. To find the solid residue, it was burned at 1000^{0}C and was found to contain 7% residue.

3.2 PREPARATION OF THE SPECIMEN

The preparation of the specimens were accomplished with mixing, moulding, drying and firing. Five different sizes of sawdust were taken for the preparation of the specimens. Four different percentage of sawdust of each size were used. As a result 20 systems were made. One type of specimens were manufactured without sawdust. The types of specimens prepared with different sizes and amounts of sawdust are shown in Table 3.2.



(a)

(b)

FIG. 3.1 SHAPE AND SIZE OF SAWDUST

(a) Sawdust size 1.68mm -- 595 micron

(b) ,, ,, 595 micron -- 420 micron

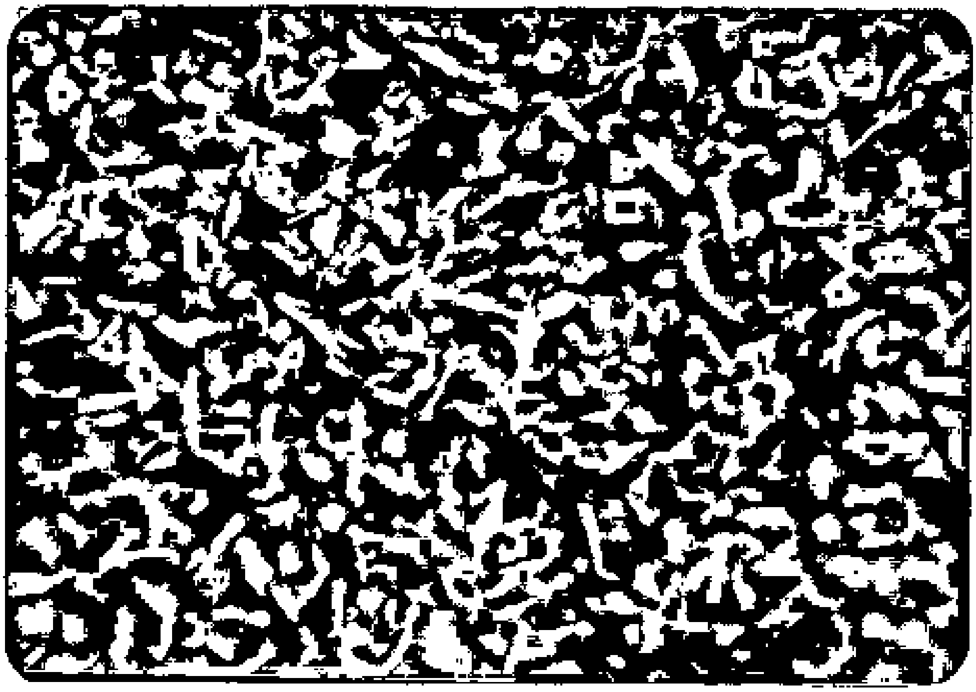
(c)

(d)

FIG. 3.1 SHAPE AND SIZE OF SAWDUST

(c) Sawdust size 420 micron -- 250 micron

(d) ,, ,, 250 ,, -- 149 ,,



(e)

FIG. 3.1 SHAPE AND SIZE OF SAWDUST

(e) Sawdust size Less than 149 micron

Table -- 3.2

Types of Specimens Prepared with Different Sizes and Amount of saudust.

Designation	Saudust size	Saudust content	clay content	Molasis cotent
1A	1.68 mm.---595 micron	7%	89%	4%
1B	,,	15%	81%	,,
1C	,,	22%	74%	,,
1D	,,	30%	66%	,,
2A	595 ------- 420 micron	7%	89%	,,
2B	,,	15%	81%	,,
2C	,,	22%	74%	,,
2D	,,	30%	66%	,,
3A	420 -------- 250 micron	7%	89%	,,
3B	,,	15%	81%	,,
3C	,,	22%	74%	,,
3D	,,	30%	66%	,,
4A	250 ------- 149 micron	7%	89%	,,
4B	,,	15%	81%	,,
4C	,,	22%	74%	,,
4D	,,	30%	66%	,,
5A	Less than 149 micron	7%	89%	,,
5B	,,	15%	81%	,,
5C	,,	22%	74%	,,
5D	,,	30%	66%	,,

3.2.1 Mixing

Hand mixing was employed to manufacture the specimens. The clay and sawdust were throughly mixed. To facilate the powder compaction process a small amount (4%) of molasses in water was added to the mixture and then the mixture was again thoroughly mixed.

3.2.2 Moulding

Specimens were prepared by hand moulding with the help of the same worker in order to be able to apply more or less the same compaction pressure during moulding. Three different size of specimens were made as follows -

Dimension	Purpose
9cm. x 4.5cm. x 3cm.	For the test of Bulk density and Cold crushing strength.
9in. x 4.5in. x 3in.	Standard size.
10 cm. Dia & 1cm thick	For the test of Thermal conductivity.

