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BY-LINES

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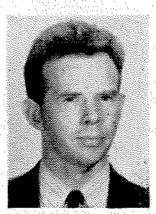

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ENGINEERING AND SCIENCE

Monthly

The Truth Shall Make You Free

CONTENTS FOR MAY, 1944

COVER ILLUSTRATION:

Hermosa tile panel being finished for installation in National Broadcasting Company building, San Francisco.

ENGINEERING AND SCIENCE MONTHLY

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The Month in Focus

THIS issue of *Engineering and Science* is largely devoted to a review of the ceramic research completed and in progress under the direction of the Industrial Design Section of the California Institute. Like almost all other current Institute activities, this research was undertaken in response to special needs created by the war.

During the past two years we have seen endless examples of industrial advances made under the stimulus of war necessity. There have been very rapid developments in light metals, alloys, and plastics. Manufacturing equipment and processes have been as rapidly improved. And American ingenuity and resourcefulness are challenged by the problem of substituting noncritical for critical materials in order to maintain production of essential consumer goods.

In this last field the ceramics industry has a particular opportunity. Both the materials and the labor required in the industry are, in general, noncritical. And southern California is a particularly advantageous place in which to explore the possibilities of ceramics development, because there is already an impressive industrial development in the ceramics field in this area. In view of these considerations a Ceramic Research Committee was set up under the sponsorship of the Institute's Industrial Design Section. The ceramics industry has provided both financial and technical assistance, and members of all the departments of the Institute have collaborated as a research staff assisting the students and faculty of the Industrial Design Section.

At the start, a varied and extensive research program was approved, and reports have been prepared as results were obtained. Research projects ranged all the way from lightweight refractories, low-loss high-frequency insulation, nonmetallic heaters, chemical stoneware and builders hardware to cooking ware, table ware, and costume jewelry. The articles which follow are a representative selection from these reports, designed to show some of the more funadmental, general problems investigated as well as specific designs for particular purposes.

The most fundamental problem, of course, is the nature of the material involved. Investigations of the physical composition and structure of clays provide the basis for precision laboratory techniques for the control of ceramic materials and aid in the design and manufacture of new products with improved resistance to temperature and mechanical shock.

Equally fundamental, from the point of view of the sales branch of the industry, are the market surveys. An example is given here of such a survey applied to permanent roofs of ceramic material, the results of which will be useful in planning production for postwar building. And supplementing this, the analysis of types of roofing tile provides a basis for improved designs.

Examples of the solutions of specific problems are presented in the ceramic gauge and the ceramic street light reflector.*

The contributions which can be made by industrial engineering are shown in the cooperative studies made in one ceramic plant in this area. The ceramics industry, perhaps because it is one of the oldest in the world, has possibly been inclined to run in traditional grooves. The results of time and motion study of the manufacturing process and analysis of materials and products flow demonstrate how industrial engineering techniques can raise the efficiency level of the industry.

Thus the whole program of research already has accomplished several related purposes. It has added new products to and improved the methods of the ceramic industry—results which will continue after the war is won. It has offered a challenge and a stimulus to the students and staff of the Industrial Design Section. And it has demonstrated that in this as in any research the most effective results can be obtained by calling upon a variety of skills and aptitudes.

A forecast of things to come in ceramics will include lightweight refractories of California and other West Coast materials which will withstand abrasion, erosion, and higher mechanical loading—ceramics having more of the properties of metals. It will include cold set clay products which are neither strictly cements nor plastics but are low in cost and are both time and weather resistant. Soon we shall see lightweight ceramic roofing for low pitch California roofs that shelter a household heated, supplied with much of its décor, and furnished with its kitchen and table ware at low cost and using new forms of materials dug from mother earth. Ceramics will be able to deliver, even before the Axis admits defeat.

