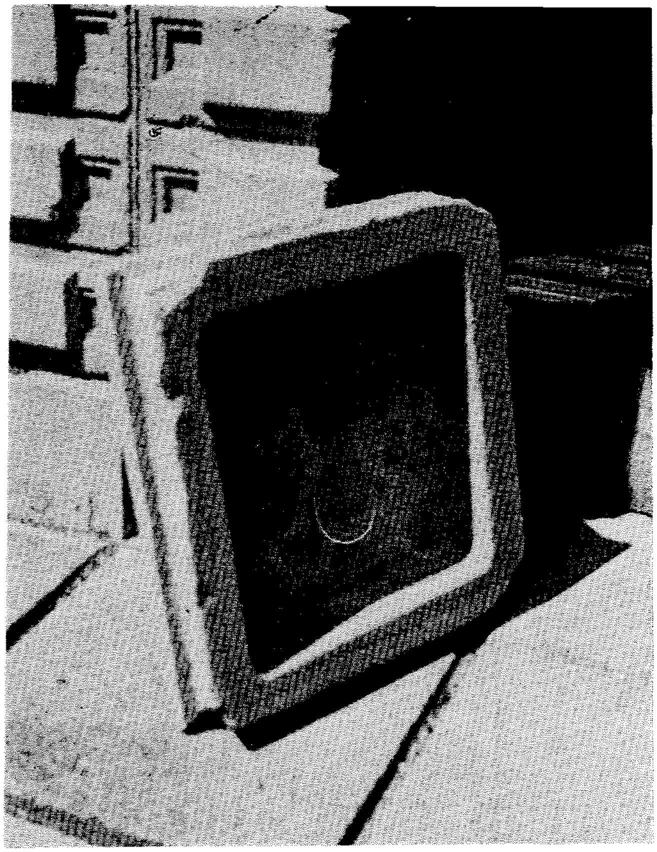


FIG. 1—The cast block is indented on the rear side, thus forming an insulation area when laid up into a wall. The edges are concave, providing a chamber into which concrete is poured around the steel bars. The block is 16 inches square. The terrace and floor of the house are of the same blocks laid horizontally.

Designs in CERAMICS

By ANTONIN HEYTHUM

INTRODUCTION

THE Industrial Design Section, like other departments at California Institute of Technology, has assisted in problems associated with the war. An extensive investigation was made of the possibilities of a wider use of ceramics, especially where they might substitute for strategic or critical war materials. This particular research was sponsored by one of the larger members of the ceramic industry. The project was formally started by the Institute in the fall of 1942 and has continued to the present.

The research, surveys and design developments are carried on by Fellows and Research Assistants under the guidance and supervision of the staff members of the Section. Since many of the problems involve questions directly related to some specialized scientific or engineering field, members of other departments of the Institute are asked to collaborate. A committee meets regularly with the director of research of the sponsoring industry to determine policy and to discuss developments of the project work.

DESIGN DEVELOPMENTS

The sound approach to any industrial design development leads through a period of thorough preparatory work, in which it has to be ascertained whether the design development in question will be worth while at all. A general survey is the first step, followed by research and eventually by preliminary planning of new designs. In many instances the survey may show that the idea for the product development under consideration is basically unsound; in other instances the work is for some reason or other not carried beyond the stage of research and only a certain number of product development ideas are carried through to the final step of designing and experimental model making, followed by a period of actual working tests.