3.2.3 Drying

The compact green specimens were naturally dried for 12 days. Only standard specimens were dried by placing them on the top of the hot kiln for one day after 11 days of natural drying.

3.2.4 Firing

After the initial drying, the dried specimens were charged in a round kiln at 50^0C. The specimens were then heated slowly to 1100^oC in 54 hours and then sharply to 1250^0C in 2.4 hours. The specimens were kept at that temperature for 9 hours and then slowly cooled to 50^0C in 100 hours. The specimens were then unloaded from the kiln.

3.3 MEASUREMENT OF BULK DENSITY

Bulk density of the specimens were measured according to the procedure described in ASTM C-134 (29).

The specimens were weighed on a balance having an accuracy +/- 0.1 gm.

3.4 THERMAL CONDUCTIVITY TEST

Thermal conductivity of the prepared specimens were measured by using Lees and Cholton's apparatus . The apparatus was made as described in the article 2.2.2.3 (Fig. 2.4) in the follwing way --------- A rectangular copper sheet having dimensions of 32 cm. x 9 cm was bent and brazed to make a hollow cylinder (steam chamber), C. Two tubes (one near the top and another near the bottom were also brazed at cylindrical surface of C . One is near the top and another is near the bottom. The top surface of C was brazed with a copper sheet and the bottom with a brass disc, B. Two brass discs (10 cm dia. & 1.5 cm tick.) were made from a thick brass plate. Two radial holes having 6 mm dia. and 5 cm depth were drilled very close to one of the surface of each disc. Then the steam chamber and the discs were electroplated with nickel. The whole system was suspended horizontally from a stand by means of three threads attached symmetrically to three hooks along the circumference of A.

3.4.1 Measurement of Thermal Conductivity

The weight of disc A , the diameter and thickness of S were measured with a balance and a slide calipers respectively. Then the specimen was polished by polishing paper for good contact and it was set according to the Fig. 2.4. The steam was passed from a distant steam generator into C . The temperature T_1 and T_2 was noted at an interval of 5 min. until they remain steady , for at least three consecutive readings i.e. for 15 min.

Then steam supply was stopped and the steam chamber with disc, B was removed. With the slab, S still on the top, A was heated by a burner to a temperature of (T_2+ 10^0C) . Then the burner was removed and A was allowed to cool. By keeping S on it , it was ensured that
C
the heat lost to the surrounding is the same as in the first part the experiment when it gained heat. The cooling time was measured for every 1^0C decrease in temperature.

Then cooling curve (Fig. 3.2) was drawn and by drawing a tangent to the curve at T_2 the dT/dt was measured and the value of k was determined by using equation 2.11.