*Due to space limitations, the description of the street light reflector will appear in the June issue of *Engineering and Science Monthly.*

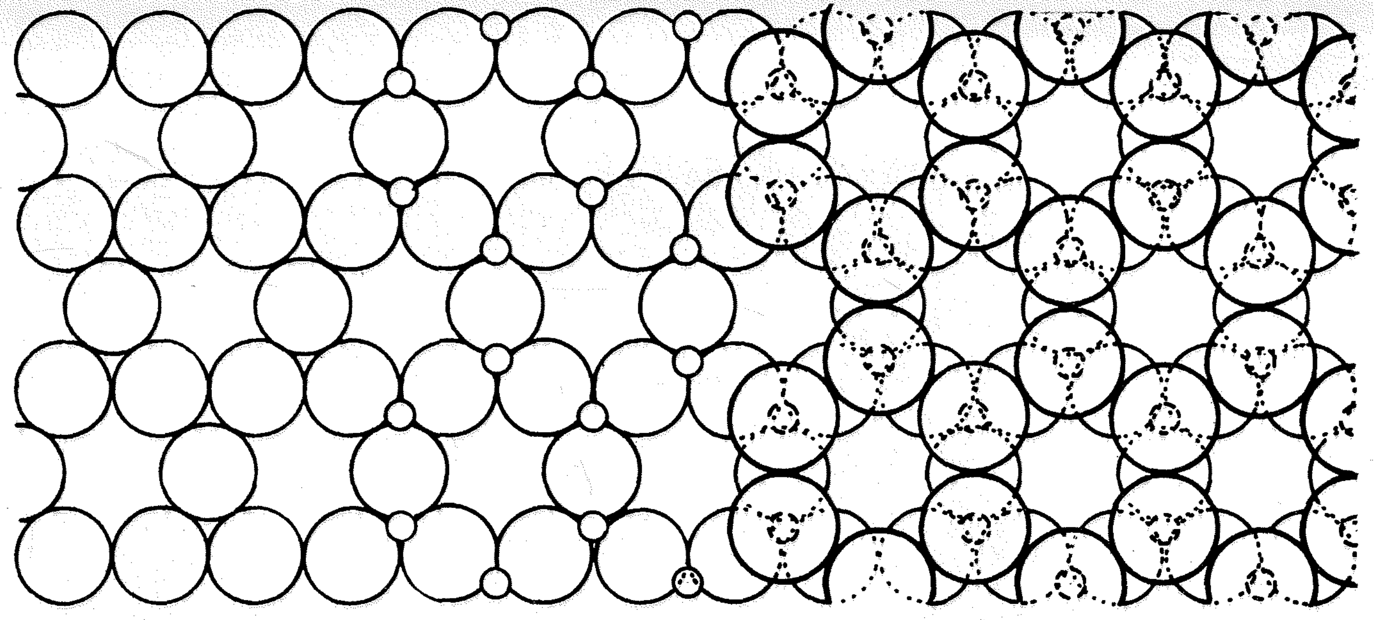


FIG. 1—Crystal structure of Hydrated Silica.

Scientific Research in Ceramics

By POL E. DUWEZ

SCIENTIFIC research in the field of ceramics may appear as a rather strange subject to many engineers and physicists. The ceramic industry is exceedingly old. For example, the manufacture of artistic porcelain had reached a remarkable state of perfection long before any scientific research had penetrated the field of industry. Very little scientific knowledge was necessary to the Chinese, Sevres, or Delft artist, but now the field of ceramics has extended far beyond the artistic domain.

A great variety of ceramic products are used in all the branches of engineering, and have to stand very severe conditions of service. They must perform with reliability at the limits of their possibilties. As a consequence the tendency is to impose very strict specifications on the ceramic material, as has been done with metals for many years. This condition has forced the ceramic industry to change progressively from an almost empirical technique to a scientifically controlled fabrication. The problems with which the ceramic engineer is faced are complex and greatly varied. The application of both physics and chemistry in the fabrication and in the use of ceramic products is so extensive that it seems strange no greater attention has been paid to it by scientists. In the following discussion an attempt will be made to describe a few typical problems in which the scientific approach has already given the ceramist a clear and accurate picture of the phenomena involved in industrial processes.

CONSTITUTION OF CLAYS

Clay being the most important raw material used in the fabrication of ceramic objects, an exact knowledge of its constitution and properties presents a very important problem. Until X-ray diffraction methods were applied to this problem. the nature of the structure of a clay particle was based mainly on hypothetical considerations. The microscopic method, so successful for the identification of crystalline components of rocks, did not give any definite information on the crystalline structure of clays because of the extremely small size of the particles. But more recently the X-ray diffraction method was systematically applied to clays by W. L. Bragg and L. Pauling, and the results of their studies not only showed the exact crystal structure of different clays, but also gave the clue to a logical explanation of some of their most important properties, and in particular their plasticity.