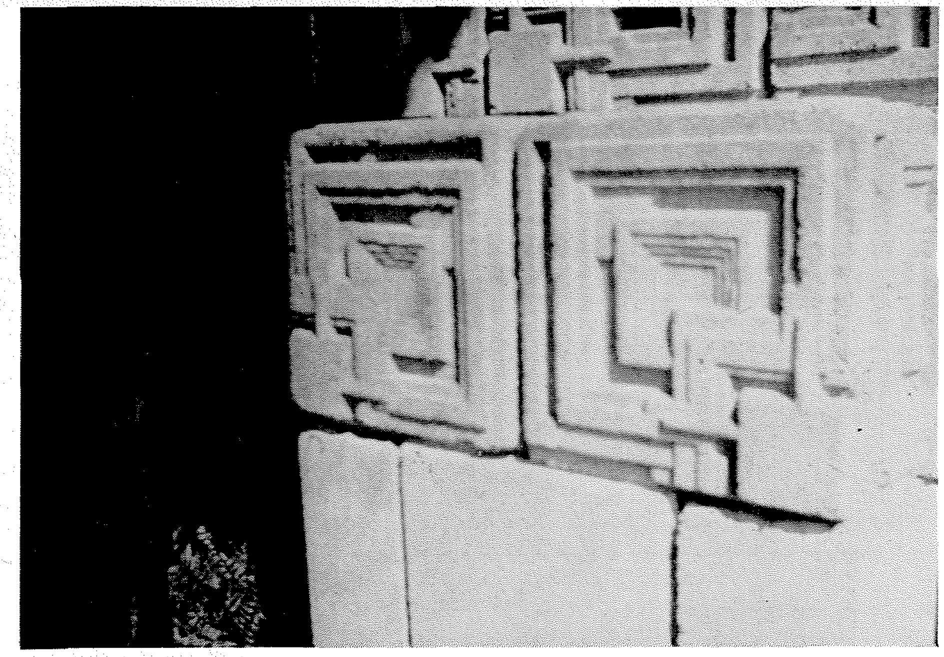
At the research committee meetings ideas are presented and discussed and decisions are made as to which ideas appear to be worthy of further consideration. A wide range of consumer articles was surveyed to determine which goods made of "critical" materials might be considered for redesigning in ceramics.

HOUSEHOLD EQUIPMENT AND UTENSILS

A long list of items was taken under consideration for kitchen equipment: cooking ware, food containers, colorful honey and cheese jars, teapots and teacups, ceramic stoves and small parts like ceramic bottle and jar-closers or coasters for glasses; for the bathroom: plumbing fixtures, handles, doorknobs, shower nozzles, soap dispensers, shelves, holders for tumblers, toothbrushes, hot-water bottles, towel hangers, paper towel holders and tissue containers.

For the living room an investigation was made on fireplace basket grates. A survey on cast iron grates was made; data and samples were collected. The whole problem of fire grates was analyzed and it was decided that redesigning in ceramics might prove a worth-while experiment. Several models were made and tested. A simplified form evolving from consideration of ease of manufacture was accepted for testing, but the present ceramic body did not allow the simplification of form necessary from an economic point of view. The models which had been developed were very similar to some which several months later were introduced by W.P.B. and reproduced in "Ceramic Industry," February, 1943.

For use in kitchens and bathrooms a design idea was presented which suggested an improved wall tile and a new system of applying tiles to walls. The design consists of a tile with projections which fit in properly spaced indentations in a prefabricated backing panel. To fasten the tiles to the prefabricated panel an improved cementing medium was suggested.



AT RIGHT

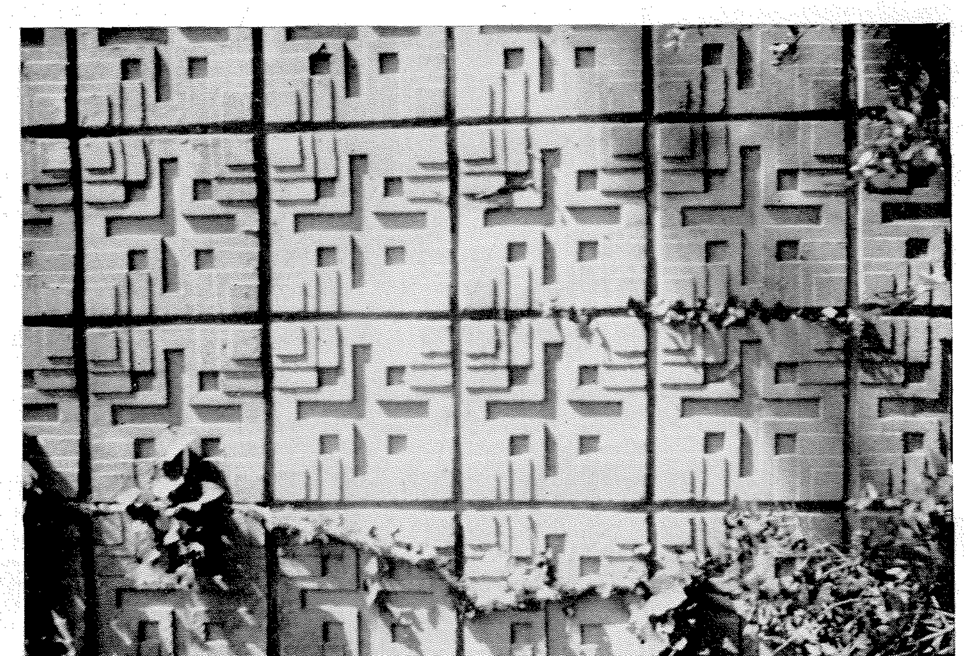
FIG. 2—This detail of the blocks in the Charles Ennis house, built in 1924, reveals one reason for making the blocks highly patterned. If they had been plain it is probable that surface irregularities introduced by weathering would have made them unsightly and worn looking. With the highly patterned surface the slight imperfections enhance their appearance.