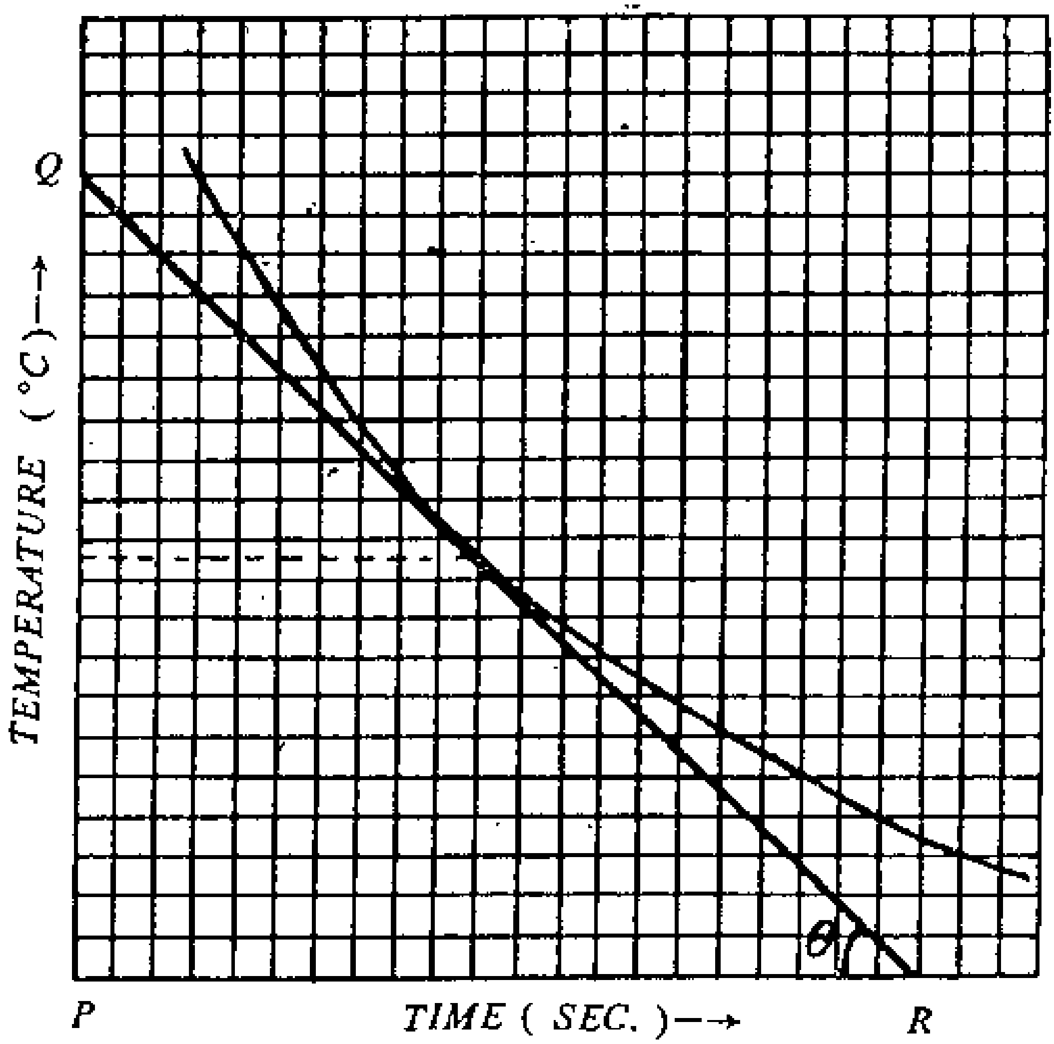


FIG: 3.2 COOLING CURVE.

3.5 COLD CRUSHING STRENGTH

The cold crushing strength was determined according to ASTM standard method C - 93 (30) .The machine used was Versa Tester 30M having an accuracy +/-10 lbs. and range up to 30,000lbs. The load bearing surfaces of the specimens were ground to make them approximately parallel planes.

CHAPTER FOUR

RESULT AND DISCUSSION

Incineration of sawdust in the clay body was found to yield clay products with a porous microstructure in the sintered bulk and observed to cause a significant modification of the physical, thermal and mechanical properties of the sawdust-clay products.

4.1 Bulk Density

As the percentage of the sawdust incorporated into the clay body was gradually increased from 7% to 30% by weight, the bulk density was found to decrease linearly (Fig. 4.1). A marked effect of the size of the sawdust content on the bulk density was found. The bulk density decreases with the increase of the size of the sawdust content in the specimens. The effectiveness of size effect increases with the increase of sawdust content.

The bulk density decreases with the increase of sawdust content due to two reasons: firstly by the addition of lighter material (sawdust) and secondly by the burning up of that lighter material. The addition of the sawdust decreases the bulk density of the unburned specimens, further reduction of bulk density occurs on burning the sawdust during firing. The volumetric contraction may however, slightly compensate this reduction in bulk density.

The effect of the size of the sawdust on the bulk density may be explained as follows : As the finer sawdust is hevier than coarser sawdust, the volume of specimen having same weight containing finer

