PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Contribution of the Materials Scientist

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The contribution of the materials scientist

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Some examples are given of recent innovation in building materials which show that the common impression that there is little innovation is false. There has been, however, a conservative attitude, and design has to some extent been hampered by the need to choose materials from the existing catalogue. The pace of innovation is likely to be accelerated in the future by two trends: specification by performance and the emergence of teaching and research in materials science. Current research and applications in the fields of cement and concrete, glass technology, metals, plastics and surface coatings are mentioned by way of illustration and an estimate of future progress is made.

In the previous paper Allen has indicated some areas where changes in architecture and in building methods will set up needs for new materials. Other pressures which bear on materials development are the continuing and increasing need for cheap housing and for the preservation of the environment both by utilization of wastes as raw materials and in controlling the excavation of the great quantities of raw materials used in the building industry. The construction industry is sensitive to changes in technology and the changes in the social habits of the population which often follow. Consider, for instance, the changes in living pattern produced by the advent of television or the increasing custom of husband and wife both working and the many problems thrown up by the discovery and exploitation of natural gas.

The picture is one of continual change in living habits, in design and in construction methods. All these changes depend for their final expression in the building on a corresponding response by materials producers.

Commentators have often accused the building industry and the materials sector in particular of a poor record in innovation. The industry is one of the oldest in the world and it would be surprising if a long process of trial and error had not produced a highly effective and aesthetically pleasing set of solutions. Such in fact is the traditional brick and mortar construction which even today sets standards of economy and performance which are difficult to match. Nevertheless, the industry has a fine record of innovation. Leaving aside inventions in the construction process such as the employment of cranes, concrete pumps, rising shuttering and the like, the last thirty years have seen remarkable revolutions on the materials side.

The estimated annual value of timber used in construction is £350 M of which 95% is imported and constant efforts are made to replace some of the timber used in housing. This led at the time of the last war to the replacement of timber floors by solid floors and to the development of new economical floor coverings. The first of these was the thermoplastic tile which itself gradually gave way to vinyl tiles and sheets of more attractive appearance and better wearing properties. Now, with the development of man-made fibres and new methods of weaving and securing the fibres the field has been invaded by carpeting. These had and still have to be supported by quite basic studies on the process of wear, on adhesion and on the mechanism of water flow through the solid floor base. Figure 1 shows the special building used at the B.R.S. on the study of water transpiration through floors and walls.

Figure 2 is the wear machine developed on the basis of the measurements made by Harper &

Warlow on the forces exerted on the floor by people walking. Since this machine uses a wear cycle with parameters within the range measured by Harper (1961), it gives a reliable rating on widely differing materials and is currently being used in evaluating the newer carpetings.

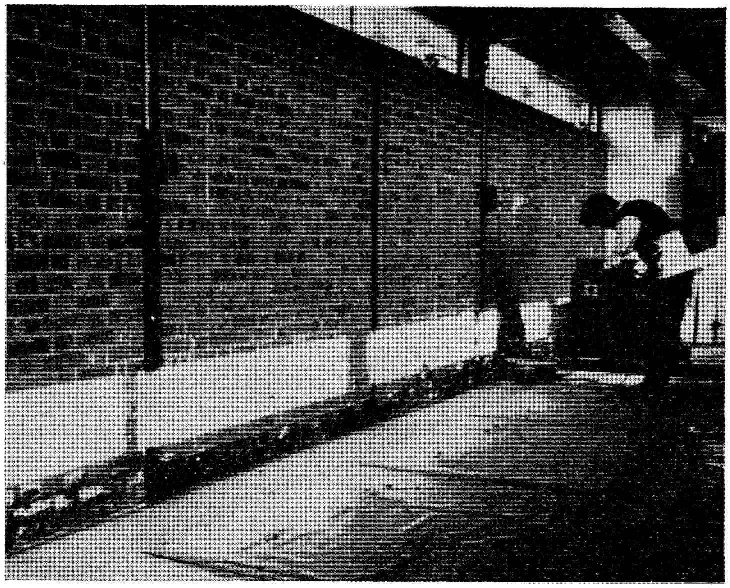

FIGURE 1. Experimental building for studying water flow in floors and walls.

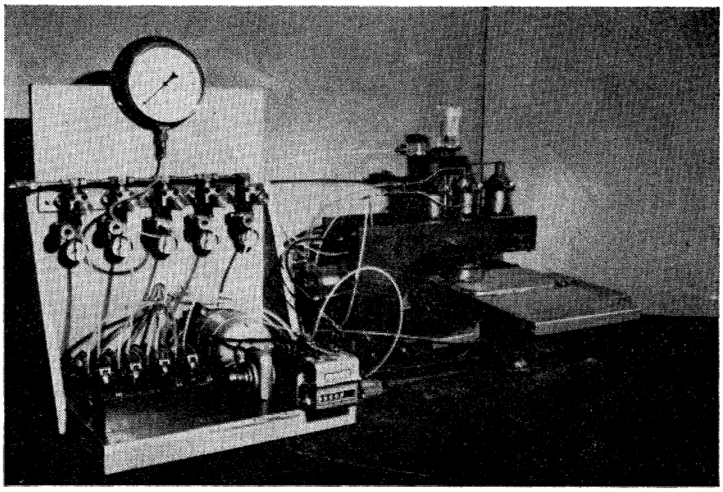

FIGURE 2. Wear machine incorporating representative sole and heel which abrade the specimen. Pressures and both translatory and rotary forces are kept within the range determined from measurements of people walking.

Slate and clay roofing tiles have been almost completely displaced by the concrete tile. At the same time asbestos cement sheeting has been upgraded and is now accepted as a permanent material. Metal sheeting, felt or plastic sheeting laid to careful specifications is used in low-pitched or flat roofings. The driving force behind these changes was almost entirely the rising cost of the traditional roofing.

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Other innovations have followed demands for raising the standard of the built environment. Statutory requirements regulating the thermal transmittance and rain resistance of walling and roofing led to the adoption of cavity construction and eventually to the introduction of fibreglass, foamed plastics, expanded vermiculite, etc. as thermal insulation. Reduced noise in public places has followed the marketing of acoustic tiling.

The situation today is that a unique opportunity exists for further advances. In the first place more logical processes of design specification and erection have been and are being developed and in the second place materials science has become recognized as a field of study and research capable of yielding great dividends.