An example of particularly extensive preliminary investigations is the research on the problem of ceramic cooking ware. Before thought could be given to the question of actual designing of pots and pans, a long period had to be given over to investigations and tests on suitable glazing. The manufacturers had developed satisfactory ceramic bodies which resisted most severe tests but still presented the problem of developing a suitable glaze or surface treatment to make the vessels impermeable. Several months were spent in research and experiments, attempting to seal only the surface of the ceramic body with oils, graphite, silica, synthetic resins, suction filtration using finely divided metals, through condensation evaporated metals, through electroplating and a number of other systems developed during the period of experimentation.

This research, in which several scientists and specialists are now collaborating, is still in progress, and until the major technical problems are solved, the question of design must wait.

RESEARCH IN BUILDING MATERIALS

This research represents an extensive survey first started by one of the students on the Industrial Design Section, with special attention being given the use of terra cotta in postwar developments. An illustrated report evaluates the use of ceramic materials on facades of a choice of buildings in the Los Angeles area. See *Figs. Nos. 1, 2, 3.* This survey was followed by a questionnaire mailed throughout the Pacific area, by which nearly 3,000 individuals and firms were reached. The evaluation of this work is described in a later section. On the basis of this survey and further specialized research, the question of roofing material for postwar houses, with particular attention to conditions in California, was analyzed and reported separately. With these preparations actual designing was then started. Several of the designs are still in the laboratory stage. While work on the question of roofs was being done, rain troughs, drain spouts, shower stalls and strainers were also considered for redesigning in ceramics.



New types of sewer pipes and their jointing were also discussed at length. A number of samples were examined, including resin-bonded plastic pipes. The joints of sewer pipes presented a special problem for which the advisory services of the Chemistry and Biology Divisions were utilized in connection with the prevention of disintegration of the joining medium by plant roots.

AT LEFT

FIG. 3—The highly textured walls lend themselves admirably to diffusing the brilliant California sunlight, thus reducing glare. Notice in the detail of the blocks the few highlights and shadows with large areas of medium-intensity light reflection.

HEATING HOUSES

Heating of houses through ceramic radiators and wall radiation from ceramics were considered. Ceramic plates or tiles wired with low temperature electric resistance elements could be applied to walls as sources for radiant heat.

Another development in building material was attempted with a design of reinforced board construction, using vermiculite (exploded mica) as filler and insulator. Execution of actual models was made possible through the use of laboratory facilities and testing equipment of the industry.

OUTDOOR AND HIGHWAY INSTALLATIONS

Street lighting, traffic signals, street signs and billboard posters offered a particularly timely subject for study during the period of dimouts, and the temporary use of hoods over street lighting fixtures for dimout purposes seemed to point the way towards permanent uses of ceramics in this field. The design of a ceramic reflector is one of the results of the thorough investigations in this direction. One of the reflectors has undergone successful working tests in Pasadena and the design has been submitted for a patent application.

Another promising case, still in the experimental stage, is the development of ceramic letter tiles more suited to general usage, particularly as more readable street signs. Alphabet and number tiles, to be used in street corner posts or on sidewalk curbs, would be quite permanent if properly installed and could be made luminous through the use of special glazes or adequate surface cutting effects.

VARIOUS TECHNICAL AND WAR PRODUCTS

In collaboration with the Electrical Engineering and Physics Departments a newly developed high frequency insulator body was tested. The results of these tests led to a selection of the most suitable composition of the body for the specific purpose.

Market surveys on lightweight refractory products led to experiments with mortar for refractory bricks. A research inquiry in heat resistant plastics was undertaken. Ceramic drying trays for plastic were tested to ascertain possible advantages of the use of the moisture absorbing quality of ceramics. The possibility of using ceramics in replacement for stainless steel in the manufacture of heat treating trays was investigated.

