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SMALL SCALE TEST FACILITY AND SOME FIRE RESISTANCE TEST RESULTS

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INTRODUCTION

The performance of walls, floors, beams, columns and other building members under fire exposure conditions is an item of major importance in ensuring safe constructions which are neither hazardous to neighbouring structure nor to the public. Fire performance of a building element can be characterized by two major factors :

(a) The thermal behaviour ;

(b) The structural behaviour.

All building elements used in a building construction must perform a structural function, at least to the extent that they are able to carry their own weight. Thus, generally, materials with low thermal properties are placed closest to the fire exposed surface, while those performing primarily a structural function are separated from fire by some form of protection. This is true even for reinforced concrete flexural members where the non-structural concrete on the tension side provides insulation to the reinforced steel as well as the concrete in compression.

Thus conventional building materials do not possess the ideal combination of good thermal and structural properties and it is for this reason that it is generally agreed that must effective way of preventing the spread of fire in a large building is to divide the building into a number of compartments by appropriate use of elements of satisfactory fire resistance. This technique is called compartmentation. Building elements used for compartmentation must have fire resistance slightly more than that is required for corresponding fire load for particular type of occupancy.

Fire endurance resistance of a building element is determined both theoretically (by numerical method) and practically (by conducting tests on building elements). For wall and floor elements the fire resistance test methods which are in common use are as per B. S. 476, ASTM E119, CSA-B. 54.3, A. S. A-30, I. S. 3809 and I. S. O. 834. These standard tests are essentially simulated fire exposures. One side of building element is exposed to the atmosphere of a test furnace, the temperature of which is controlled to follow a standard time-temperature curve representing an idealized building fire.

The small-scale test furnace to determine fire resistance in respect of thermal insulation criterion has been provided in Fire Research Division of Central Building Research Institute, Roorkee and is in service since 1973. This equipment is used not only for fire tests on wall or floor panels but also for fire doors, windows, proto-type record protection cabinet etc. The furnace is a research tool designed for evaluating fire resistance of building elements (wall or floor) of size 1m x 1m in respect of thermal insulation criterion only. The unique feature of the small scale test facility is its capability to evaluate fire resistance of both wall and floor or roof by providing openings both at top and in front and closing one or other of these with appropriate blanking units depending upon whether it is used for testing a floor or wall specimen.

DESIGN CRITERION OF FURNACE

In general the design requirements of furnace are :

- Suitable openings
- Furnace dimensions
- Composition and temperature conditions
- Wall construction
- Passage
- Means for elimination of undesired materials
- Adequate doors
- Furnace atmosphere
- Type of burners
- Type of fuel

Industrial or laboratory furnaces and ovens are, as a rule, used for prolonged heating of material (charged) at some constant temperature level. As the length of time, to bring the furnaces or ovens to temperature (although early is desirable), is rarely critical, the design can be based on the calculated heat loss to the surrounding at a maximum operating temperature under steady state conditions. However, in furnaces which are used to determine fire resistance of building elements, criterion, deposition of slag, elimination of flyash and furnace atmosphere are not applicable. The furnaces used are not of industrial type (which are easy to design based on steady state maximum temperature as mentioned above) but are of special type having variable temperature with time and with five sides only (the specimen under nest is mounted it such a way that it forms the closing side of the furnace) always operated under variable state conditions. Thus if we take care of testing the glazing and compare it with the fire resistance testing of light-weight concrete wall, considerably more heat energy has to be supplied in former case, to have the same time-temperature curve in both the cases, as the heat losses through glazing will be considerable higher than in the latter case. Thus, the heat requirement conditions in Fire Research furnaces vary from test to test although the standard time-temperature curve is same in all the cases.

SMALL SCALE TEST FURNACE

Simply described, the small scale test furnace is a rectangular shaped refractory brick lined steel box heated by six medium capacity gas burners. The test specimen 1.15m x 1.15m serves as top or front closer of the box. Perimeter support of the test specimen is provided by specimen holder which is supported by structural streel frame of the furnace.

FURNACE DETAILS

(a) Refractory

It can be noted from Fig. 1 that the structural frame of the furnace consists of steel plates assembled by bolting and welding. The floor and side walls of the furnace are protected by a permanent refractory system consisting of 112.5 mm. layers of light-weight insulating bricks and medium duty fire bricks. Bulk density of light-weight insulating bricks is 0.77 gm./c.c. and that of medium duty fire bricks is about 2.6 gms/c. c. The thermal conductivity of light-weight and medium duty fire bricks are 1.76×10^{-1} and 8.3×10^{-1} at 100°C & 3.66×10^{-1} and 1.218×10^{-1} KCal/hr. sq. m, C/m at 1200°C respectively. Two square frames of structural steel lined with castable refractory and vermiculite cement are fixed on top and front sides of the furnace with nuts and bolts to accommodate specimen (to be tested) and blanking cover.