Specification by performance

Many building specifications are still written in terms that dictate the use of named materials; the quality of these may be regulated by reference to a British Standard or Agrément certificate, but these documents in turn often concentrate more on the definition of a material and its

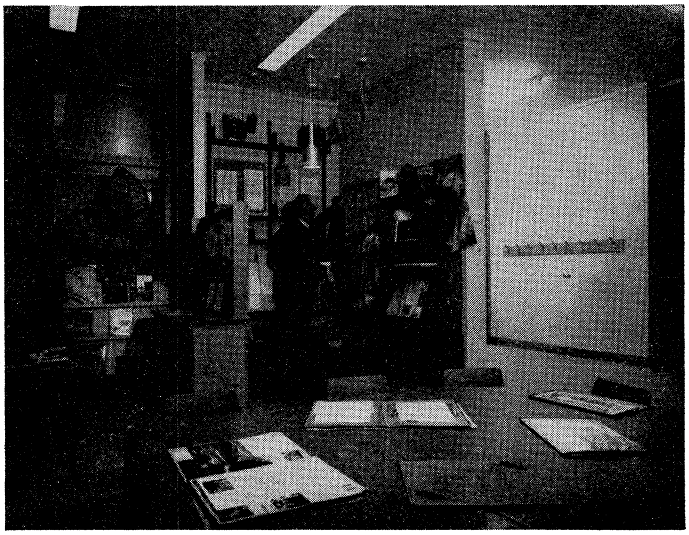

Figure 3. A prototype classroom built to the specification of the Department of Education and Science using glass fibre reinforced gypsum partition units.

composition rather than what its measured performance should be. The new tendency is to use performance specifications. At various levels these lay down criteria for the properties of the building as a whole, for its components and for the materials from which it is constructed. A correct performance specification will therefore give the guide lines to be followed by the materials scientist in developing new materials. An example of this process is given by the Department of Education and Science in their specification for schools partitioning systems. This lays down requirements in respect of dimensions, stability, impact resistance, fire resistance, sound insulation, decoration, performance of fixed fittings and cost. Various solutions have been found and the result has been that the Consortia of the Department have been able to place bulk orders for satisfactory materials at low cost. This same performance specification was used by the Building Research Station in developing the new material, glass fibre reinforced gypsum, since it afforded an opportunity to demonstrate the improvements in tensile and impact strength inherent in fibrous materials (Majumdar 1971). Figure 3 shows a prototype classroom constructed from this material.

The attempt to draw up performance specifications has drawn attention to gaps in our knowledge about the conditions to which materials are exposed in practice, and some current research is aimed at filling these gaps. For instance the measurements of joint movements, temperatures and moisture conditions being sponsored by the Sealant Manufacturers Conference will enable meaningful tests to be devised for use in designing sealants and gaskets. Some early development of plastics sheeting and mouldings for external use was marred by lack of durability arising from an underestimation of the effect of the ultraviolet component of sunlight in conjunction with moisture. In collaboration with R.A.P.R.A. and using data obtained with the ultraviolet light meter devised by Harris (1968), accelerated weathering cycles related to natural conditions have been worked out.

Materials science

The current impetus to materials science stems from the needs of the great technological industries such as power, space, transport and electronics where the high value of the product enables maximum use to be made of research and development. In comparison with these industries the amount spent on construction research as a proportion of the gross national product is extremely low, about 0.06 % in 1965. On the other hand, the industry is so large and the quantity of material used so great that the total product value is very high indeed and this leads to attempts by new industries to get a share in this vast market. Building is thereby able to use the experience of other industries.

Some five years ago the representatives of the then Ministry of Public Building and Works raised with the Building Research Station Advisory Committee the need for better methods of protecting structural steelwork in fire. It was suggested that an intumescent paint could be developed for this purpose and a contract was subsequently placed for this work with the Atomic Weapons Research Establishment at Aldermaston who had experience on char formation from plastics. In addition to performing its fire protection role adequately the paint had to achieve standards of durability, surface hardness, ease of application, cost and so on. The Establishment was successful in producing a formulation based on epoxy resin which produces a voluminous low density char at 200 to 300 °C; a 6.3 mm coating gives 1 h 30 min fire protection and a 2.5 mm coating 30 min. Figure 4 shows the paint before and after expansion of the char by heating.

Another example which shows how materials science can be effectively applied to a clearly stated problem is the synthetic clay Laponite, patented by Dr Barbara Neumann of Laporte Industries. Natural clays of the bentonite type are often used as gelling agents; a particularly effective mineral being hectorite, a magnesium bentonite. It is, however, rare in occurrence and invariably impure. By co-precipitation of gels under carefully controlled conditions, Dr Neumann (1965) was able to produce a form of hectorite (figures 5, 6), which owing to its purity and the control of particle size is many times more effective as a thickening agent than the natural product. Its purity is such that it can be used in cosmetics and medicines; it is used in a substantial tonnage of emulsion type paints to thicken and stabilize them and particularly to impart thixotropic properties.

Aspects of materials science which will influence building materials development over the

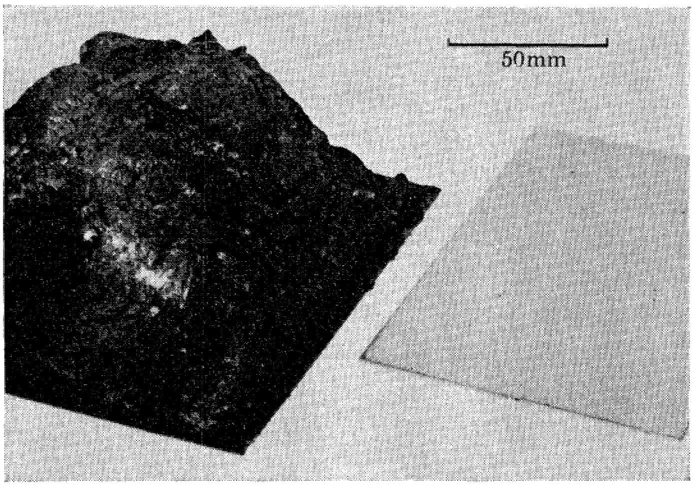

FIGURE 4. Fire protective intumescent paint developed by the Atomic Weapons Research Establishment. Before and after heating to 300 °C.

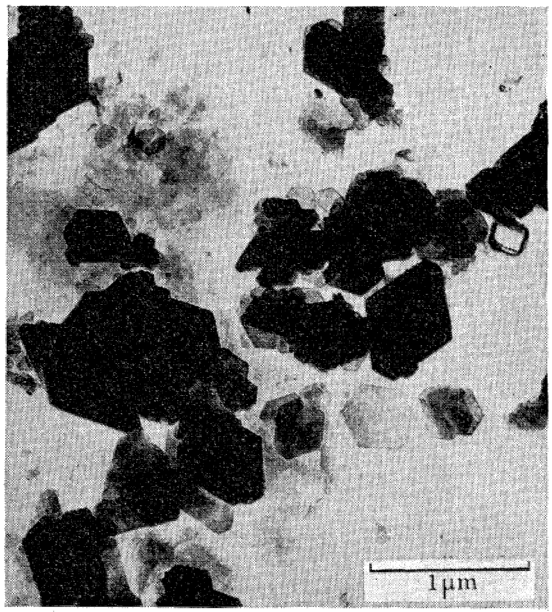

FIGURE 5. Electron micrograph of synthetic hectorite clay.