An exhaustive market survey on chemical stoneware led to the design development of a dipping basket for use in the plating shop. One of the graduate students was in charge of the design. A special report about acid-resisting cements for stoneware completed this development. Use of ceramics was further suggested for grinding wheels, fast-cutting wheels, battery cases, and as a part in the design of standardized poultry houses.

Precision gauges for which glass had been tried as a substitute for steel have been redesigned for manufacture in ceramics and a number of models were distributed to users for testing purposes.

A report has been submitted on tests made with ceramic heaters for use in airplanes at high altitude flights. Other investigations covered the possible use of ceramics instead of metal parts in certain types of non-magnetic land mines, in hand grenades, and in the composition of bullet-proof armor.

CONCLUSION

This report, which covers the major items with which the research group occupied itself at one time or another, shows that the project, originally intended to concern primarily design aspects, grew well beyond this scope. Therefore, credit for work accomplished and recorded herewith goes to a large degree to the collaborators from other departments. This is as it should be, because the success of any planning in the field of design depends largely on intelligent collaboration between scientist, engineer, and designer.

Many errors can be eliminated and expenses for unsound design developments avoided, when preliminary research is carried on thoroughly and with the help and advice of qualified experts.

This is a valuable lesson, especially for students, who thus have an opportunity to learn through close contact with actual practical problems the importance of careful investigation and the necessity for cooperation.

CERAMIC ROOFING MATERIAL SURVEY*

This survey was made with the purpose of determining the form of roofing material which would be most suitable in the California climate. The sponsor of the research indicated an interest in the possibilities of ceramic material. Before any designing was done, it was considered necessary to determine the opinion of different groups using roofing materials by means of a survey of architects and designers who plan the structure, the real estate group who sells it, and finally the consumer, the man living in the house and having direct experience with the product of the designer's and architect's mind. Firms manufacturing roofing materials and firms concerned with prefabrication were queried. The questionnaire sent out early in 1943 requested the following information:

1. *In your opinion will consumer demand be for:*
   a. Modern houses which will bear little resemblance to traditional residences ....%
   b. Houses designed and built in the traditional manner ....%
   c. Prefabricated houses designed without preconceived style ideas............ ....%
   d. Prefabricated houses made to imitate traditional design and construction methods............ ....%
   e. State other possibilities............ ....%
   Total 100 %

2. *Is there a trend in residential construction to:*
   a. Flat roofs............
   b. Low pitched roofs............
   c. Steep pitched roofs............
   d. No trend............
   e. Your comment ....

3. *What characteristics do you like in a roofing material?*
   a. Physical properties ....
   b. Color, texture and other aesthetic qualities............
   ....

4. *Regarding terra cotta roofing tiles:*
   a. Would you use improved terra cotta roofing tiles on your future buildings?............
   b. If yes, which improvements would you think desirable?............

5. *Your comment:*
   a. What is your conception of the ideal roofing material for the postwar house?............

*This section prepared with the assistance of Marilen Hart.

Between April and July, 1943, this questionnaire was sent to 1400 architects and to 400 contractors, with the assistance of Robert Dickenson, graduate student. The assembled replies were classified, analyzed, and evaluated. It was reported that from the total of 1800 questionnaires sent out, 232 architects and 18 contractors returned usable answers to the questionnaire. The architects anticipate that one half of the postwar houses will be traditional in design, one fourth modern, one tenth newly-conceived prefabricated units, and the remainder divided among traditional, prefabricated, mobile, multiple and other types. The few contractors predicted more traditional and less modern building. Architects expect a general trend to low-pitched and flat roofs, with very little steep-pitch work. Contractors expect no flat roof work and the retention of considerable numbers of steep-pitch designs.

The most desirable characteristics of roofing materials were listed, in order of frequency of mention, as follows: wide color range; permanence; fire retardation; wide texture range; weatherproofing; insulation; light weight; low cost; easy maintenance; good walling surface; strength; non-mechanical appearance; availability of a wide range of sizes and shapes. The shape most desired is a good flat tile.