(b) Burners selection and arrangement

Major consideration in the selection and arrangement of burners for the furnace are :—

— the initial high heat demand and precision temperature control posed by standard time-temperature relationship,

— the requirement of uniform heating over the entire fire exposed area of test specimen,

— avoidance of direct flame impingement upon any portion of the specimen which would cause local hot spots, and

— luminosity of flame sufficient to permit ready observation of the specimen through viewing windows even during the early phases of a fire test.

A survey of other testing furnaces of bigger size installed indicated the popular solution of this problem to be one of employing a multiplicity of independently controlled small burners. One furnace installation was equipped with a total of 80 number of burners. This design facility could not be followed due to some technical complications. The solution obtained was to use six medium capacity LPG burners mounted in three sides of the furnace and in staggered arrangement as shown in Fig. 1. Each burner has a maximum out put capacity of about 65000 Kcal/hr. and can be adjusted to project flame across 0.75 m width of combustion space. Thus, six burners, balanced and operated in unison, lay down a uniform blanket of flame which covers the plan area of the furnace at the burner level. Flame turbulance results in further filling the furnace volume with live flames to a level somewhat below the tips of the furnace thermocouples.

Burners are premixed flame type where combustion air required is sucked by burners from the atmosphere and no extra air from any equipment is needed. Liquefied Petroleum Gas having a nominal heating value of about 27500 Kcal per mm³ is used as a fuel and is fed to the burners from a 2.5 cms I. D. mains at about one atm. gauge pressure. Mixing of fuel and air occurs within the burners just before the burner flame. The burners are ignited manually with each burner having a separate valve to ensure against the escape and accumulation of any explosive mixture.

(c) Flue Gas Disposal

Spent furnace gases are removed through chimney attached to the blanking slab which is either placed in front or top depending whether test is being carried out for floor or wall specimen.

(d) Other details

One window of size 6.25 cm. dia. for viewing the fire exposed surface of the specimen during test is provided in the back wall of the facility. Low cost mica sheet provides adequate short-term service which is replaced after about six tests.

Measurement of furnace temperature for control and record purpose is accomplished by two thermocouples located in the furnace as shown in Fig. 2. The temperature of outside face of the specimen is measured by copper-constantan thermocouples soldered to a copper disc.

TESTING PROCEDURE AND CRITERION OF FIRE RESISTANCE.

Fire resistance test is carried out by exposing a test specimen to heat in a furnace so as to simulate its exposure to heat in a fire. The test specimen, in general, should be representative of the construction for which classification is desired as to materials dimensions of compartments and workmanship. When necessary, the test specimen should be conditioned before testing in order to bring its strength, moisture contents and material properties as in practice.

As far as possible, the specimen is tested under restraining conditions that are similar to actual conditions in service. Load bearing elements should also be subjected to load (should be