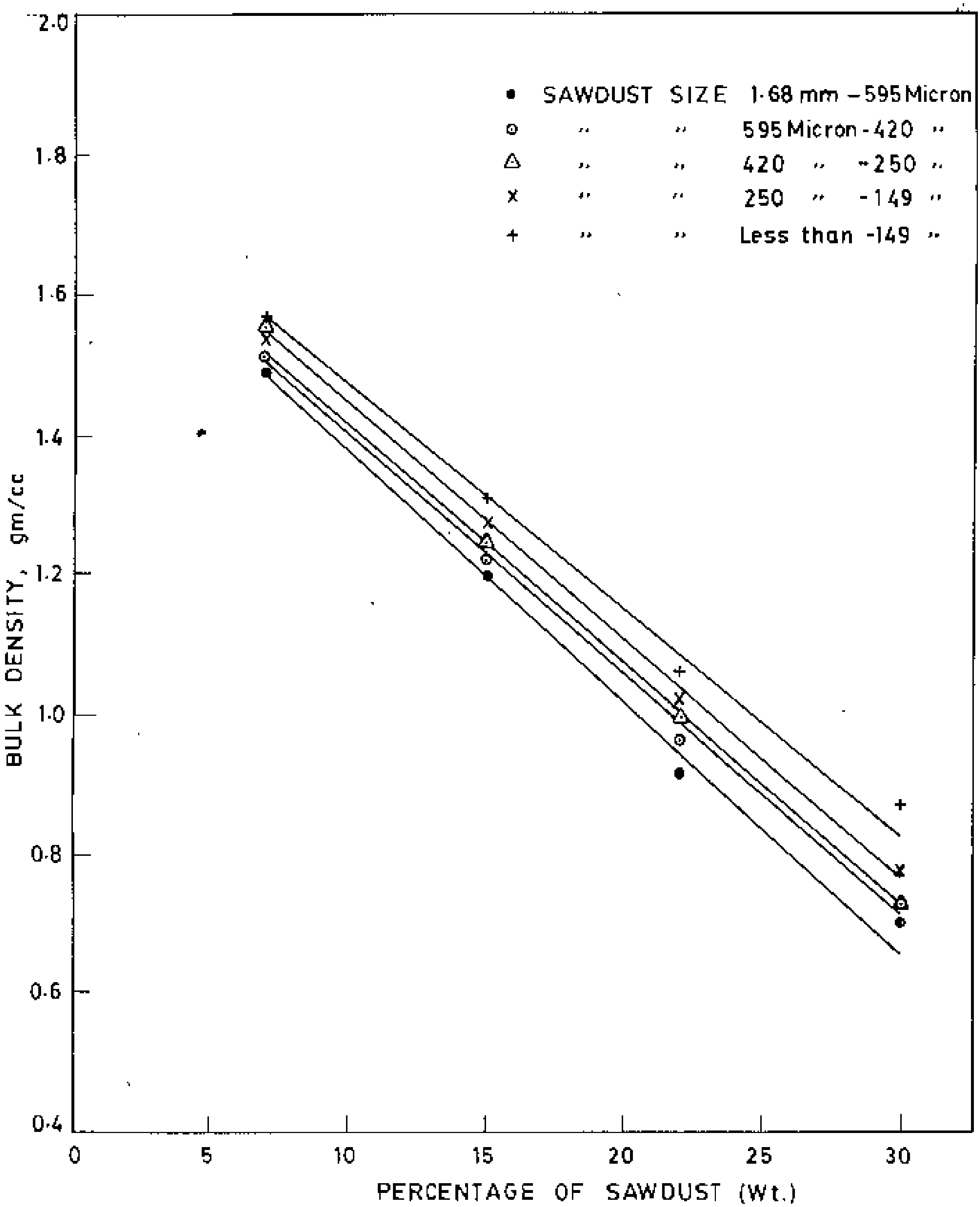


FIG. 4.1 EFFECT OF SAWDUST CONTET ON BULK DENSITY.

sawdust is lesser than that of containing coarser sadust i.e. finer sawdust gives lesser volume whereas coarser yields greater volume. For constant weight, the bulk density is inversely proportional to volume, then the bulk density of the specimens having finer sawdust is greater than that of the specimens having coarser sawdust.

4.2 THERMAL CONDUCTIVITY

The effect of sawdust content in clay sawdust system is shown in Fig. 4.2. The thermal conductivity was observed to decrease from 127.6(10^{-5}) cal/cm sec deg.C to 37.5(10^{-5}) cal/cm sec deg.C (average thermal conductivity of the specimens having 30% sawdust and five different sizes with standard daviation 2.45) as the sawdust content was increased from 0 to 30% by weight. The decrease in thermal conductivity with the increase of sawdust content is in agreement to Budnikov (14).

The decreament of thermal conductivity with the increase of sawdust content (i.e. porosity in the product) can be explained in terms of the mean free path. With the increase of porisity the mean free path decreases resulting in lower thermal conductivity (35).

In the present study a distinguishable effect of the size of sawdust content of the specimen wass not observed. This may be due to the inhomogeneity of structure.