A majority of architects (63 per cent) and a minority of contractors (28 per cent) gave an unqualified "Yes" to the question: "Would you use improved tiles?" The ideal terra cotta tile, from the point of view of both architects and contractors, would combine these characteristics: light weight; low cost; improved method of interlocking; wide range of colors, textures, sizes and shapes; elimination of under-roofing by better waterproofing and increased structural strength; less fragility; walking deck surface; and a non-mechanical effect.

Following the survey of architects' and contractors' opinions on trends and future developments in roofing materials, a smaller survey was made of home owners, real estate dealers, and building and prefabrication firms. The same questionnaire was sent, with a different introductory letter for each group, appealing only to that group. Usable answers were received from 74 out of 200 home owners contacted; 55 out of 250 realtors; 23 out of 60 designers; and 14 out of 50 building and prefabricating firms who received questionnaires. The home owners' opinion is that one half of the postwar homes will be traditional in design, less than one fifth modern, and one third will be about evenly divided between traditionally styled prefabricated homes and newly-conceived prefabricated units. Realtors and builders predict 60 per cent traditional homes and only 5 per cent modern prefabricated units. Designers favor 30 per cent modern and only 36 per cent traditional; the rest divided equally between modern prefabricated and traditional prefabrication. Realtors expect quite a trend to low-pitched roof design with some steep, while home owners, designers, and building firms expect very little steep-roof trend; low-pitched mainly with about 28 per cent flat. The most desirable characteristics of roofing materials were listed, in order of frequency of mention, as follows: durability; waterproofness and weather resistance; fire-resistance; insulating properties; harmony with style of house and surroundings; light weight; ease of application; freedom from repairs or very low maintenance; rough textures; wide range of colors with earth colors and natural most frequently mentioned. Realtors led in willingness to use tiles (49 per cent), with home owners and designers (48 per cent). Builders and prefabricated-house designers show the most sales resistance to improved tiles; only 33 per cent indicated a willingness to use them. About 12 per cent of all answers were undecided or unfamiliar with the product.

The ideal terra cotta tile from the standpoint of home owners, realtors, designers, and business firms would combine these characteristics: light weight; low cost; durability; nonabsorbency and nonleaking; improved anchoring to prevent wind damage, interlocking with the roof; large, simple shapes; flat tile; greater range of colors; tile resembling shingles and shakes; and tile with enough strength to permit walking on to repair roof. All groups contacted showed a consistency in opinion on trends. Comparison of roofing material characteristics desired by the different groups was interesting in that the architects and contractors were first concerned with aesthetic qualities, while the home owner, using the architects' and contractors' product, placed these qualities last, as might be expected, preferring his roof to be first of all weatherproof, permanent, and fireproof.

ROOFING TILE DESIGN*

Tabulation of the results of the survey on ceramic roofing materials showed a definite preference for this material. It was also indicated that an improved design might greatly increase the use of tile for roofing. Terra cotta has the advantage of being fire resistant and lasting, and provides insulating qualities. There are, however, several often repeated criticisms of the tile now in use. The most usual seems to be that it is too heavy. Consequently, in addition to the greater cost of the roofing material itself, there is the necessity of heavier construction in the house, which again adds to the cost. Another problem has been fastening the tile securely enough to prevent it from blowing off and yet not adding to weight or labor cost in laying. Many of the present methods of laying tile make it difficult to replace broken units.

The first step in working out an improved design for terra cotta roofing tile was to make a study of all the various forms now in use. These forms fall into three main groups, viz.: normal tile (Spanish, etc.), flat tile (shingle tile), and single lap tile (including pan tile and interlocking forms). Since some of these date from ancient times, it was desirable to examine the historical development as a basis for understanding recent inventions.

The normal tile in use today functions on the same principle as that used in some of the earliest known tiles. For example, this type of tile was used on the Temple of Hera in Greece about 1,000 B.C. "The real or typical normal tile is a trough shaped piece of clay ware of a more or less flattened semi-circular cross-section, enough smaller at one end so that the exterior of the small end will fit into the interior of the large end and thus provide for the necessary lap. The troughs are thus seen to be sections of the frustum of a cone. The length varies from 12 to 18 inches. For the execution of certain styles of architecture, these half-round pieces are placed on the roof so that one half of the pieces act as covers for the other. That is, two rows of the half-rounds are carried up the roof inverted, or with the troughs up, and just far enough apart so that a single row, trough down, will interlock with the two inverted rows, thus forming a cover for their edges and the space between."[1] (See *Fig. No. 4A.*) This form was developed before the advent of the trussed roof and therefore was

*This section prepared with the assistance of Barbara Winchester.