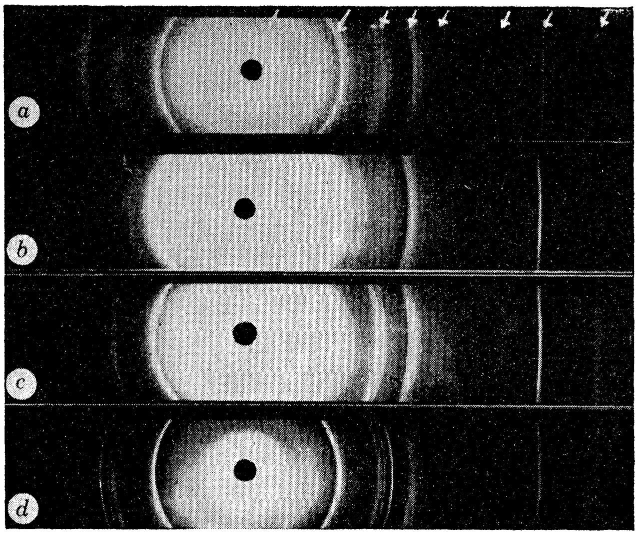

FIGURE 6. Powder X-ray diagrams of hectorite. (*a*) Synthetic; (*b*) natural, purified in the laboratory; (*c*) and (*d*) commercial products. Lines attributable to the hectorite structure are marked by arrows.

next decade include the increasing knowledge of composites, of fracture behaviour in general and of surface films.

Laminar composites are one solution to the need foreseen by Allen for clip-together construction. The problems to be solved are compatibility of the various components under thermal and moisture induced stresses, and the development of sufficiently durable adhesives. Fibrous composites containing glass, plastics or metal fibres all have high fracture toughness if suitably fabricated. The matrix may be plastics, gypsum or cement mortar. Stiffness can be obtained by folded, box or corrugated sections which are then very light in weight. However,

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some applications will have acoustic requirements which can only be solved by adequate mass; this applies increasingly to external walling for which acoustic absorption has not hitherto been thought a necessity. For such massive constructions masonry or concrete will continue to be required since these are the cheapest ways of obtaining acoustic absorption in conjunction with thermal capacity and structural stability. The surface properties of materials are particularly important in increasing durability and reducing maintenance. On metals oxide films can be exploited to produce self-colour and to avoid painting altogether. Surface active films can be used to control the deposition of dirt.

It is impossible in the scope of this paper to consider every subdivision of materials, but in conclusion some of the important areas where changes are expected will be reviewed.

Cement and concrete

The majority of cement manufactured falls in the ordinary or rapid hardening classes; it has been estimated that consumption of these will rise by 50% in the next decade. The great increases in efficiency which have and will be obtained by use of the preheater system of burning and by automation (X-ray analysis of materials and computer control) are therefore of great economic importance. As production rises it will become more and more necessary to use unconventional raw materials. The first plant producing cement and sulphuric acid from gypsum obtained as a by-product of fertilizer manufacture will shortly be completed. This, besides proposal for production of cement and phosphate rock from impure limestones in Togo, is based on experience of the successful plant in Uganda which uses carbonatite limestone. The Building Research Station is acting as consultant to both projects.

Very rapid hardening cements are produced by fine grinding together with the use of special compositions and chemical admixtures. These methods do not, however, give the possibility of reaching working strengths within a few hours, which would be desirable for some industrial building methods. For this purpose blended cements have been proposed in which chemical compounds can be used together which would not form in equilibrium in the normal burning process. A similar technique is used to make a cement of controlled expansion by mixing ordinary cement with expanding cement containing calcium aluminium sulphate.

As an alternative to increasing the rate of hydration or modifying the chemical nature of the reaction products, mechanical properties can be controlled by regulating the porosity of the set mass. For instance, air may be introduced to produce insulating light-weight concretes; at the other end of the scale Lawrence (1969) has reached compressive strengths of 400 N/mm^2 by heavily compacting cement paste of low water content.

Almost half the cement produced is marketed as ready-mixed concrete; the problem of retaining working properties long enough for transportation will be met by the use of set-retarding admixtures.

The successful development of fibrous reinforcement of cement paste or mortar would lead to applications in the form of thin sheets or shells, in situations where high impact resistance or energy absorption are required, in increasing fire resistance, in at any rate partial replacement of asbestos, and in decorative finishes. The fibres used in these applications may be steel (sometimes stainless or brass coated), glass or plastics. One problem to be solved is the mixing of fibre with the cement paste, especially at high fibre contents and in the presence of coarse aggregate.

The homogeneity of fibrous composites may be investigated non-destructively by ultrasonics. Figure 7 taken at the National Physical Laboratory shows (on the left) a plot obtained by scanning a glass fibre reinforced cement board with a pulsed ultrasonic beam, plotting the areas above and below a fixed percentage transmission. The same board was then cut into cubes

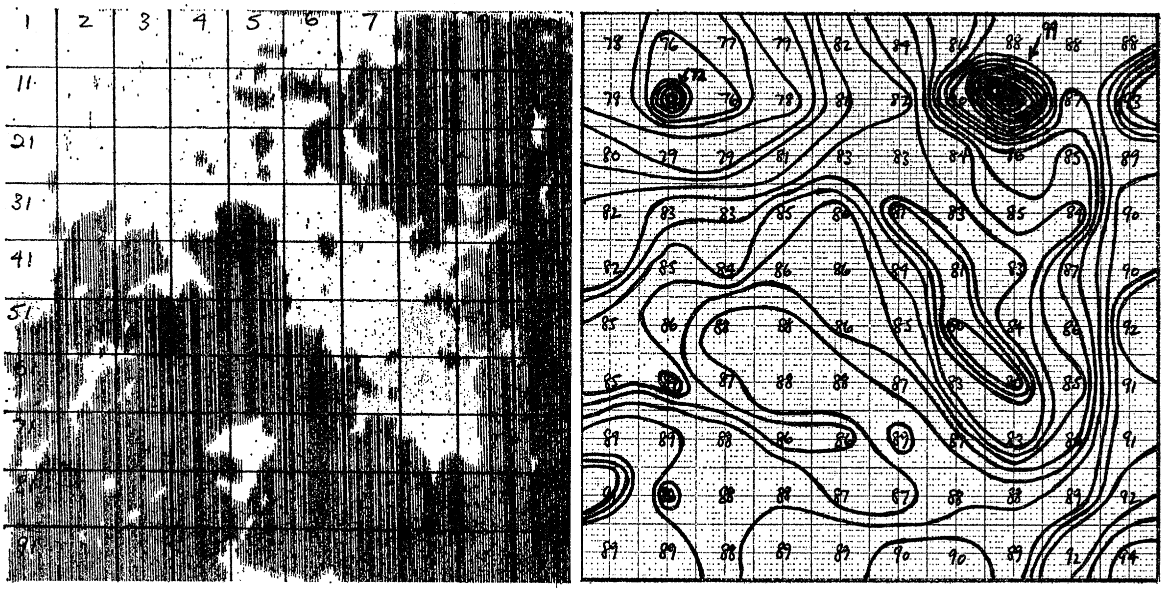

Figure 7. Specimen of glass reinforced cement. Left, the trace obtained by scanning the board with a pulsed ultrasonic beam at 5 MHz. White areas have relative percentage transmission below 50 %, black areas above 50 %. Right, a contour plot of relative density measured on samples cut from the same specimen. The numbers represent the first two decimal places above 1.00, e.g. 78 represents a relative density of 1.78.