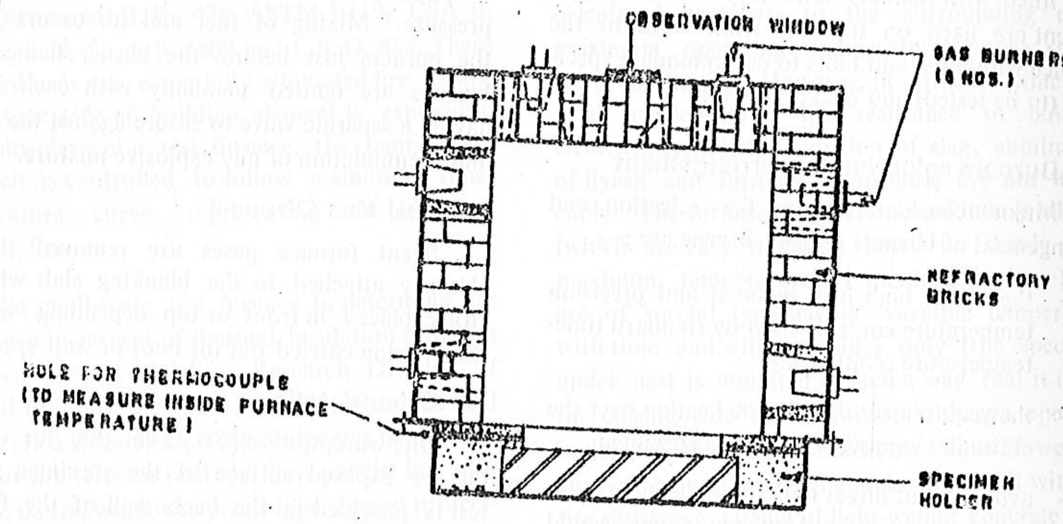

FIG. 1 SECTIONAL PLAN OF SMALL SCALE TEST FURNACE

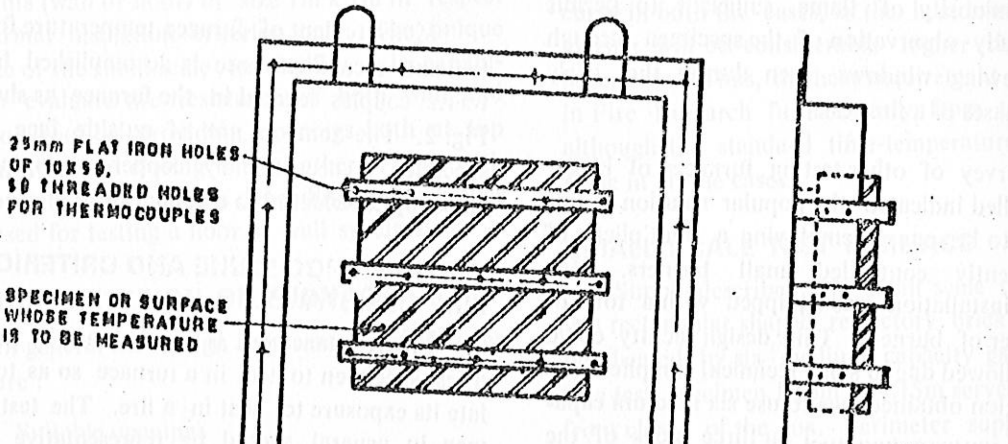

FIG. 2. ARRANGEMENT FOR TEMPERATURE MEASUREMENT OF UNEXPOSED SURFACE OF SPECIMEN.

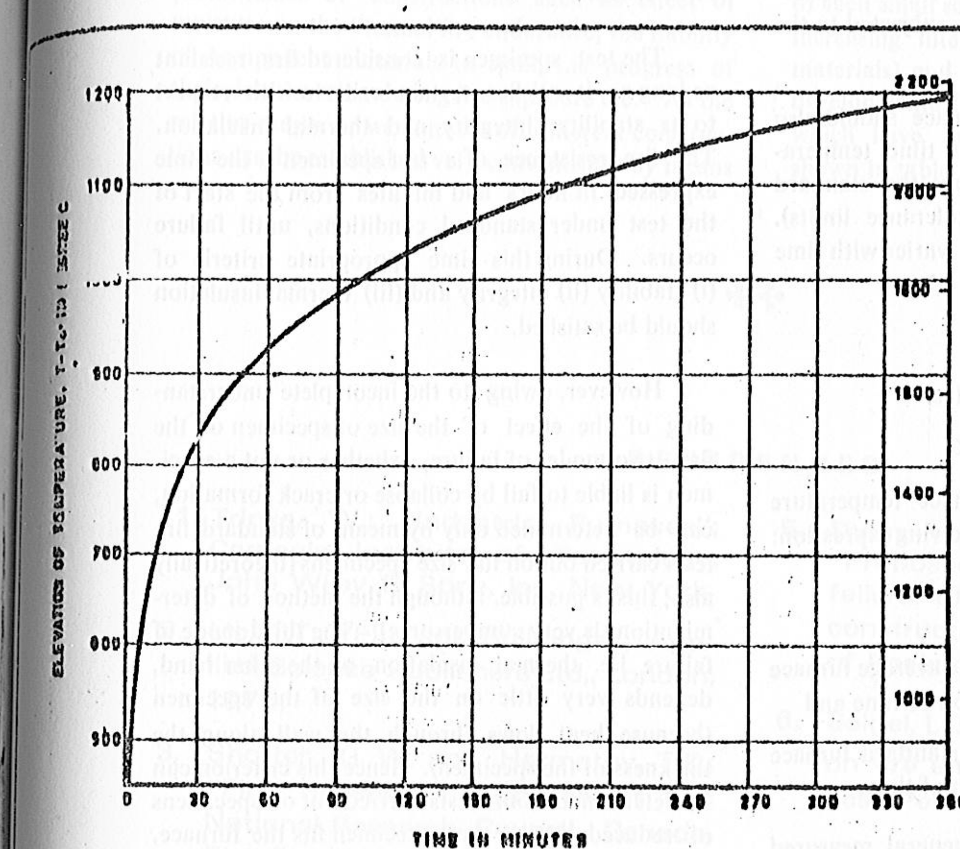

FIG. 3. STANDARD TIME-TEMPERATURE CURVE

MAXIMUM TEMPERATURE — 2300 °F

TEST DURATION — 8 HOURS.

TABLE - TEMPERATURE RISE AS A FUNCTION OF TIME

TIME t IN MINUTES	ELEVATION OF FURNACE TEMP. T-To DEGREE C	ELEVATION OF FURNACE TEMP. T-To DEGREE F
5	556	1033
10	659	1219
15	718	1325
30	821	1510
60	925	1697
90	986	1807
120	1029	1886
180	1090	1994
240	1133	2072
300	1193	2180
480 OR OVER	1260	2300

maintained constant during test) which produces stresses in the critical regions of the same magnitude that would have been produced normally in a full size specimen when subjected to the design load.