[1]*Geological Survey of Ohio*, Fourth Series, Bulletin 11, "Manufacturing of Roof Tile," Wolsey Garnet Worcester, State of Ohio, Columbus, Ohio; August, 1910.

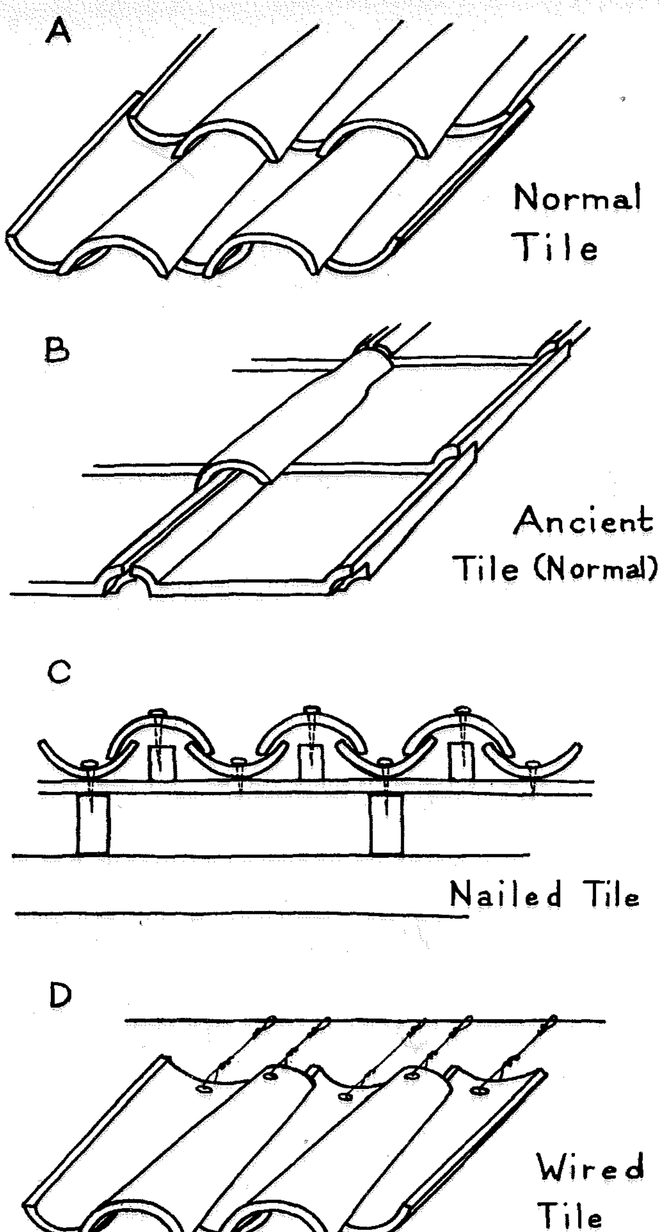


FIG. 4.

designed for the smaller low pitch roofs (15 degrees or less). In this early period there was no attempt to fasten each tile individually. The tile course at the eaves was secured and the remainder of the roof laid above, each course bearing against the one below. This was made possible by a special form of lap joint at the lengthwise overlap. (See *Fig. No. 4B.*) The weight of the individual tile was great enough to keep it from blowing off.

It may be noted here that this fitted lap joint made the effective pitch of the tile more nearly the same as the roof pitch. The difference in pitch between the tile and the roof is caused by the overlapping at horizontal joints lengthwise to the tile and depends on the relation between the length of the tile, the thickness, and the amount of overlap. (See *Fig. No. 5.*) It may be readily seen that the lower the roof pitch, the more important this factor becomes. In an extreme case the pitch on the tile might be such that the water could run back under the tile above. This danger point is often approached in Spanish style roofs. In an attempt to imitate the aged rustic appearance of poorly repaired European roofs the tiles are piled closer in certain areas. This decreases the pitch on some tile and in addition leaves open space that must be filled with plaster. The effective pitch of the tile is a critical factor in the design of all roofing tile and affords possibilities of improvement in future tile design. The fitted lap joint permitted closer fitting of the imbrex (cap tile used as cover for side joinings with convex side up).

