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The Behaviour of Autoclaved Aerated Concrete Blocks, Supplied by Thermalite Ltd., in the Fire Protection of Structural Steel Columns

British Steel Corporation

Research Organisation

THE BEHAVIOUR OF AUTOCLAVED AERATED CONCRETE BLOCKS, SUPPLIED BY THERMALITE LTD., IN THE FIRE PROTECTION OF STRUCTURAL STEEL COLUMNS

D.J. Latham G. Thomson R.R. Preston

SYNOPSIS

Indicative fire tests have been carried out on 203 x 203 mm x 52 kg/m blocked in columns to determine the influence of the density of the concrete blocks on heat transfer. Autoclaved aerated concrete blocks in densities ranging from 534 kg/m^3 to 875 kg/m^3 provided similar insulation to the steelwork and are suitable for a ½ h fire resistant design. The thermal conductivity of the blockwork increased with temperature. At a mean temperature of 600°C the thermal diffusivity is similar to certain sprayed fire protection coatings but becomes inferior at higher bulk temperatures.

KEY WORDS

3. +BS 476
4. Fire Protection
5. Concrete Aerated
6. Columns
7. Thermal Conductivity
8. Design
9. Lab Reports

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1. INTRODUCTION

A series of design guides describing means of designing fire resistant steel structures, without the specialist application of conventional fire protection materials, is being prepared in collaboration with the Building Research Establishment (DoE). The first guide describes designs for free standing steel columns to provide a ½ h fire resistance rating. Large columns, with H_p/A ratios less than 50 m^{-1} have sufficient inherent fire resistance to be used in the fully exposed state. For smaller column serial sizes the required fire resistance is obtained by the use of blockwork between the column flanges.

The principal autoclaved aerated concrete blocks are supplied under the trade names of Celcon, Durox and Thermalite. They are manufactured from cement, lime, sand, pulverised fuel ash and aluminium powder. Once these materials are mixed with hot water the aluminium reacts with the lime to form hydrogen; the slurry subsequently increases in volume forming a micro-cellular structure which gives insulation, lightweight and strength, Fig. 1. The material is then cut into the sizes required by the customer and cured by high pressure steam in autoclaves to make them physically and chemically stable. The important material properties with regard to thermal performance are given for each block type in Table 1. The data have been obtained from the trade literature and show that at ambient temperature the thermal diffusivity increases with the nominal density of the block.

Experiments have shown that the transfer of heat to a steel surface in intimate contact with the insulant is comparatively insensitive to changes in specific heat of the insulant with increasing temperature but that changes in thermal conductivity can have a more significant effect. It was therefore important to determine the extent to which the thermal conductivity of autoclaved aerated concrete blocks changes with temperature. The volume of moisture in the block also influences behaviour.

At the time when the first draft of the BRE design guide was prepared four BS476:Part 8 fire tests had been carried out on columns with the webs protected by aerated concrete blocks. The measured densities of the blockwork ranged from 582 to 865 kg/m^3 and the moisture content from 5.0 to 9.0%. With one exception the actual block type used in the construction was not known. On the evidence available at the time it was decided to restrict the block densities used in the design to >650 kg/m^3 until more information became available.

Discussions on fire resistant steel design were subsequently held with Thermalite Ltd. who were interested in the concept of blocked in columns. The company supplied autoclaved aerated concrete blocks of known density for further study. This report describes the BS476:Part 8 indicative fire tests on blocked in columns using these materials together with thermal conductivity measurements on the blocks using the hot wire method.

2. EXPERIMENTAL PROCEDURE

Thermalite Ltd. provided the following autoclaved concrete blocks:-

(a) 'Turbo' - approximate dry density 490 kg/m^3, reference HT46 and identified by 6 wavy scratches.

(b) 'Shield' - approximate dry density 685 kg/m^3, reference HS46 and identified by 9 wavy scratches.

(c) 'Hi-strength' - approximate dry density 745 kg/m^3, reference HH46 and identified by 4 wavy scratches.