The heat input to the test furnace should also be controlled in such a way that time temperature curve obtained should follow the standard time-temperature curve (within tolerance limits). The standard furnace temperature varies with time according to the relationship (Fig. 3.)

$$T - T_o = 345 \log (8t + 1)$$

Where t is time expressed in minutes.

T is furnace temperature in °C

The mean deviation of furnace temperature as a percentage is given by the following expression:

$$M.D. = \frac{A - B}{B} \times 100$$

Where A is the integral value of the average furnace temperature as a function of time and

B is the integral value of standard furnace temperature as a function of time.

Furnace temperature are in general measured by means of Chromel-Alumel thermocouples which are placed in several locations within the furnace to give an approximation to its average temperature. Since the standard rate of change of temperature is very fast during the early stages of a fire test, a dynamic error in the temperature indicated by the thermocouples can be introduced due to this rapid rate of change. The magnitude of this dynamic error will depend upon the time lag of thermocouples and their recording device.

$T = \frac{WC}{...}(T \times \frac{1}{h}$ where $\frac{WC}{A}$ is constant for measuring arrangement).

Where W is weight of thermocouple in lbs.

h = Total heat transfer coefficient at the surface of the thermocouple.

A = Surface area of the thermocouple

T = Time lag.

If h falls within the range 5 to 50, then time constants ranging from 0.01 to 9.0 minutes may be anticipated.

The test specimen is considered fire resistant as long as it satisfies certain criteria with respect to its stability, integrity and thermal insulation. The fire resistance of a test specimen is the time expressed in hours and minutes from the start of the test under standard conditions, until failure occurs. During this time appropriate criteria of (i) stability (ii) integrity and (iii) thermal insulation should be satisfied.

However, owing to the incomplete understanding of the effect of the size of specimen on the first two modes of failure, whether or not a specimen is liable to fail by collapse or crack formation, can be determined only by means of standard fire tests carried out on full size specimens (theoretically also, this is possible, although the method of determination is very cumbersome). The third mode of failure i.e. thermal insulation, on the other hand, depends very little on the size of the specimen (because heat flows through the wall along the thickness of the specimen). Hence this criterion can be determined from tests carried out on specimens of reduced size so that specimen fits the furnace, thermal performance may be approximately same as for the full construction. But structural performance will not be same even if an attempt has been made to apply loads to develop design stresses in the specimen; for example, if we consider the case of a 10 meter long simply supported uniformly loaded beam, if this beam is reduced in length to fit a 5 meter furnace, (shear stresses can be maintained by applying the same full design load for the full size beam to the shorter specimen) the maximum normal stresses will be only one half of those developed in the full size beam because normal stresses are directly proportional to beam length square.

CONCLUSIONS

The fire resistance test for load bearing elements such as walls and floors should be conducted on full size specimens in large furnaces. However, small scale test furnace besides determining the fire resistance in respect of thermal insulation criterion can also be used to study various aspects of the performance of constructions such as effect of moisture on the thermal fire endurance, the liability of component materials to spall, the progress of their deterioration during fire exposure etc. As the relative merits or weaknesses of different constructions can be established very conveniently by means of such small scale fire endurance tests, there is an increasing interest by manufacturers (of building materials) and designer to use such tests in their developmental work. Some tests of wall panels which have been conducted on this furnace are shown in table I.

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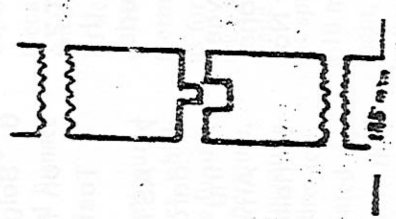
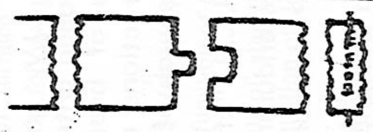
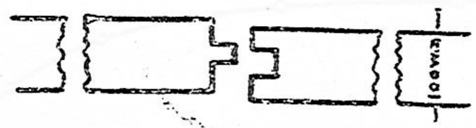
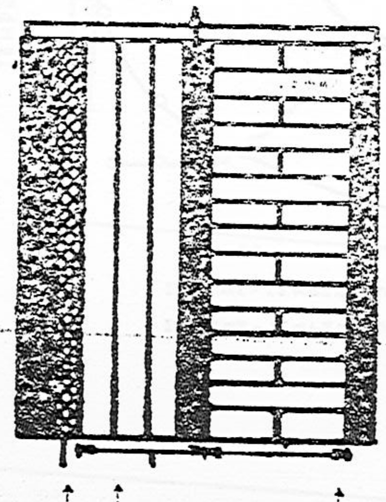
1. Trinks, W.; "Industrial Furnaces"; Carnegie Institute of Technology, John Wiley & Sons, Inc. New York.
2. Lie, T.T.; "Fire and Buildings"; Applied Science Publishers Ltd., London, 1972.
3. Shorter, G. W. and Harmathy, T.Z.; "Fire Research Furnaces at the National Research Council, Canada, Fire Study No. 1.
4. Davey, N., and Ashton, L.A.; "Investigation on building fire"; National Building Studies Research paper No. 12 (Building Research Station).
5. Dyen, J.V. and Robertson, A. F.; "Proposed criteria for defining load failure of beams, floors and roof constructions during fire tests"; J of Research of N.B.S. 63 C(2) 1959.
6. Seigel, L.G., "Effect of furnace design on fire endurance test results"; Fire Test Performance ASTM STP 464.
7. ASTM Designation: E-119-67 "Standard Methods of fire tests of building construction and materials"; American Society for Testing Materials, Philadelphia, Pennsylvania.