The roof laid with normal tile is essentially a series of comparatively deep channels which attempt to direct the water downward and off the roof. The channelling principle seems particularly well adapted to the low-pitched roof where it would be easier for the water to flood sideways in a wind storm. However, two difficulties were encountered with later use of the normal tile. As steep roofs were developed it was necessary to fasten the tile. Also there was a desire to lessen the load on the roof, and lighter weight tiles were made. These had to be fastened even on the flat pitch roofs. The normal tile design is not well adapted to individual fastening. In general three different methods have been used, viz.: nailing, wiring, or setting in mortar. Nailing this type of tile requires very long nails; the one holding the imbrex must be driven between the two tegula (tiles laid concave side up). (See *Fig. No. 4C.*) The use of nails with terra cotta adds to breakage and also makes it more difficult to replace broken units. Where the roof depends on building felt under the tile, nailing pierces holes in the paper. Wiring normal tile is done by stringing heavy wires or straps horizontally or vertically and then wiring each tile to this stringer (See *Fig. No. 4D* for one method). This method makes a flexible roof but involves a higher labor cost in laying. Mortar may be used alone to hold the tile, or with one of the above methods to seal the joints. In any case, use of mortar is not permanently satisfactory, as portland cement cracks because of expansion and contraction of the roof materials. The use of plastic cement is satisfactory as long as it remains plastic, but in time it will harden and is then subject to the same faults as those described above. In fact, any tile design that depends on an additional material for security against weather nullifies one of the valuable qualities of the terra cotta, that of permanency. The roof is then only as lasting as the supplementary material.

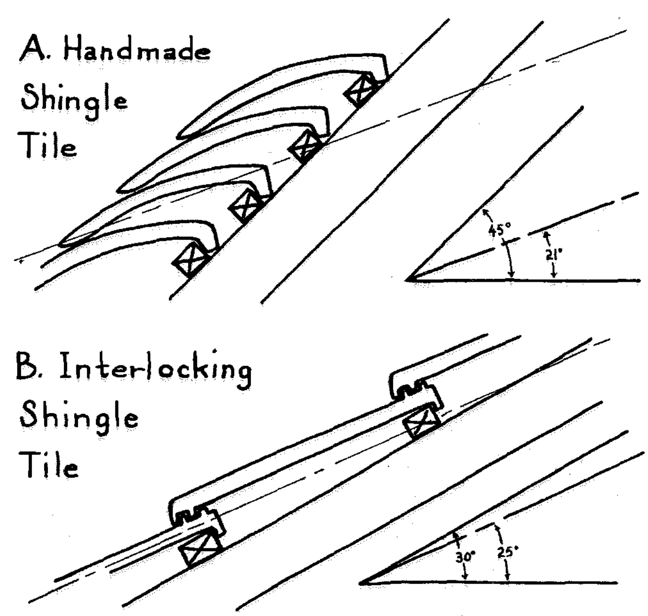


FIG. 5.

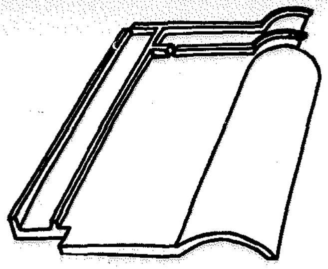


FIG. 6.

The second type of tile design is the flat tile or shingle tile. This is fundamentally the same as the wood shingle, and was developed for use on steeper roofs, particularly in England. The method of laying shingle tile (with almost two-thirds overlap) means that the roof is covered with three layers of tile and consequently may be very heavy. In addition the units are often smaller and if the tiles are nailed it requires more labor to lay them. Some shingle tile, particularly in the eastern hemisphere, have nibs or lugs on the under side at the top, by which they are hung on the roof purlin. This makes roof repair easier. The shingle tile, in contrast to the normal tile, is well adapted to individual fastening, as the top of each tile comes in direct contact with the roof. Because of the design of the shingle tile and the method of laying, the effective pitch of this tile would always be less than the roof. However, this is partially overcome in some types by designing the tile with a taper from top to bottom. Later tile developments have been based on these first two types. An early modification of the normal tile was the S-shaped tile or pan tile. This in effect combines the imbrex and the tegula (cap and pan) in one piece, so that one side laps over the next tile and the opposite side is itself covered. This design saves in weight and has an added advantage; the top of each tile is in contact with the roof so that fastening is easier. This may be done with nibs or nails. The principle of channel drainage is the same as in the normal tile, but the S-shaped tile has an advantage for use on steeper roofs where it must be securely fastened. Further improvements have been made on the S-shaped tile in the interlocking Spanish tile. (See *Fig. No. 6.*) This eliminates any necessity for mortar by interlocking grooves at the end and side joining. This tile is laid with continuous join, as are normal tile and pan tile.