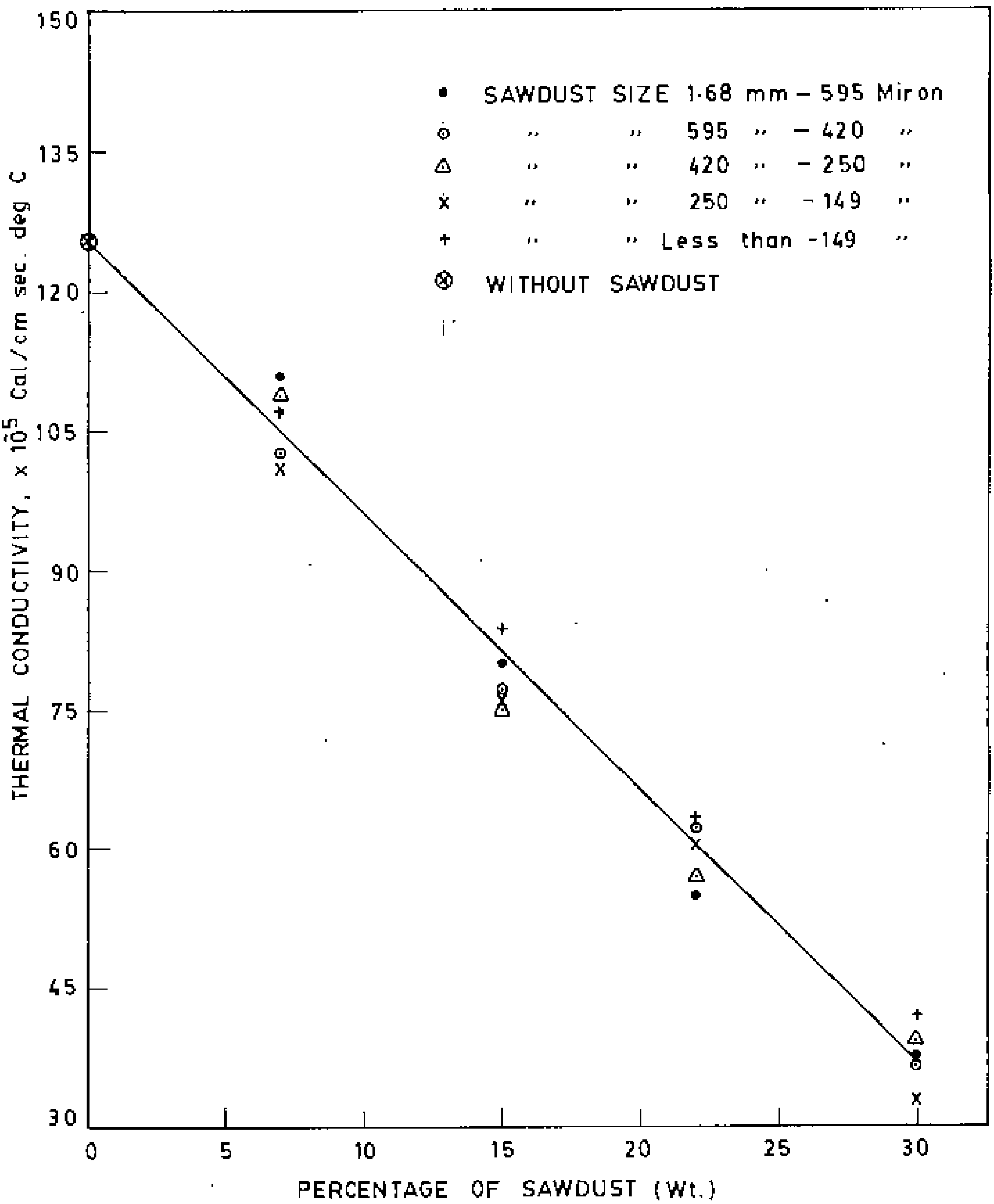


FIG. 4.2 EFFECT OF SAWDUST ON THERMAL CONDUCTIVITY.

4.3 COLD CRUSHING STRENGTH

The development of porous microstructure in the clay body was found to affect the compressive strength as shown in Fig. 4.3 . The cold crushing strength of the specimen without sawdust was found to be 4159.60 psi. This is reduced to 11.80 psi for the coarsest sawdust content of 30% by weight and to 134.93 psi for the finest sawdust content of same weight.

The compressive strength was found to decrease sharply to around 7% sawdust content and then exponentially .

A very clear effect of the size of the sawdust was also observed. The finer the size of the sawdust the higher the strength and vise versa. The difference between the compressive strength of the specimen with finest and the coarsest sawdust was found to decrease with the increases of the percentage of sawdust . On the contrary the ratio between the compressive strengh of the specimen having the finest and the coarsest sawdust increased with the increase of sawdust content.

The effect of bulk density on copmressive strength (Fig. 4.4) was found to be similar to that observed by Low et al (36).

With the increase of sawdust content the amount of voids in the specimen increases and the load bearing cross-sectional area decreases. As a result the strength decreases with the increase of sawdust content. The effect of size of the sawdust may be explained in