10 mm edge and the density of each cube was determined, giving the contour plot shown in the right half of the diagram. It appears that the ultrasonic scan gives a good estimate of density (and therefore glass content) variation.

Plastics

It has long been recognized that, except for special applications, plastics cannot economically compete with masonry and concrete in the structural parts of the building. Nevertheless, the amount of plastics used in construction is expected to increase at some 8 % per annum, exploiting the advantages of chemical resistance, ease of fabrication and cheapness in comparison with the metals which they often replace. Research in progress is expected to extend the temperature range over which they can be used and the next decade should see the development of modified polyvinylchloride or polypropylene oxide hot-water systems. A comparatively new polymer, polyacetal, is suitable for plumbing fittings usually carried out in brass or bronze. Problems which may arise from the shearing forces developed during jointing and in forcing jammed valves could be solved by fibrous or wire reinforcement. Higher temperatures may be reached by using ladder or ring structure polymers; some, e.g. polyoxy-diazole, can be fabricated as fibres. At present, however, the cost of temperature resistant plastics is excessive and problems of thermal movement and combustibility remain. Glass reinforced plastics, which are expected to increase in use, have the advantage over other composites of being translucent. By using mesh of hard drawn steel wire for reinforcement instead of glass fibre, a strength and

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stiffness midway between glass reinforced and carbon fibre reinforced plastic can be obtained. Structural foams with stressed dense skins are able to compete with wood in many applications.

Very large diameter pipes are now possible both extruded in thermoplastics and filament wound in glass reinforced polyester and interesting procedures have been developed. Plastics piping can be inserted into unserviceable existing mains, welding the sections together. Mobile extrusion machines are being developed; one project in Finland produced a 4.6 km tube in one section.

Great interest is shown in polymer mortars and concretes. These may be of two types; a normal cement mortar with an addition of polymer or a mortar in which the polymeric material is the sole cementing agent. The latter have high adhesion and a tensile strength not possible with cement mortars. They are used extensively in repair work and are proposed for joining together the units of the British Ceramic Research Association's MG plank.

Addition of polymer to mortar or concrete, as at present practised, results in filling in of the pore structure. This can be done effectively also by soaking the concrete in a monomer, curing subsequently with γ-radiation or heat. With a combination of steel fibre and monomer impregnation bending strengths of 8 times and toughness of 60 times the control mortar have been reached. No evidence for chemical bonding between the silicate and organic components of these products has been found, although this is theoretically possible and might be worth further attention in research.

Ceramics and glass

These materials have great potential because of the wide range of chemical composition covered by the processes, and the comparative cheapness of the raw materials. Very high strength, thermal stability, durability and wear resistance can be obtained by controlled crystallization of a preformed glass, as in the Slagceram process worked out by the British Iron and Steel Research Association. Cladding panels have been made in similar material. The process

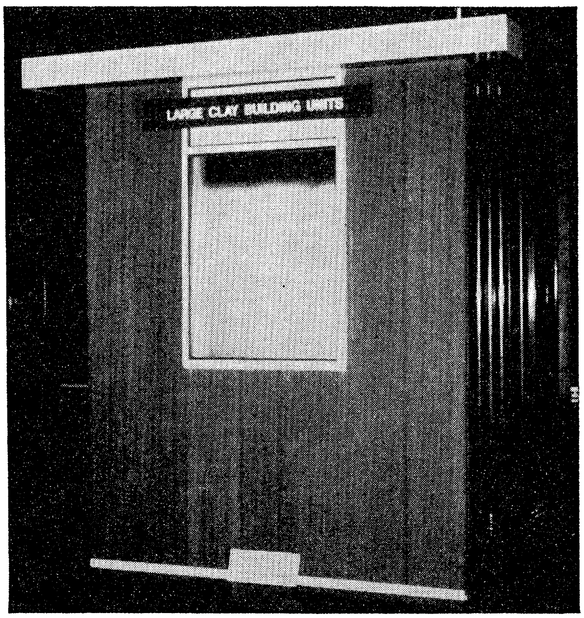

Figure 8. Unit made up from the British Ceramic Research Association's large fired clay planks.

tends to be costly because of the several heat treatments required; hot pressing has been suggested as an alternative. Solar heat-absorbing glass is made by similar processes or by lamination or by application of surface films. With the glasses at present available absorption of heat is only marginally greater than absorption of light so that except for very large window areas supplementary artificial lighting is required. Several methods are available for toughening glass. By controlled porosity it might be possible to develop transparent glasses of low thermal conductivity.

In the field of more conventional structural ceramics, a better understanding of the drying and firing process, together with selection of raw material, makes it possible to fabricate large units which can be incorporated in the building with less labour and using the plastics mortars already referred to. Figure 8 shows a panel made up from the B.C.R.A. MG plank, 2.6 m long, 300 mm wide and 100 mm thick.

Metals

The cost of lead, copper and zinc relative to other materials is likely to react against expansion in use. Applications are more likely in the area of coatings or alloys; for example, galvanized reinforcing bars are increasingly used where the normal protective action of the concrete is insufficient. Both aluminium and steel are available colour coated, reflecting the drive towards reduced maintenance costs; steel can also be coated with lead. An interesting development is the use of weathering steels. These corrode by natural weathering at a rate which rapidly falls off with time to negligible proportions. At the same time the steel acquires a brown colour, deepening with time. To obtain the desirable patina slight weathering must take place but highly corrosive or marine atmospheres are not suitable. For fixings stainless steel can be used, this is also another alternative in protecting reinforcement in concrete. In general, improvements in the steelmaking process will give the possibility of using higher working stresses, the necessary stiffness being obtained by girder design. The increased use of welding calls for better notch ductility.

Conclusion

These examples will, it is hoped, show that innovation in materials can keep pace with general trends, provided that clear specifications are available and that development is based on well-organized programmes of basic research in silicates, metals and plastics.

The work described has been carried out as part of the research programme of the Building Research Station of the Department of the Environment and this paper is published by permission of the Director.

References (Nurse)

Harper, F. C. 1961 National Building Studies Research Paper 32. London: H.M.S.O.
Harris, P. B. 1968 *J. scient. Instrum.* **1** (Series 2), 1007–1010.
Lawrence, C. D. 1969 The properties of cement paste compacted under high pressures. Research Report 19, London: Cement and Concrete Association.
Majumdar, A. J. 1971 *Proc. R. Soc. Lond.* A **319**, 69–78.
Neumann, B. S. 1965 *Rheologica Acta* **4**, 250–255.