2.1 Indicative Fire Test

A 203 x 203 mm x 52 kg/m BS4360:Grade 43A universal steel column was obtained from a local steel stockholder and cut into three indicative specimens, each 900 mm in length. Six chromel/alumel (Pyrotenax) 3 mm diameter thermocouples with Inconel sheaths and insulated hot junctions were attached to each of the columns. These thermocouples were located at a distance of 300 mm from each end of the column at the centre of the web and at the quarter width positions on the outside of diagonally opposite flanges, as shown in Fig. 2. The 3 mm diameter thermocouples were embedded into the steel to a depth of approximately 6 mm. The columns had lightweight blocks built between the flanges using respectively 'Turbo', 'Shield' and 'Hi-strength' material held in position using ordinary strength mortar.

The furnace atmosphere temperatures were recorded by additional thermocouples located at a position of 25 mm from the exposed flange of each column.

All thermocouple outputs were monitored during the fire test using a Compulog 4 computer controlled data acquisition system and the information was stored on a floppy disc.

2.2 Thermal Conductivity Measurement

The hot wire technique is more rapid than the steady state panel test approach and is considered to be the more appropriate for fire protection materials. In principle, this depends upon surrounding an electrically heated wire by the material under investigation and measuring the rate at which the wire temperature rises.

The autoclaved aerated concrete blocks were cut into bricks measuring 200 x 100 x 50 mm thick. The moisture content (in wt. %) and density of each sample at the time of the test were measured. Two bricks of the same density were pressed together by a weight to ensure that they were in intimate contact with the Ni-chrome heating ribbon. Once the insulant had been stabilised at a chosen temperature, determined by a chromel alumel thermocouple attached to the ribbon, the value of thermal conductivity was displayed as a digital read out on the Kyoto Electronics Manufacturing Co. Ltd. meter TC-31.

The thermal conductivity of Thermalite blocks HT46 and HH46 was measured at increasing temperatures up to a maximum of 1000°C. The blocks of intermediate density were examined at room temperature and at 200, 650 and 800°C.

3. RESULTS AND DISCUSSION

The steel temperature data recorded from each blocked in column are given in Tables 2 to 4 together with the furnace atmosphere temperatures. When 30 min of the BS476:Part 8 test had elapsed the gas temperatures in the vicinity of the 'Hi-strength', 'Turbo' and 'Shield' blocks were respectively 871, 829 and 801°C, whereas the ISO temperature was 834°C. On completion of the test the gas temperatures in the vicinity of the columns ranged from 932 to 984°C, the corresponding ISO temperature being 942°C.

The average temperatures measured in the flanges of each column are shown in Fig. 3. The behaviour of the steelwork in contact with the 'Turbo' and 'Hi-strength' blocks was identical despite the differences in the associated gas temperatures (the flange temperatures after 30 min being approximately 620°C). Thus, the use of the lightest and the heaviest autoclaved aerated concrete blocks gave similar thermal response. The 'Shield' material was not as consistent; although the furnace heating rate in its vicinity was the lowest of all three indicative samples the associated rise in temperature of the steel flange in the later stages of the test was the highest. After 30 min, for example, the average temperature of the flange beneath the 'Shield' blocks was 40°C greater than beneath the 'Turbo' material.

The average temperatures measured in the webs of each column are shown in Fig. 4. Irrespective of the blockwork density the behaviour of the steelwork was identical. The web temperature after 30 min was 314°C. Tests on foamed concrete have shown that for a given rise in temperature of the unexposed surface the fire endurance increases with a decrease in unit weight[1]. For example, based on a rise in temperature of 139°C a 50 mm thick slab with a dry density <700 kg/m^3 would satisfy a 1 h rating. The Building Standards (Scotland) Regulations 1981 quote a minimum thickness of 60 mm for autoclaved aerated concrete blocks of different density to satisfy up to 2 h fire resistance. The thickness of the blockwork used in this exercise was far greater than this requirement.