TABLE – I

NON-LOAD BEARING WALL PANELS - FIRE RESISTANCE TESTING

Specification of specimen	Construction details	Fire Resistance (Thermal Insulation Criterion only	Remarks
1	2	3	4
1. Lightweight foamed concrete wall panels autoclaved. Size : 1.15m x 300mm x 125mm.	Jointing mortar cement : sand (1:3). Exposed side of the specimen, plastered with two coats. 1st coat : Thickness -4mm lime, cement, sand mortar. 2nd coat : Thickness 12 to 16mm. Lime, cement, sand mortar. Total thickness of plaster not more than 20mm. 	> 5 hours (Refer Fig. 4)	1. The exposed surface plaster of specimen developed crack and fell down just after one hour. 2. Hair cracks were observed at outer surface of the panel after 170 minutes. The temp. of surface at that place was 61°C, while at the joint it was 70°C. 3. The exposed surface of the panel after cooling becomes yellowish (colour change) and approx. 2cms. thick pieces spalls froms this surface. (Test discontinued).
2. Lightweight foamed concrete wall pannels autoclaved. Size : 1.15m. x 600mm. x 100mm.	 Mode of construction same as in 1 above.	7 hours (Refer Fig. 5)	1. Vertical cracks appeared on plasrer of exposed surface after 45 minutes and plaster fell down after 95 minutes. 2. Small cracks on the exposed surface after 180 min. 3. Same as in 1 above.

NON LOAD BEARING WALL PANELS - FIRE RESISTANCE TESTING

Specification of specimen	Construction details	Fire Resistance (Thermal Insulation Criterion only	Remarks
1	2	3	4
3. Lightweight foamed concrete wall panels autoclaved. Size : 1.15m x 250mm. x 100 mm.	 Mode of construction same as in 1 above.	7 hours (Refer Fig. 5)	1. Exposed surface behaviour same as in 2 above. 2. Small cracks on the exposed surface after 180 minutes. 3. Same as in 1 above.
4. Sandwitch brick and styropor foam construction. Size : 1150 x 1150 x 316mm. Styropor foam slab Size : 1150x1150x25mm.	12 mm. Cement Sand (1 : 4) plaster  225 mm brick wall 75 mm Styropor foam slabs Chicken wire mesh	>5 hours 15min. (Refer Fig. 7)	1. On the exposed surface cracks visible on plaster after 20min. 2. Horizontal cracks became bigger in size after one hour. 3. Thermocole started melting and comes out through cracks and burns with flame after 152 min. This continued upto the end of 3rd hour. 4. After 4½ hours the temperature of the unexposed face remains constant.