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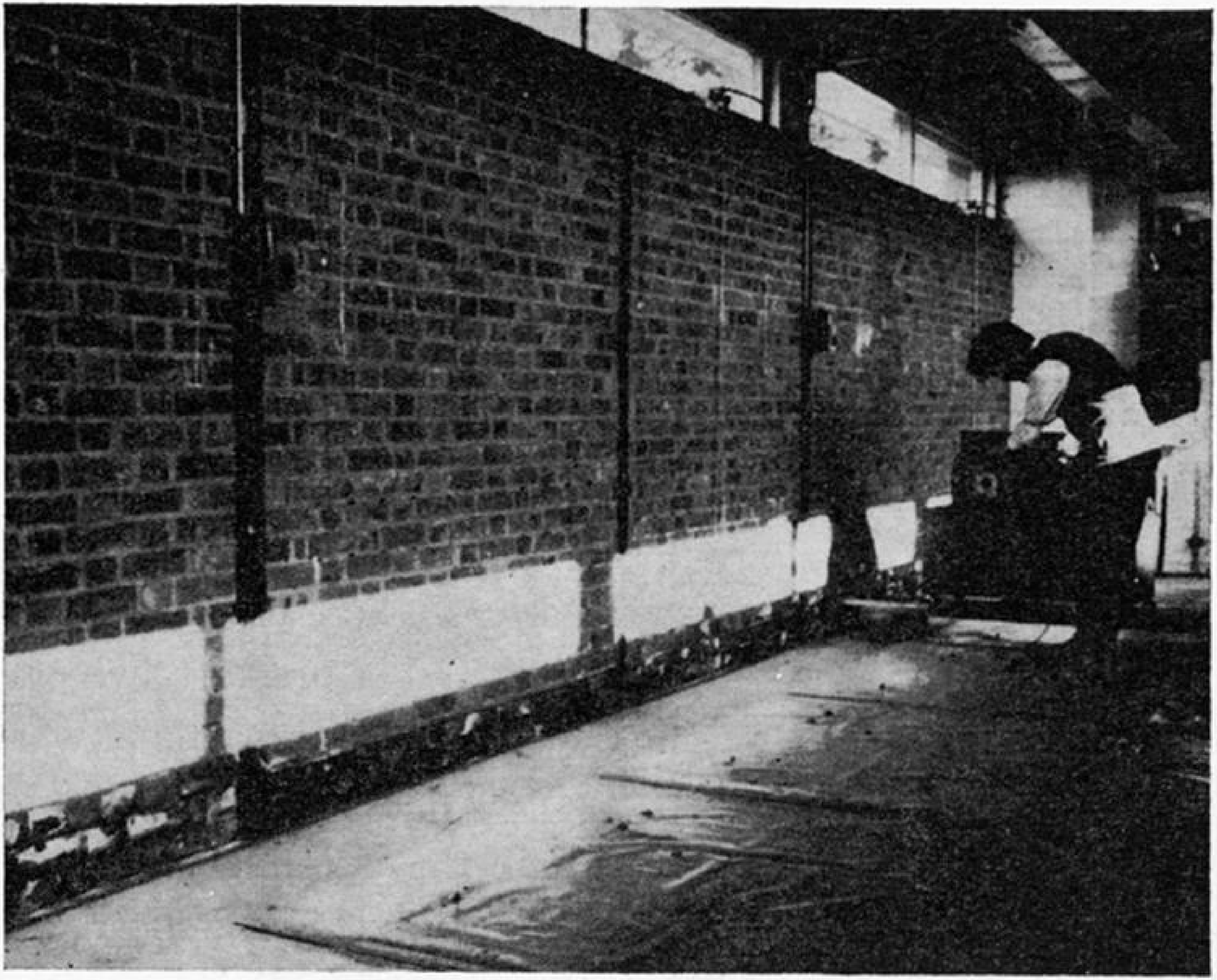

ɪɢᴜʀᴇ 1. Experimental building for studying water flow in floors and walls.