The laboratory thermal conductivity measurements on the three blockwork types are presented in Table 5. The bulk densities were found to be about 8% greater than the approximate figures supplied by Thermalite Ltd. In common with lightweight refractory concretes the thermal conductivity, λ_i, at ambient temperature increased with density from 0.13 W/m K at 534 kg/m^3 to 0.21 W/m K at 815 kg/m^3. Despite differences in the weight percentages of retained moisture, the hot wire method gave results similar to the traditional panel test. For example, 'Hi-strength' registered the respective thermal conductivity values of 0.21 and 0.19 W/m K with moisture contents of 7.2 and 3.9%.

The KEM hot wire method has close similarities to the procedure proposed in BS1902-Section 5.6 (1985) for testing refractory materials[2]. The elevated temperature thermal conductivity values for the three Thermalite materials are shown in Fig. 5. In general, the 'Turbo' and 'Hi-strength' followed a similar trend with little change in λ_i up to 400°C followed by a more rapid rise thereafter. This might be a consequence of the significance of radiative heat transfer with rise in temperature, being roughly proportional to T^4. Accurate measurement relied on the maintenance of intimate contact between the mating blocks and the heating wire throughout the exercise. The 'Shield' material developed extensive craze cracking at the higher temperatures as shown in Fig. 6. This behaviour gave the uncharacteristically high value of thermal conductivity that was measured at 650°C and presumably influenced the steel heating rates observed during the later stages of the indicative fire test on the steel column incorporating 'Shield' blocks.

The passive fire protection of steelwork can be achieved by using a number of materials. One of the cheapest methods involves the sprayed application of mineral coatings. The variation of the thermal conductivity of sprayed vermiculite cement and perlite with temperature, as measured by the hot wire method[3], are compared with the 'Hi-strength' results in Fig. 7. These materials have similar densities. The calculated behaviour of a lightweight concrete is also included[4]. The data from the autoclaved aerated blocks fit within the envelope of the curves.

Apart from thermal conductivity, λ_i, the volumetric specific heat, ρCp, is an important property which indicates the ability of the insulant to store heat. An average value of specific heat is generally accepted for calculation purposes, typically 1050 J/kg°C for the more dense sprays and 1200 J/kg°C for cellular concrete. By reference to Fig. 7, therefore, the rates of heat transfer (λ_i/ρ_{Cp}) through the blockwork and the sprayed coatings are similar for a mean insulant temperature of 600°C but the blockwork is inferior at higher temperatures.

The general observations from this investigation have shown that, autoclaved aerated concrete blocks in the range of densities normally supplied provide similar protection to 203 x 203 mm x 52 kg/m universal columns. This 'blocked in' section represents the lightest member to achieve ½ h fire resistance under maximum compressive load (BS449:1969). On the basis of current test data the extent to which this concept can be extended to other free standing sections is limited to an exposed H_p/A value of <69 m^{-1}, a flange thickness of >12.5 mm and an individual block thickness >60 mm provided that stability of the section under load is satisfied.

4. CONCLUSIONS

Free standing 203 x 203 mm x 52 kg/m universal columns with blocked in webs achieved ½ h fire resistance under maximum applied load as determined by BS449:Part 2:1969. Autoclaved aerated concrete blocks ranging in density from 534 to 815 kg/m^3 provided similar fire protection to the steelwork. The average flange temperature after 30 min in the BS476:Part 8 fire test was 620°C and the average web temperature was 314°C for columns fitted with Thermalite 'Turbo' and 'Hi-strength' blocks. Although the web temperatures were similar beneath 'Shield' blockwork the corresponding flange temperatures were 40°C higher.