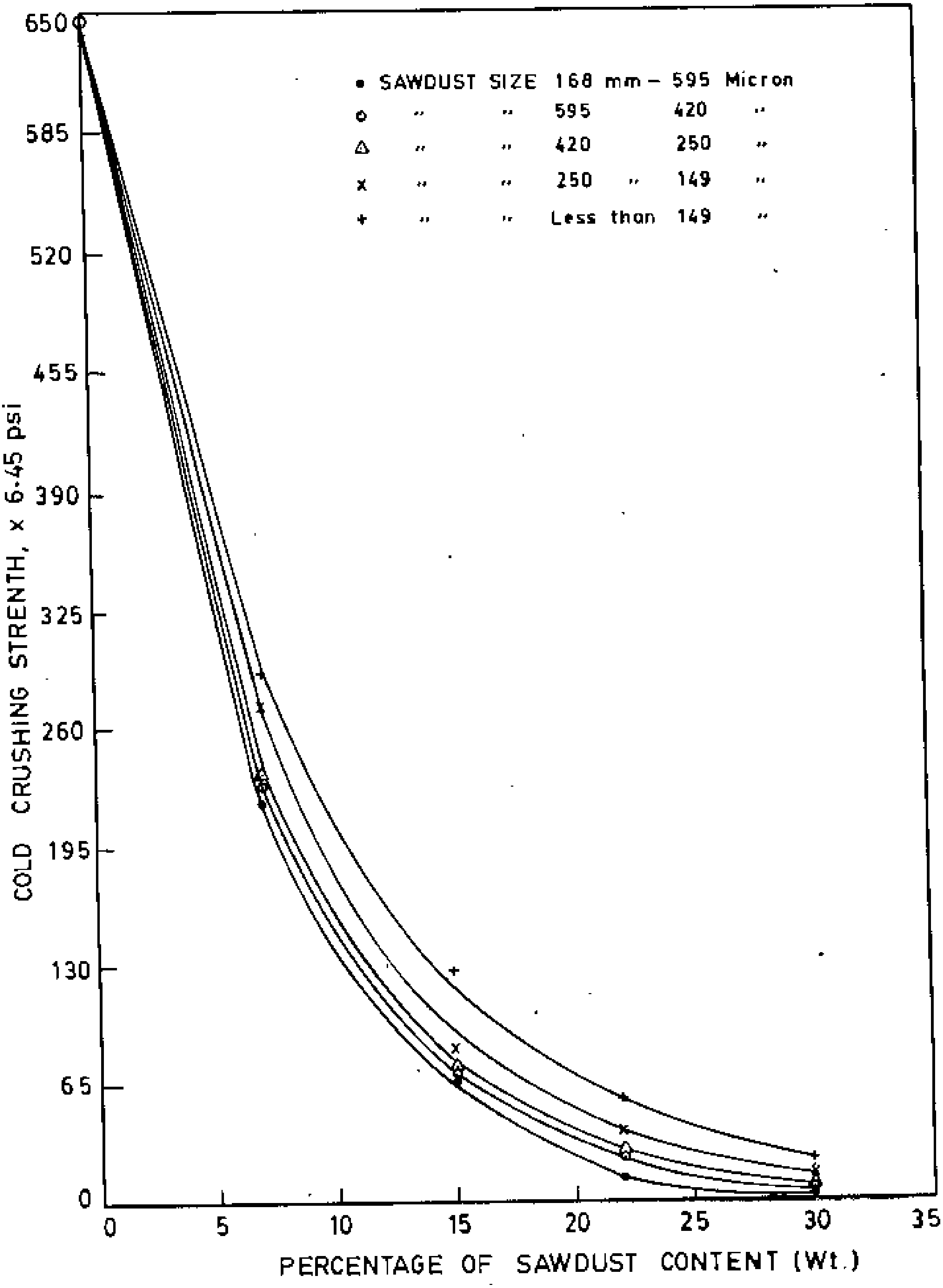


FIG. 4.3 EFFECT OF SAWDUST CONTENT ON COLD CRUSHING STRENGTH.