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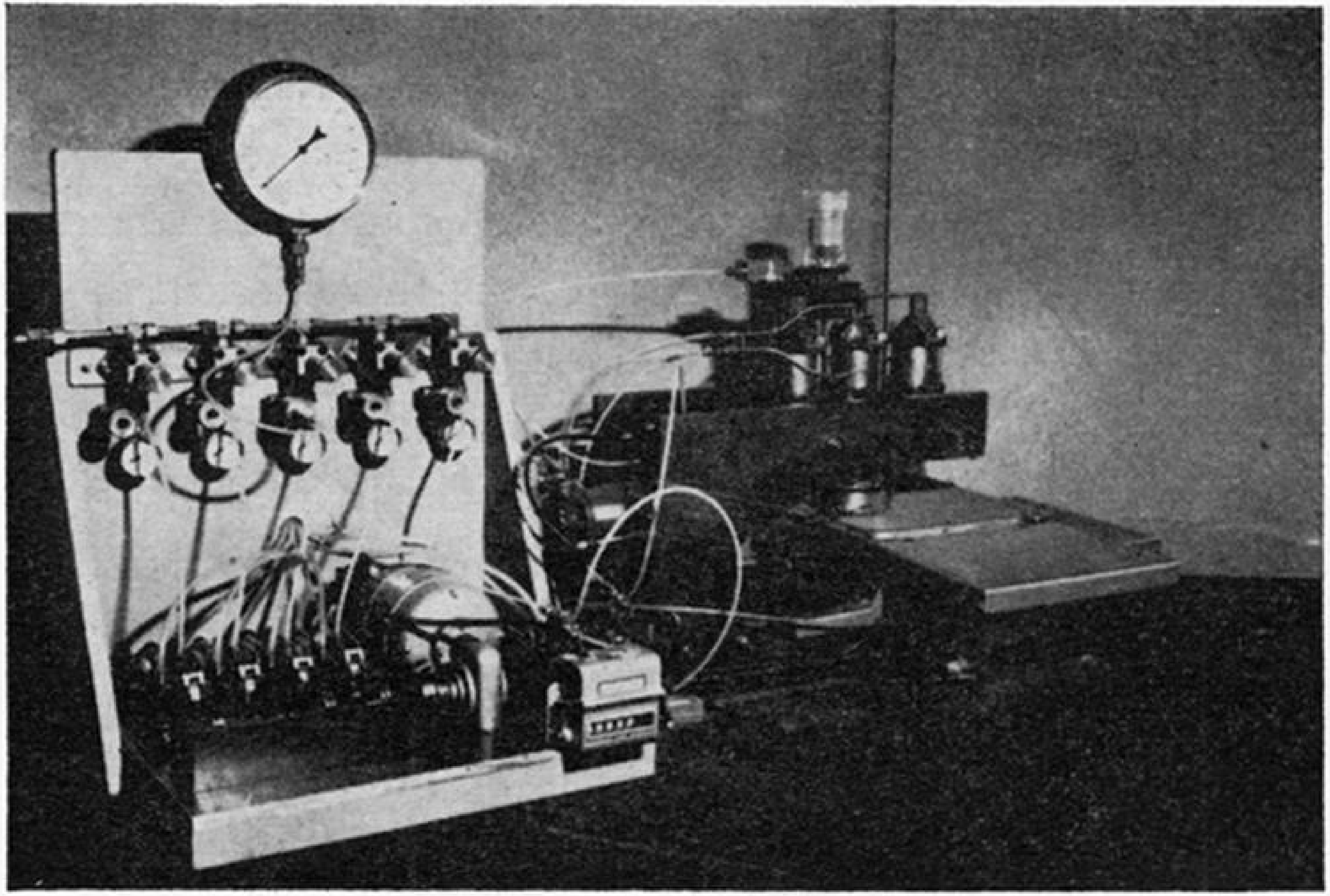
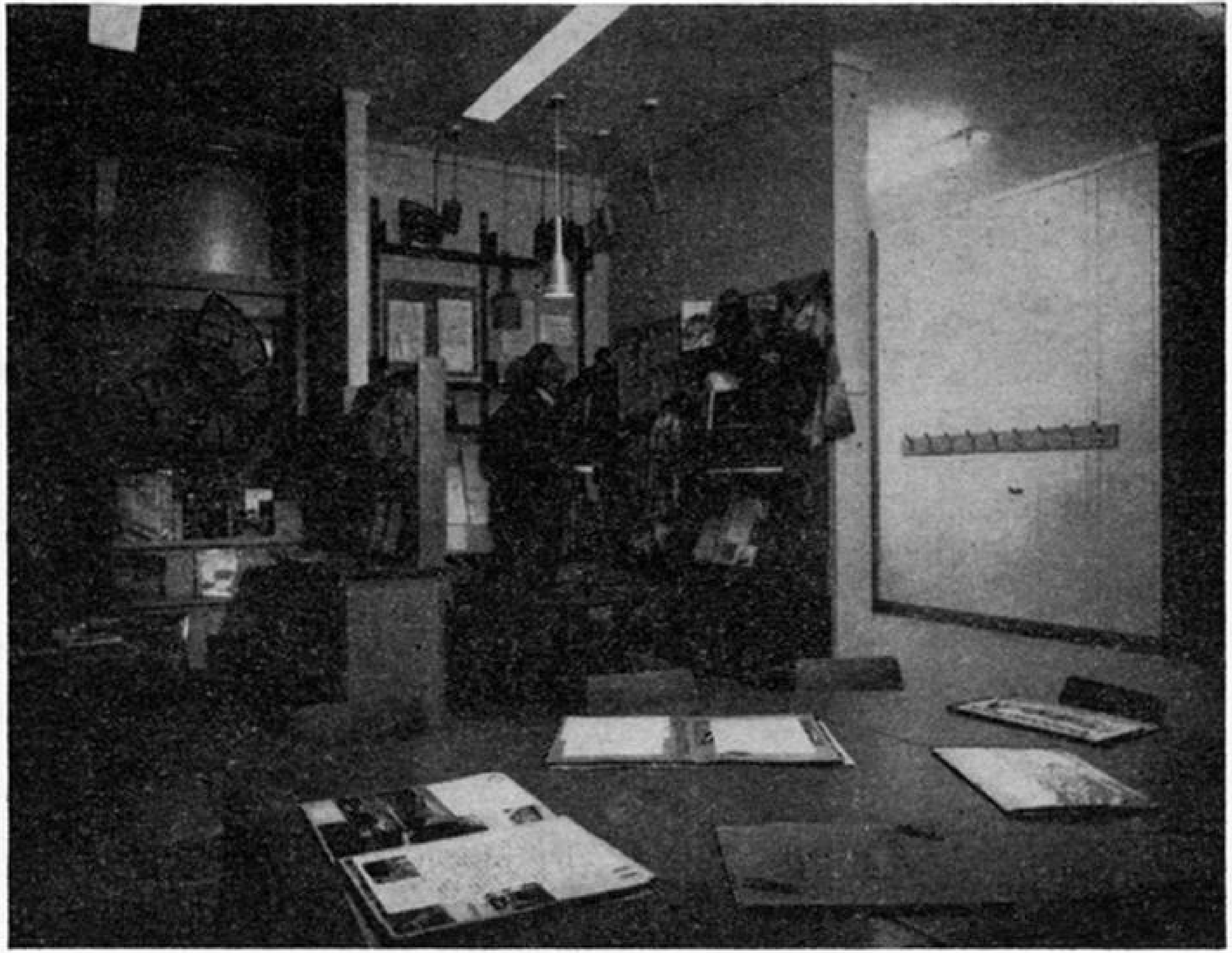


IGURE 2. Wear machine incorporating representative sole and heel which abrade the specimen. Pressures and both translatory and rotary forces are kept within the range determined from measurements of people walking.



IGURE 3. A prototype classroom built to the specification of the Department of Education and Science using glass fibre reinforced gypsum partition units.

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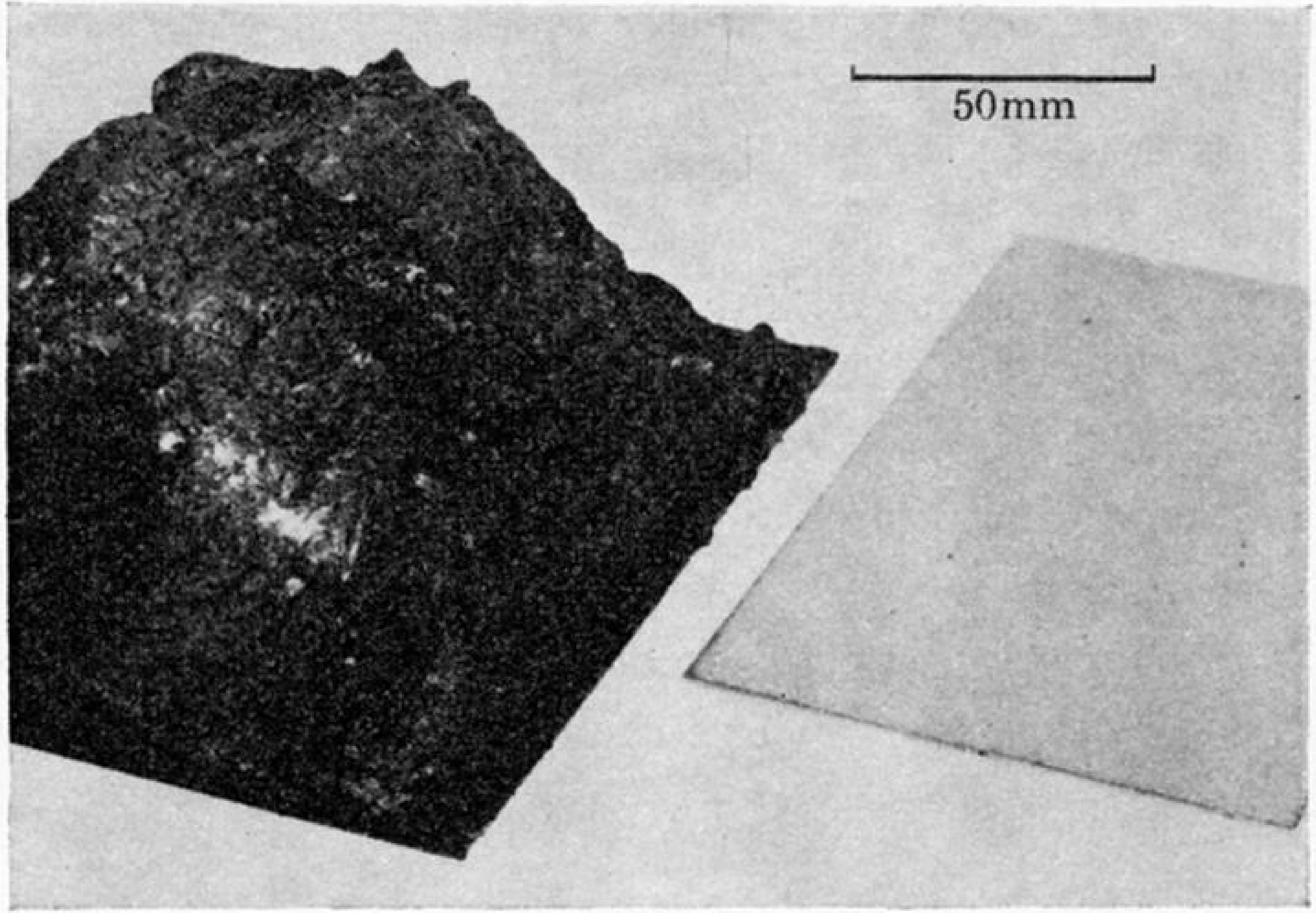