Thermal conductivity measurements at 20°C using the hot wire method increased with density from 0.13 W/m K at 534 kg/m^3 to 0.21 W/m K at 815 kg/m^3. The thermal conductivity increased with temperature particularly above 400°C. Typical values at a block temperature of 600°C were 0.23 W/m K for a density of 534 kg/m^3 and 0.35 W/m K for the highest density examined. These results were consistent with measurements on other fire protection materials. Care was necessary to ensure that any thermal distortion was kept to a minimum and that no cracks in the material influenced the measurements.

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D.J. Latham
Principal Investigator

G. Thomson
Investigator

R.R. Preston
Manager,
Rails and Sections Department

J. Lessells
Research Manager -
General Steel Products

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TABLE 3 STEEL HEATING RATE - 'SHIELD' BLOCKS

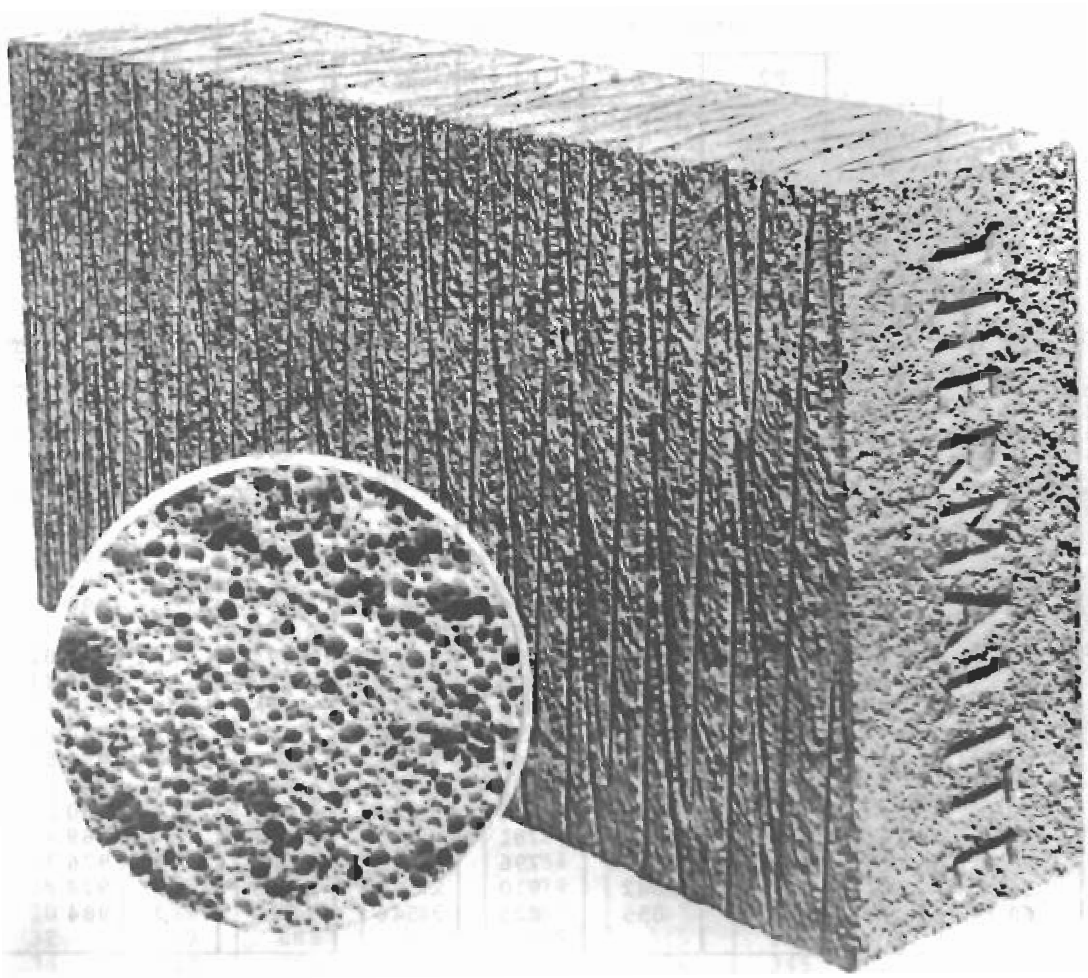
Time	Steel Temperature, °C						Furnace Temperature °C
	F1	F2	F3	F4	W1	W2	
0	11	12	13	11	11	11	12
2	40	70	39	53	13	10	474
4	87	130	78	95	17	15	544
6	151	196	136	151	28	25	656
8	213	250	188	195	45	41	677
10	282	308	248	242	96	65	726
12	347	363	306	291	101	97	705
14	406	412	356	338	128	125	695
16	457	452	401	375	152	150	703
18	513	495	457	419	175	173	741
20	577	547	518	574	211	208	758
22	596	564	536	491	223	219	759
24	627	594	570	524	245	241	765
26	655	621	598	554	268	263	778
28	678	643	622	579	280	284	785
30	699	665	646	603	313	305	801
32	719	683	668	625	335	325	813
34	733	703	687	647	356	345	818
36	744	720	706	667	376	363	830
38	757	738	723	687	395	382	841
40	773	751	740	706	414	400	850
42	789	760	751	723	431	417	860
44	806	773	763	740	448	434	871
46	821	789	777	751	464	450	880
48	839	805	794	762	479	465	886
50	854	820	809	776	493	480	895
52	866	835	823	791	507	493	902
54	879	850	839	807	520	507	912
56	890	864	853	821	534	520	915
58	900	878	866	837	547	533	926
60	908	890	879	853	560	545	932