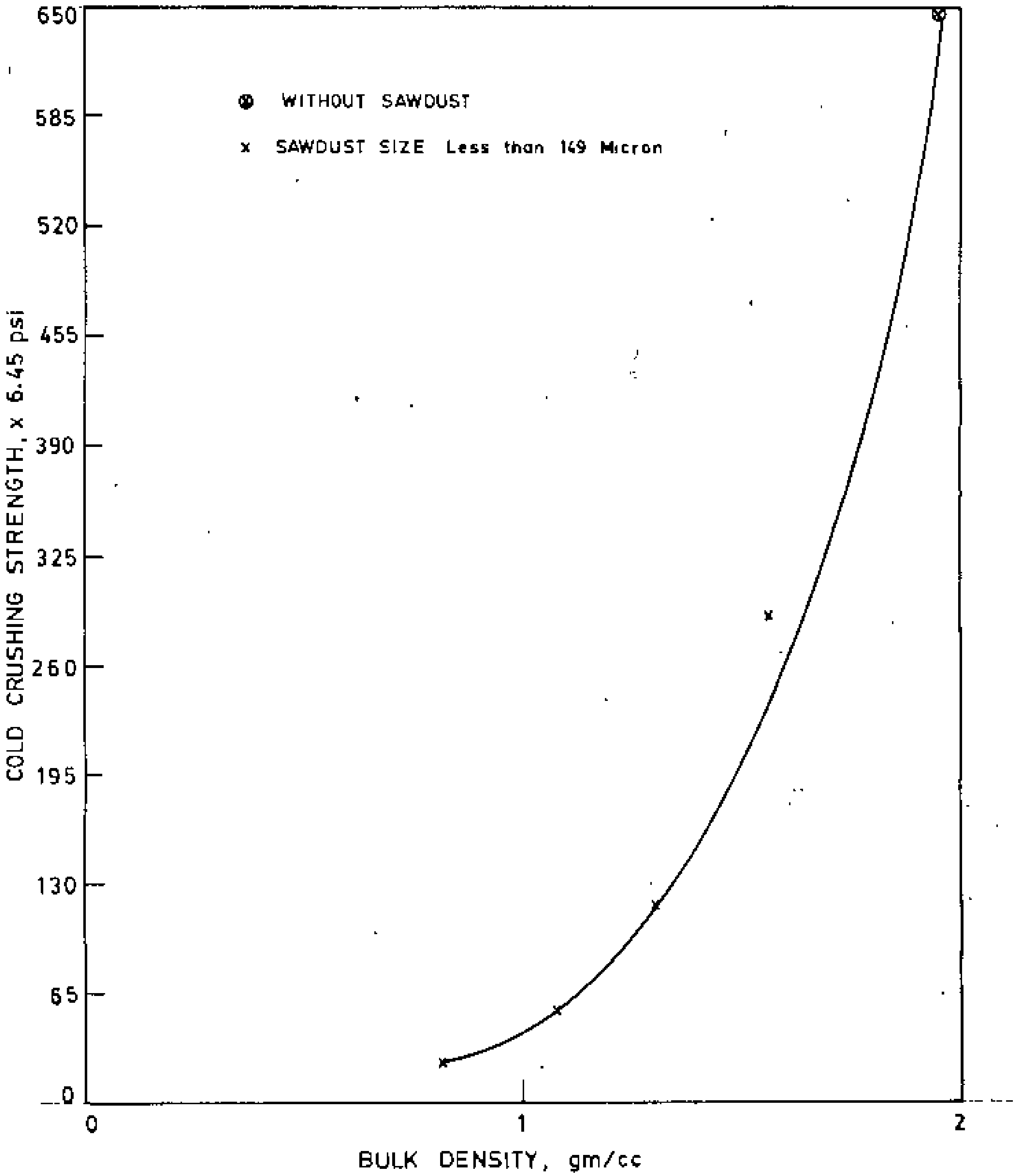


FIG. 4.4 EFFECT OF BULK DENSITY ON COMPRESSIVE STRENGTH.

the following way : Finer sawdust resulted in fine pores having small crack length than those created by the coarser sawdust particles. As a result compressive strength of the specimen having finer pore was found to be higher than that of the specimen having coarser pores . The shape of the sawdust i.e. the shape of the pore became elongated to irregular round shapes when the size changed from coarsest to finest and the number of irregular round particles in the finer size sawdust was more than that in coarser size. As a result the strees concentration factor is larger for specimens containing coarser sawdust particles and thus strength is higher for specimens containing finer sawdust than those containing coarser sawdust.

Again as mentioned before (Figs. 3.1 a-e) the coarser sawdust was relatively more elongated and has more sharp corners than the finer one. Thus the stress concentration factor of the coarser pores will be multiplied and the resulting strength of those specimens having coarser sawdust is expected to be lower than that of the specimen having finer sawdust.

The relationship between cold crushing strength and thermal conductivity of the prepared insulating bricks was derived from the curves of Cold crushing strength vs. Sawdust content and Thermal conductivity vs. sawdust content (Fig 4.2 and 4.3) and is shown in Fig. 4.5. This figuire may be used for easy selection of the insulating bricks for some specific purpose. It can also be seen from the figure that the specimen prepared by using finer sawdust gives a good combination of strength and insulation property. It has been