FIGURE 4. Fire protective intumescent paint developed by the Atomic Weapons Research Establishment. Before and after heating to 300 °C.

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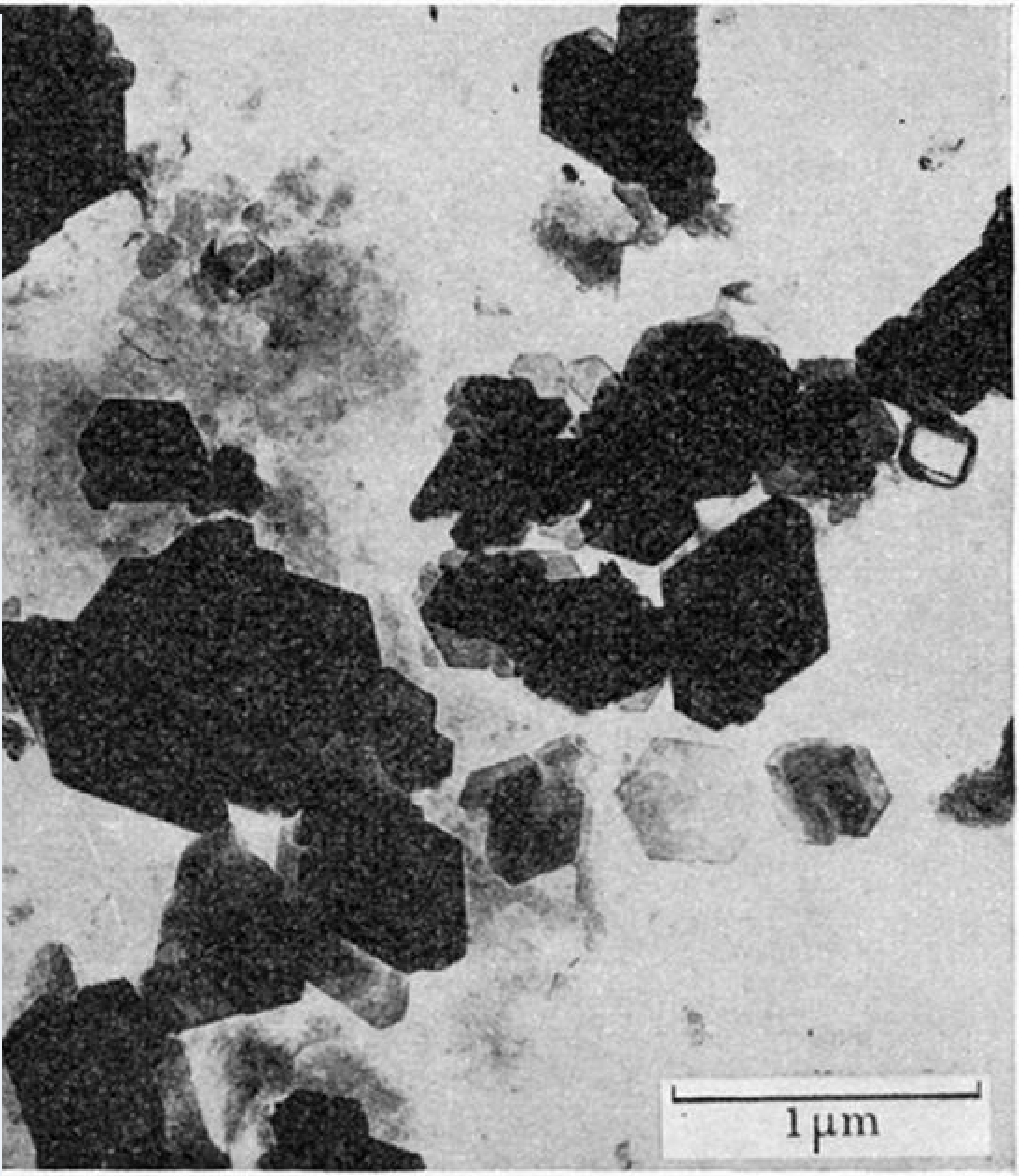
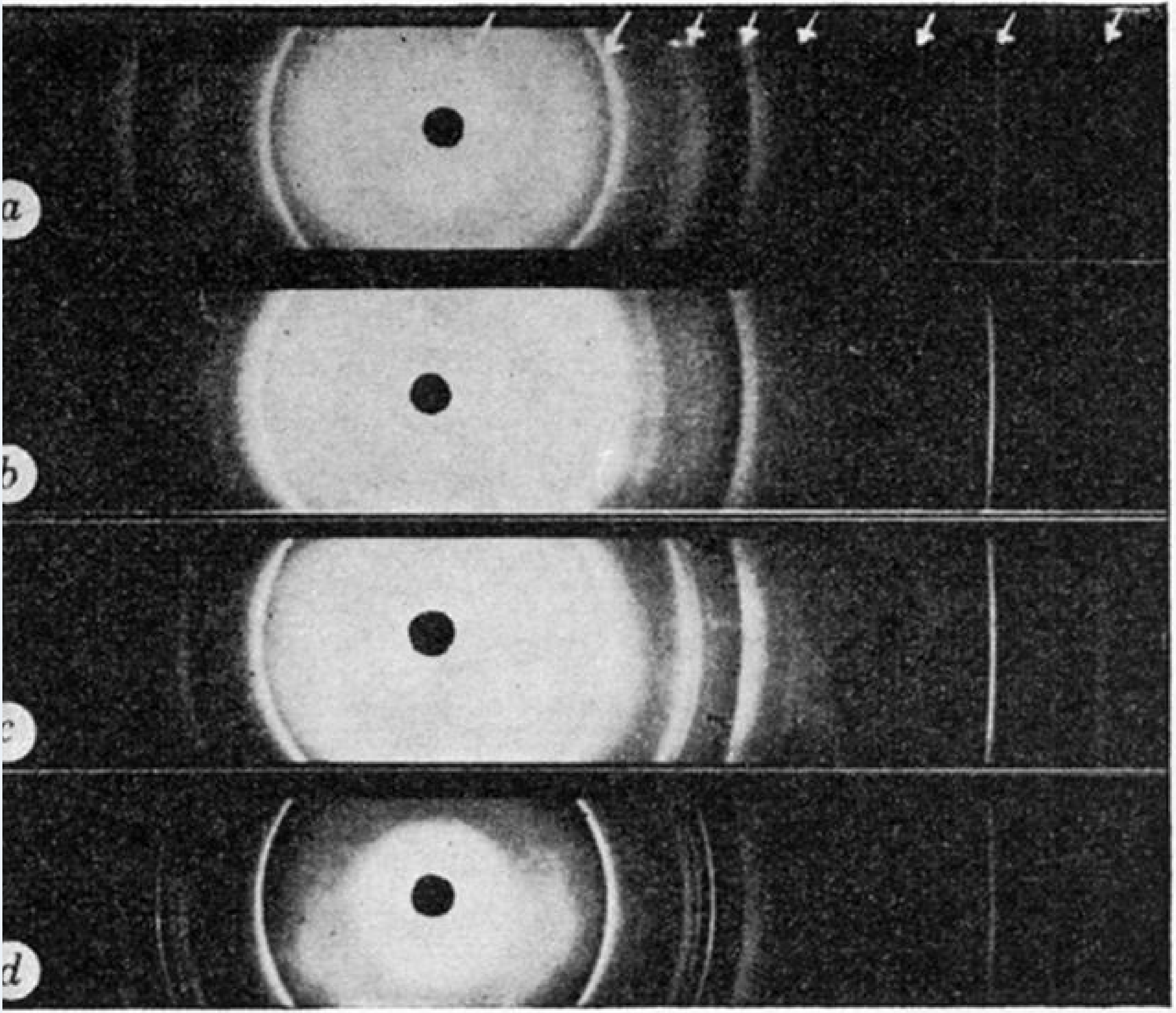