TABLE 4 STEEL HEATING RATE - 'HI-STRENGTH' BLOCKS

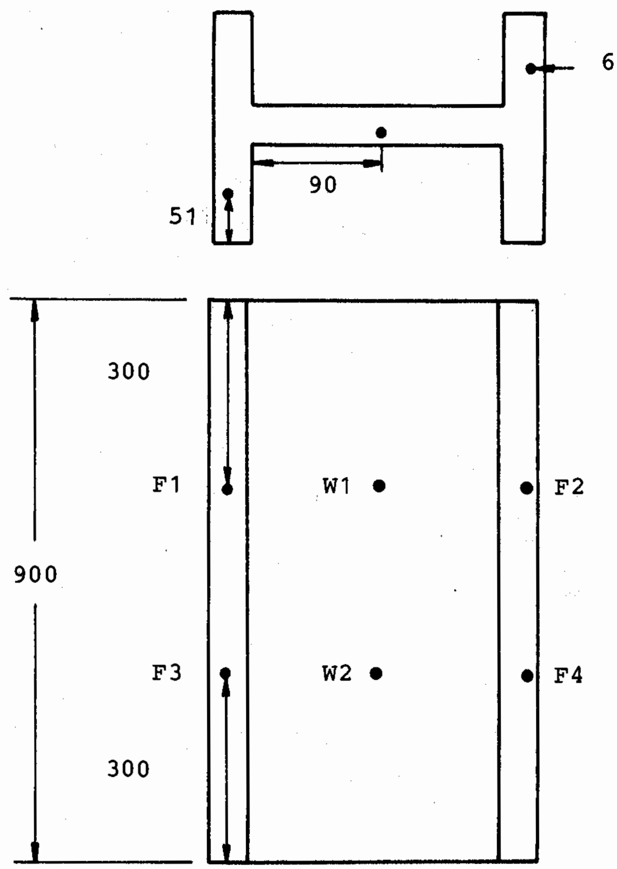
Time	Steel Temperature, °C						Furnace Temperature °C
	F1	F2	F3	F4	W1	W2	
0	11	11	11	11	12	12	11
2	57	32	34	25	13	11	413
4	112	77	78	56	20	15	501
6	181	137	132	98	34	26	643
8	235	194	185	142	58	43	673
10	296	254	239	191	93	65	736
12	352	312	292	238	121	98	753
14	400	364	342	285	157	125	769
16	441	408	383	325	187	150	782
18	483	459	431	375	212	174	818
20	536	522	492	439	247	209	832
22	551	541	510	459	258	220	839
24	580	575	542	495	278	242	848
26	607	604	573	527	298	263	855
28	629	629	599	555	317	283	865
30	650	650	623	581	335	304	871
32	669	671	645	605	352	323	883
34	687	690	665	626	369	341	891
36	704	706	684	646	386	359	899
38	719	721	702	665	402	376	910
40	733	733	718	684	418	394	921
42	744	742	730	702	433	410	927
44	754	755	739	718	448	426	933
46	767	770	754	732	462	441	940
48	781	785	769	741	475	456	950
50	795	800	784	753	488	470	957
52	808	814	798	766	500	482	960
54	822	828	813	781	512	495	969
56	838	843	828	796	523	506	976
58	849	857	842	810	535	518	978
60	862	868	855	825	546	529	984