Shingle tile also have been made with interlocking features in order to permit decrease in the amount of overlap and thus in the total weight of the roof. Ordinarily the interlocking grooves are not very deep and the tile still requires more overlap than the true interlocking tile. The best type of interlocking tile design integrates features of all the preceding types. It is designed to be laid "broken join," as are the shingle tile, so that the water carried by the joints of one course is emptied onto the center of a tile in the next course below. The upper surface of the tile forms channels to carry the water, as in the case of the normal tile (See *Fig. No. 7*). The depth of these channels should be related to the pitch and length of the roof in order to prevent flooding toward the lower edge.

The side overlapping is the same principle used in the S-shaped tile; that is, lapping over on one side and under on the other. These side joints are closely fitted, usually with one deep groove and one or more shallow grooves providing extra protection. The gauge sideways is set within the limits of movement in these grooves. Similarly the horizontal joints are interlocking grooves, limiting the gauge from top to bottom. While means are provided for individually securing each tile either by nibs, nailing, or wiring, there is added support in the interlock. Just as in the case of the Greek tile, each unit supports the one above it. In addition, the tile above may hook over the one below, thus providing support from above. The interlocking system has decreased the weight factor by reducing overlapping to a minimum. One tile has been made that has, in addition to interlocking features, a hollow structure. This development suggests the possibility of further decrease in weight and added insulation. Interlocking tile may be designed so that when it is laid, the pitch of the tile is nearly the same as the roof. (See *Fig. No. 5B.*) For this reason it functions efficiently on low pitch roofs as well as steep types. Tile of the interlocking type, if well made, provides a tight-fitting, interwoven surface. However, there remains the problem of satisfactorily integrating these units with the roof structure.

Present methods of securing interlocking tile to the roof structure vary with the location. In Europe, nibs are used and the tiles are hooked on the purlins without felt. In areas subject to severe winds, tile are made with provisions on the underside for wiring top and bottom. In this country it is customary to lay them over boarding and felt, nailing through the tile. As has been previously pointed out, there is very little justification for using building felt and then piercing it with holes. If the tile is well made it should be weatherproof without an added material.

Future designs in this country should give more careful consideration to the close and imperative relationship between roof covering and understructure, because the question of tile design is merely a part of the general problem of roof construction.

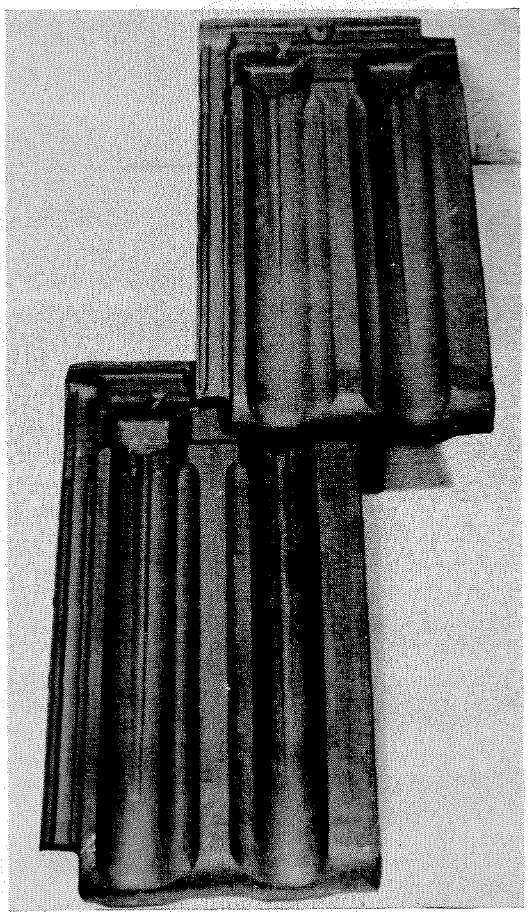


FIG. 7—French type of interlocking tile (Ludowici).