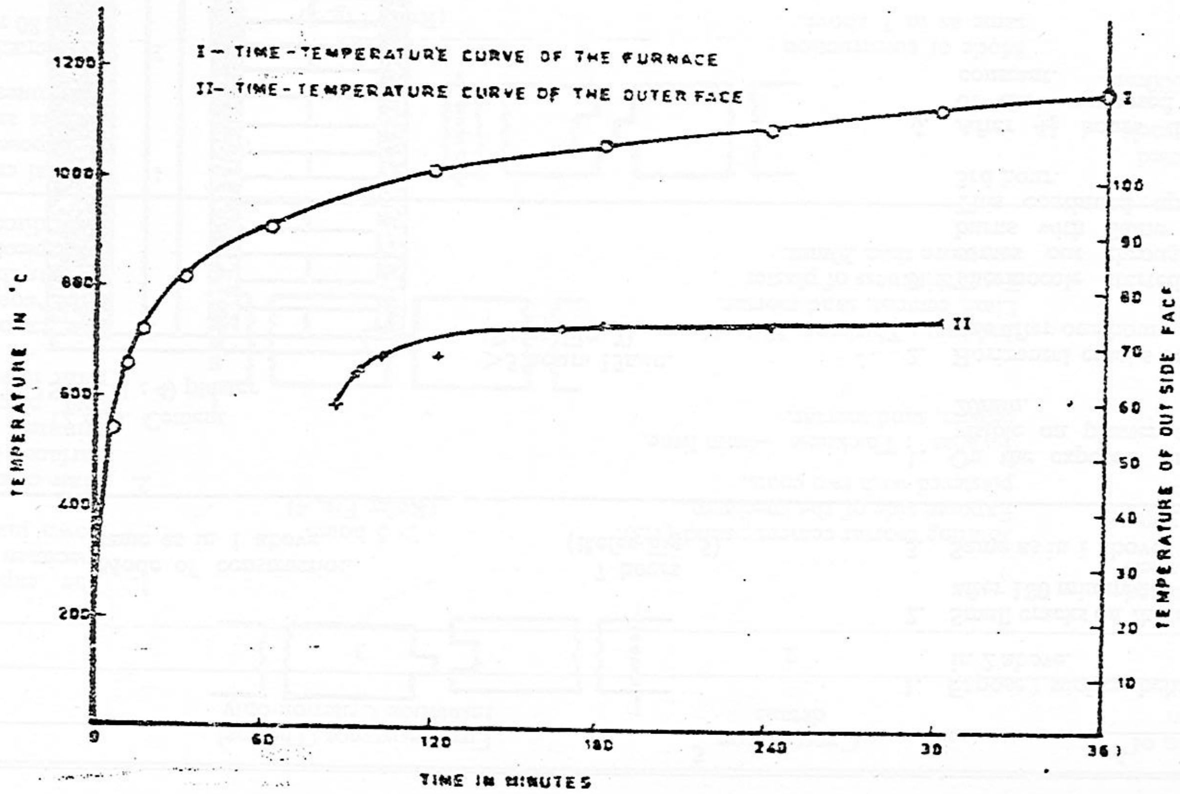

I — TIME-TEMPERATURE CURVE OF THE FURNACE
II — TIME-TEMPERATURE CURVE OF THE OUTER FACE
TEMPERATURE IN °C
TEMPERATURE OF OUT SIDE FACE
TIME IN MINUTES
I
II