TABLE 5 THERMAL CONDUCTIVITY RESULTS ON THERMALITE BLOCKS USING THE HOT WIRE TECHNIQUE

	HH46	HS46	HT46
Bulk density, as-received, kg/m^3	808 822	704 718	531 537
Average	815	711	534
Moisture, % (by weight)	6.50 7.95	6.02 5.36	6.19 5.84
Average	7.22	5.69	6.02
Thermal conductivity, W/m K			
Room temperature, °C	0.21	0.16	0.13
200°C	-	0.18	0.14
400°C	0.21	-	0.16
600°C	0.25	-	0.23
650°C	-	-	-
800°C	0.39	0.39	0.33
1000°C	0.49	-	0.45

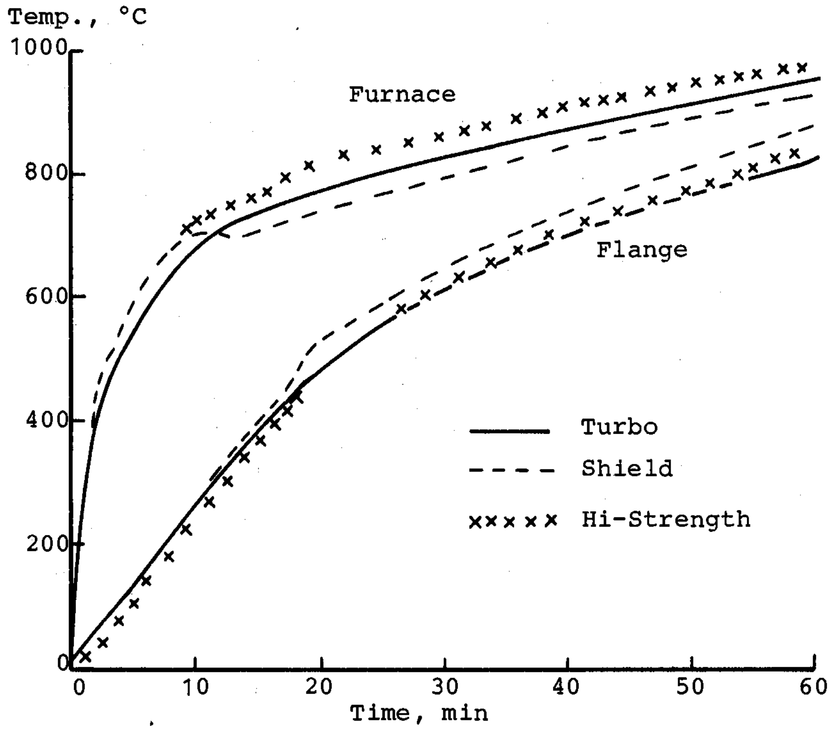


MICROCELLULAR AUTOCLAVED AERATED CONCRETE BLOCK MANUFACTURED BY THERMALITE LTD. FIG. 1



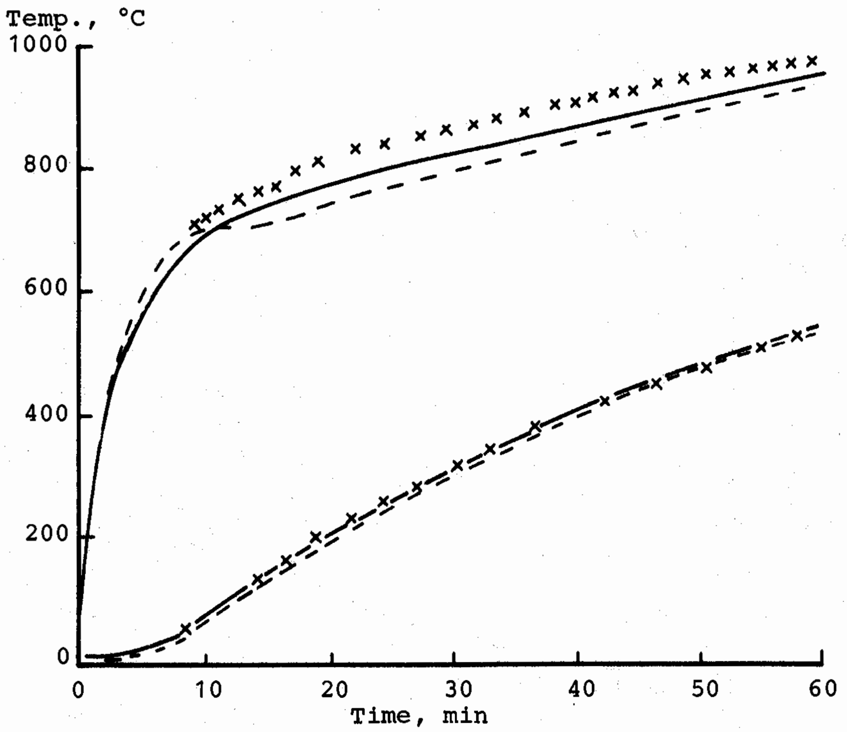
THERMOCOUPLE ARRANGEMENT USED ON THE 203 x 203 mm x 52 kg/m COLUMNS

FIG. 2
(R2/6433)



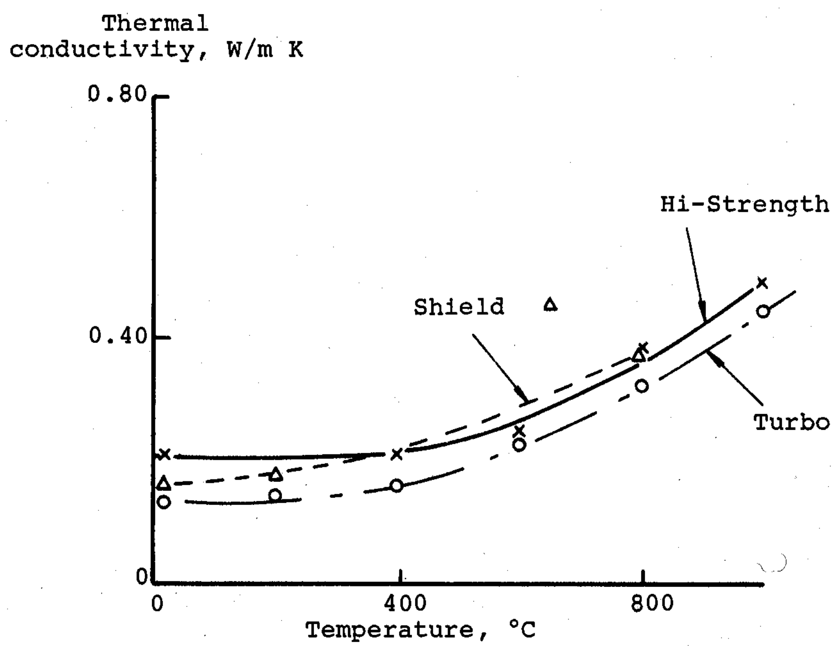
FLANGE TEMPERATURES OF 203 x 203 mm x 52 kg/m COLUMNS FITTED WITH DIFFERENT DENSITIES OF BLOCKWORK MEASURED IN A BS476:PART 8 FIRE TEST