FIGURE 5. Electron micrograph of synthetic hectorite clay.



IGURE 6. Powder X-ray diagrams of hectorite. (*a*) Synthetic; (*b*) natural, purified in the laboratory; (*c*) and (*d*) commercial products. Lines attributable to the hectorite structure are marked by arrows.

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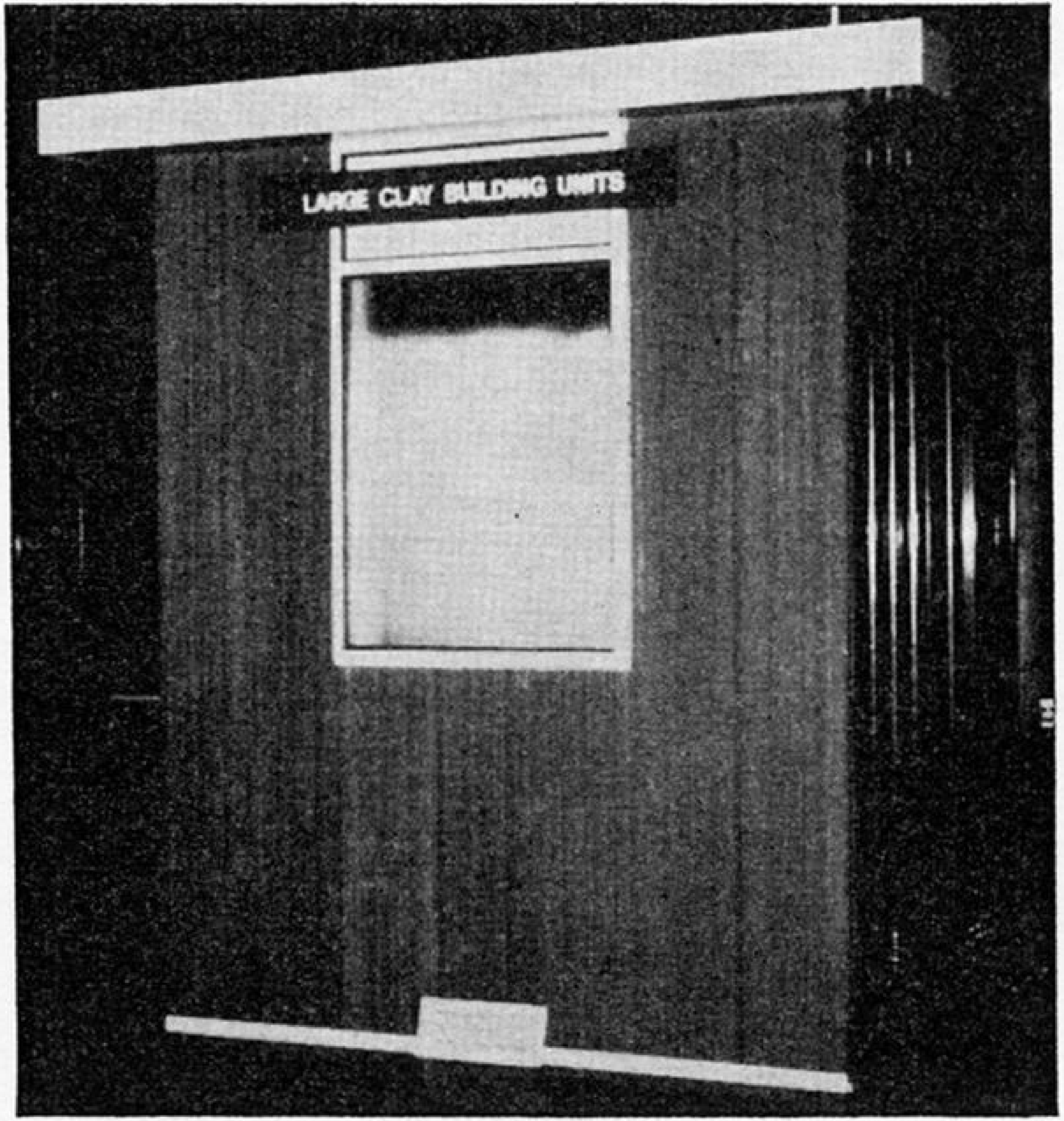

IGURE 8. Unit made up from the British Ceramic Research Association's large fired clay planks.

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