FIG 4

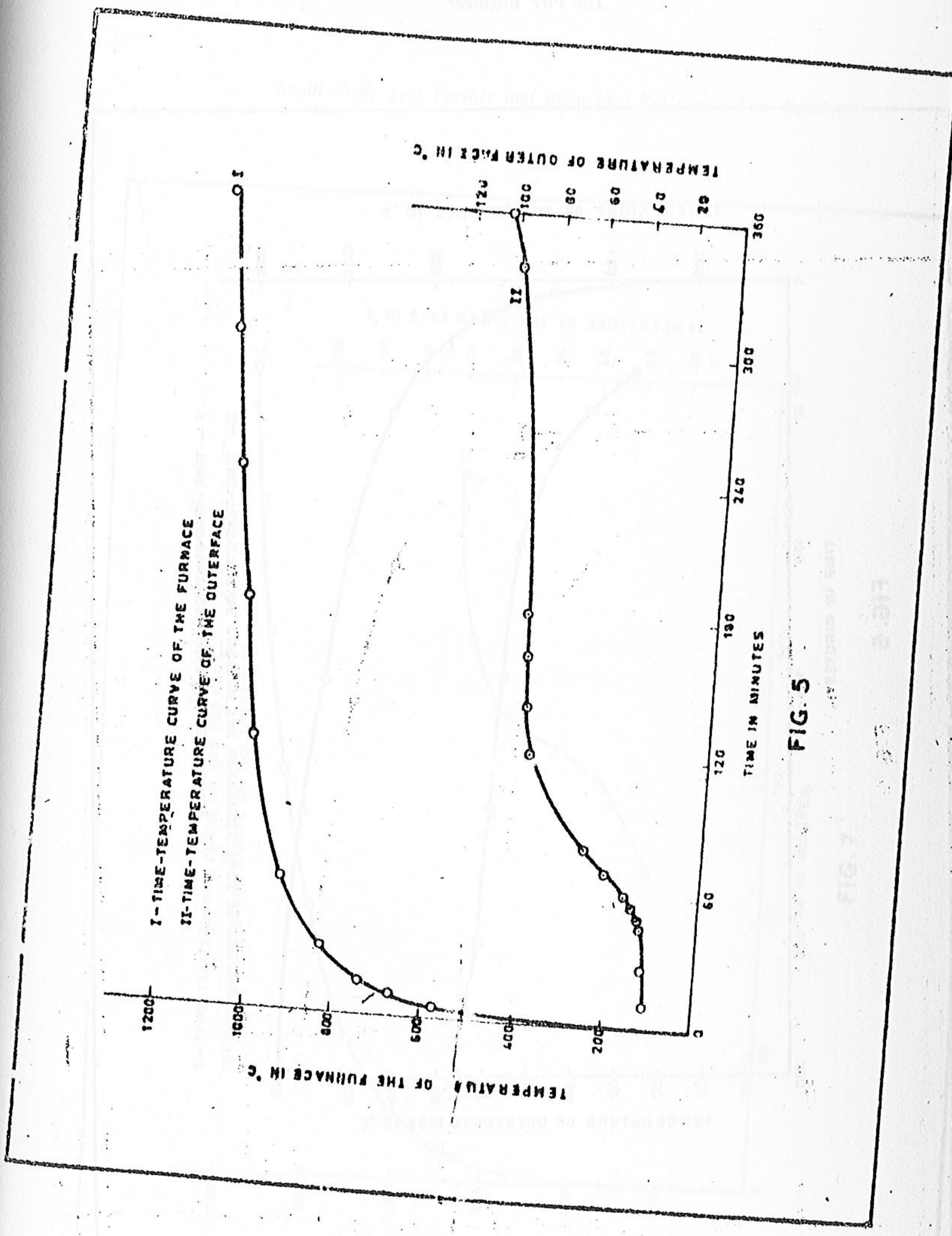

I - TIME-TEMPERATURE CURVE OF THE FURNACE
II - TIME-TEMPERATURE CURVE OF THE OUTERFACE
TEMPERATURE OF THE FURNACE IN °C
TEMPERATURE OF OUTER FACE IN °C
TIME IN MINUTES
0
60
120
180
240
300
360
200
400
600
800
1000
1200
20
40
60
80
100
120
I
II

FIG. 5

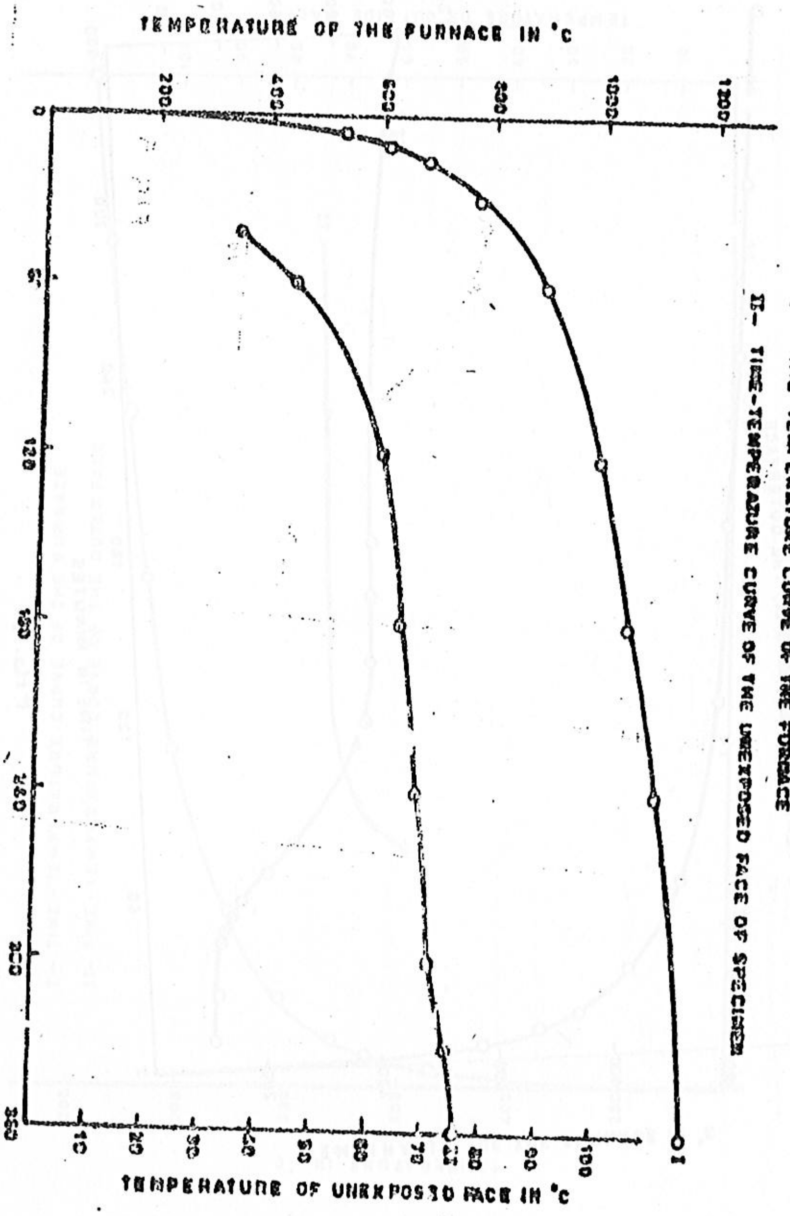

TEMPERATURE OF THE FURNACE IN °C
I — TIME-TEMPERATURE CURVE OF THE FURNACE
II— TIME-TEMPERATURE CURVE OF THE UNEXPOSED FACE OF SPECIMEN
TIME IN MINUTES
TEMPERATURE OF UNEXPOSED FACE IN °C