FIG. 3
(R2/6434)



WEB TEMPERATURES OF 203 x 203 mm x 52 kg/m COLUMNS FITTED WITH DIFFERENT DENSITIES OF BLOCKWORK MEASURED IN A BS476:PART 8 FIRE TEST

FIG. 4
(R2/6435)



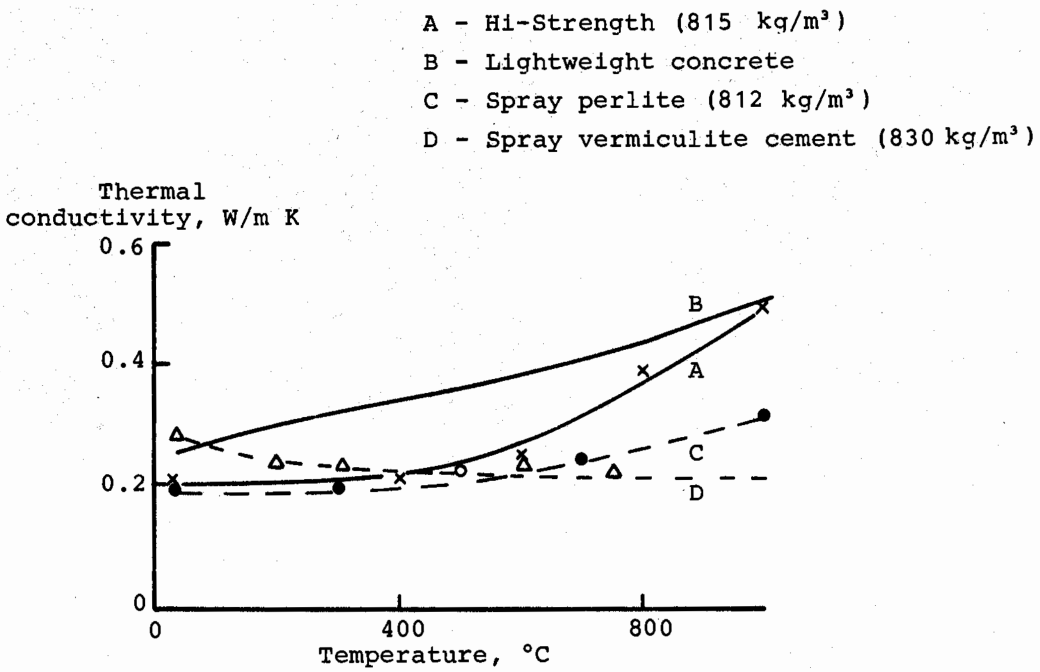
<u>THERMAL CONDUCTIVITY OF THERMALITE BLOCKS - HOT WIRE METHOD</u>

FIG. 5
(R2/6436)

Turbo Shield Hi-Strength

THERMALITE BLOCKS FOLLOWING THERMAL CONDUCTIVITY TESTS UP TO 1000°C

FIG. 6



THERMAL CONDUCTIVITY OF INSULANTS OF SIMILAR DENSITY

FIG. 7 (R2/6437)

INITIAL CIRCULATION

Director, Research and Development

Dr. R. Baker

Swinden Laboratories

Dr. T. Bagshaw
Mr. T.R. Kay
Dr. B.R. Kirby
Mr. J. Lessells
Mr. D.E. Wainman

GENERAL STEELS GROUP

BSC Plates, Sections and Commercial Steels

Redcar

Mr. R.A.C. Latter
Mr. J.T. Robinson
Mr. M.J. Thorndike

EXTERNAL CIRCULATION

Mr. W. Millard - Thermalite Ltd.
Mr. M.J. Robinson - Thermalite Ltd.
Mr. G.M.E. Cooke - FRS, BRE/DoE