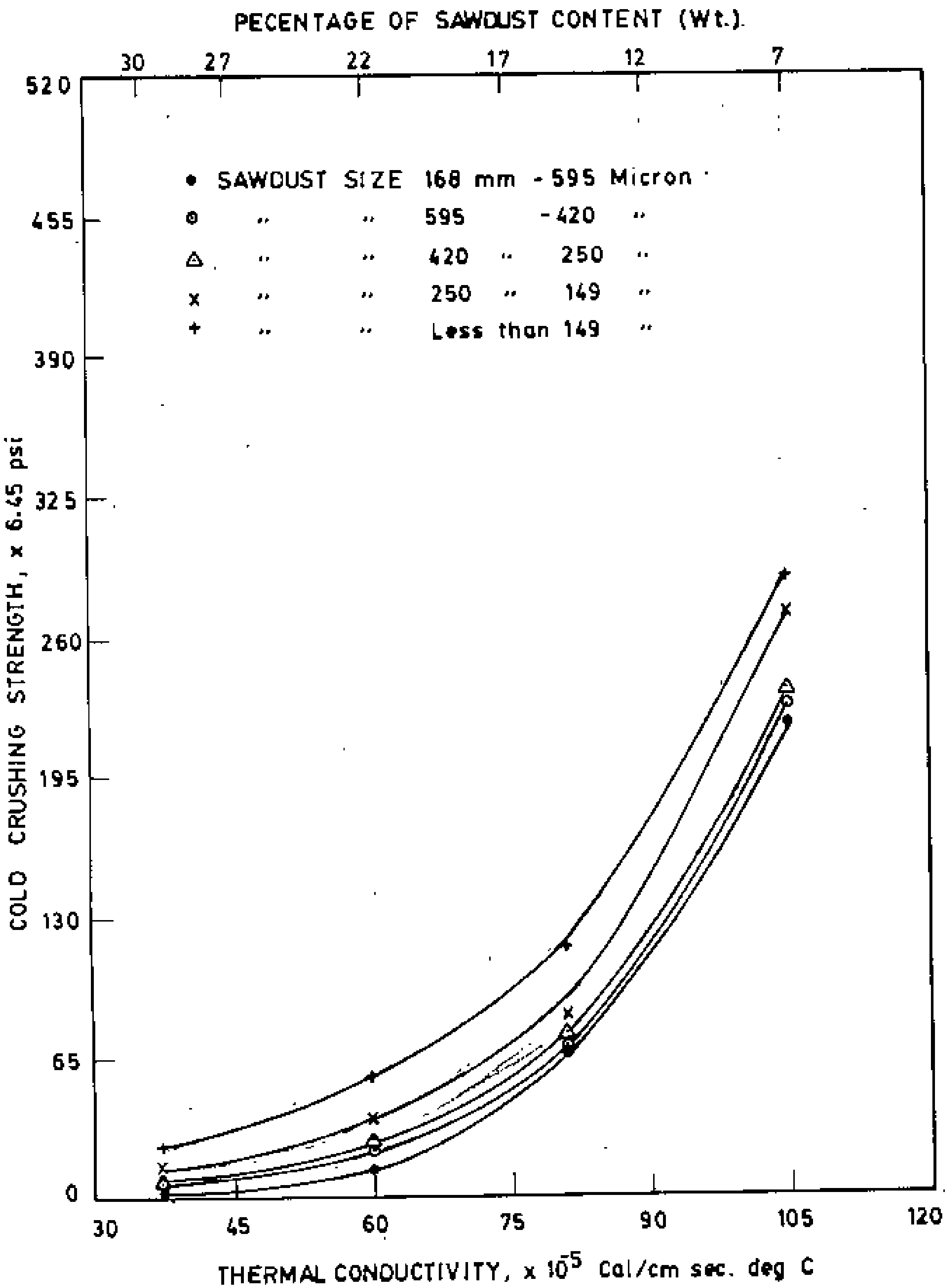


FIG. 4.5 COLD CRUSHING STRENGTH VS. THERMAL CONDUCTIVITY.

observed that pores of larger size contribute to increasingly high conductivity, while small porosity remains a good barrier to heat flow (37). Therefore at furnace temperature the bricks prepared by using finer saudust will be very effctive for heat insulation.

CHAPTER FIVE

CONCLUSION AND SUGGESTION

5.1 Conclusion

The following conclusions may be drawn from the work done so far:

1. For the same size of sawdust the bulk density decreases linearly with the increase of sawdust content. For the same of sawdust content the bulk density is higher in specimen containg finer sawdust and vise versa.

2. The thermal conductivity decreases with the increase of sawdust content. The effect of size of sawdust on thermal conductivity, however, could not be established.

3. The compressive strength decreases with the increase of sawdust content. For the same of sawdust content the finer size the higher is the compressive strength.

4. The bricks produced by using finer sawdust is suitable for a good combination of strength and insulation.

5.2 Suggestions for further work :

To establish the optimum size and content of sawdust to obtain a good combination of thermal and mechanical properties the following works are to be performed :

1. The life of refractories depends on their spalling resistance. Spalling resistance of these materials should be found out.

2. The refractories are used in the furnace at high temperatures. Therefore the thermal and mechanical properties of these refractories should be found out at higher temperatures.

3. The stability of refractories depends on their refractoriness. Without finding the temperature at which the material can survive the material can not be used efficiently. So the refractoriness of these insulating bricks must be determined.

4. The present study was done mainly on the effect of porosity. By varying clay composition it may be possible to obtain a good combination of physical, mechanical and thermal properties. In this work the clay contained a small amount of basic oxide. By increasing the basic oxide content in the the thermal conductivity might be decreased .

5. Moulding pressures and firing temperatures have a significant effect on the thermal, mechanical and physical properties. By varying them the optimization of these properties of the insulating bricks may be carried out.

6. In this work it was not possible to maintain the pressure in specimen preparation precisely constant. It can be possible by machine moulding.

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