FIG. 6

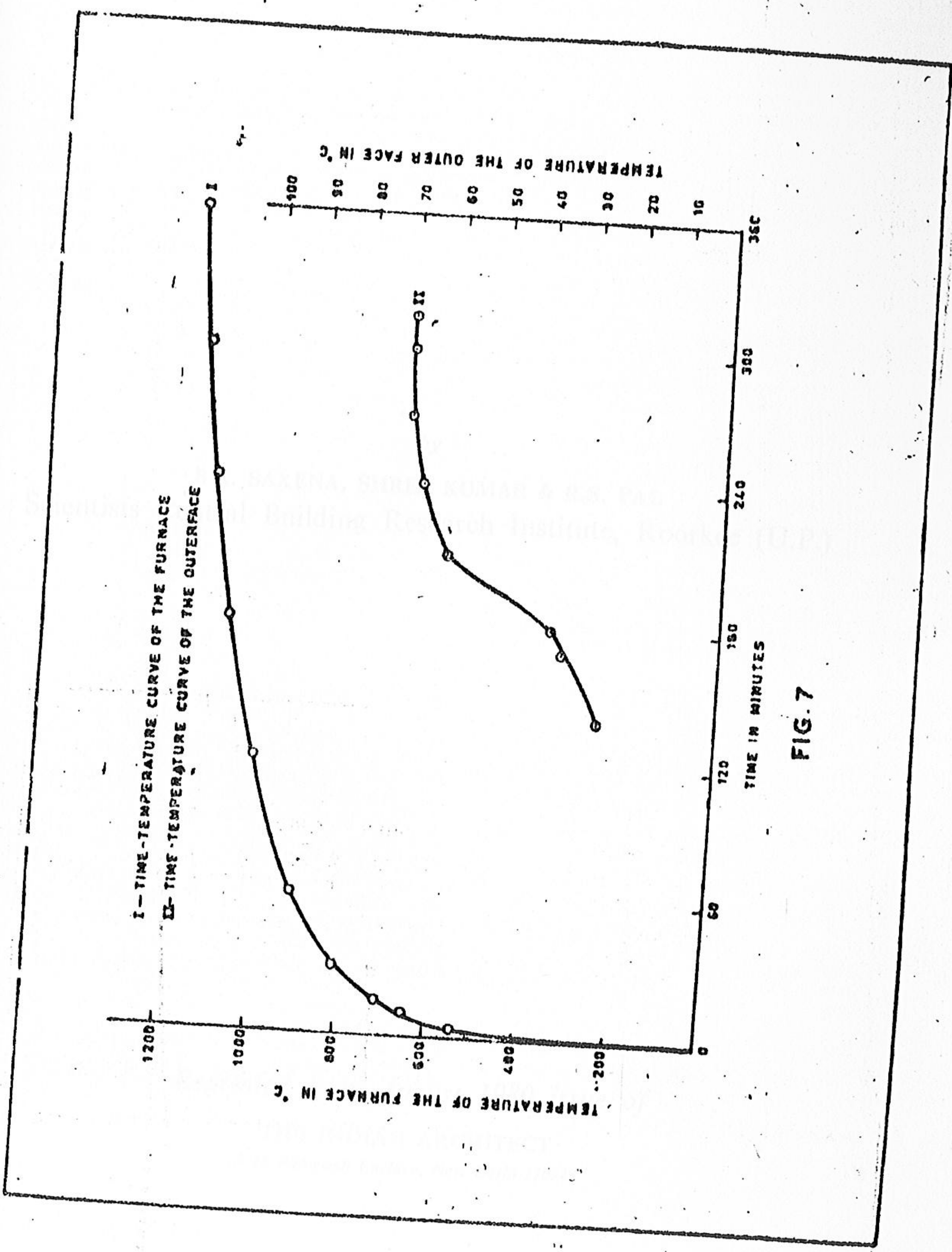

I — TIME-TEMPERATURE CURVE OF THE FURNACE
II — TIME-TEMPERATURE CURVE OF THE OUTERFACE
TEMPERATURE OF THE FURNACE IN °C
TEMPERATURE OF THE OUTER FACE IN °C
TIME IN MINUTES
I
II
0
60
120
180
240
300
360
200
400
600
800
1000
1200
10
20
30
40
50
60
70
80
90
100

FIG. 7