The crystal structure of clay is very complex, and it would be beyond the scope of this article even to try to give an account of the work which has been done in this field. However, it is possible to present a rather intuitive picture of the nature of the clay crystal, how it differs from other crystalline rocks and why it possesses such characteristic properties as plasticity. In a crystal of clay, as in any other crystal, the atoms are arranged in a definite pattern, forming a lattice. The special feature in a clay crystal is that the lattice is built of sheets of atoms. The crystal can be represented by a succession of parallel planes, the atoms being regularly arranged in each plane with the successive planes piled one on top of another.

The structure of kaolinite ($2SiO_2Al_2O_3 2H_2O$) will be described here as a typical example. It has been shown that unlike metals, such crystals as kaolinite are composed of ions and not atoms, and also that the hydrogen is always combined with oxygen to form a single ion called hydroxile (OH^-). The different ions composing the kaolinite crystal are, therefore, Al^{++++++}, Si^{++++}, O^{--}, and OH^-.

Before explaining the structure of kaolinite it is useful to consider two crystalline elements called hydrated silica and gibbsite. The hydrated silica is formed of three superimposed layers of hydroxile, silicon, and oxygen, respectively. A top view of these three layers is shown in *Fig. No. 1,* in which the ions are represented as spheres whose diameter is proportional to that of the ion. The bottom layer consists of oxygen ions arranged in a hexagonal plane lattice. On top of this layer is a layer of silicon ions forming also a hexagonal pattern. Since the diameter of the silicon ions is much smaller than that of the oxygen, the silicon ions fit into the space betwen three joined oxygen ions. The third layer is made of hydroxile ions placed just on top of each silicon of the middle layer. The diameter of the hydroxile is large enough so that the sphere representing these ions rests on the three oxygens of the bottom layer and the silicon is closely packed between four surrounding ions. It can be readily seen that the valences of each ion are saturated. Each silicon exchanges its four valences with three oxygen ions and one hydroxile. Each oxygen is saturated by two silicon, with which it is in contact, and one hydroxile exchanges its only charge with a silicon ion.

The second crystalline element entering the composition of clays is the gibbsite ($Al(OH)_3$). It consists of three superimposed layers; namely, hydroxile, aluminum ion, and hydroxile. The bottom layer of hydroxile forms a closely packed hexagonal arrangement, as shown in *Fig. No. 2.* The aluminum ions constitute the second layer and are distributed in a hexagonal lattice. The top layer of hydroxile is closely packed like the bottom layer but displaced in such a manner that each hydroxile rests on three hydroxiles of the bottom layer. As in the case of the silicon in the hydrated silica, the aluminum ion is small enough to fit in the center of six closely packed hydroxiles.

The clay known as halloysite is obtained by stacking the three layers forming the gibbsite on to the three layers of hydrated silica. This results in six successive layers—oxygen, silicon, hydroxile, hydroxile, aluminum, hydroxile. The reason for the bond which exists between the two middle layers of hydroxiles (one from the gibbsite and the other from the hydrated silica) is not quite clear because they lack any unsaturated valence. The forces involved in this kind of bond would seem to be due to the interaction between the electrical fields emanating from the two layers.

The crystal structure of kaolinite is very easily obtained from that of halloysite. The two middle layers of hydroxiles are combined into one single layer. When the consolidation occurs, the hydroxile ions combine in such a way as to form molecules of water, which are expelled. This process leaves a layer consisting of hydroxiles and oxygen. The kaolinite structure is, therefore, composed of five layers of ions in the following order: oxygen, silicon, hydroxile and oxygen, aluminum, and hydroxile.

The structural formula of a clay of the pyrophillite type is also obtained by putting together the structure of hydrated silica and gibbsite. But in this case the gibbsite is inserted between two layers of hydrated silica, accompanied by a contraction and expulsion of water.

These structural formulas are easier to visualize when they are written with certain coefficients which give for each layer the number of atoms corresponding to six hydroxiles in the gibbsite structure. The two fundamental elements, hydrated silica and gibbsite, and the three typical kinds of clays may be represented as shown in Table No. 1.

In a particle of clay, a great number of these crystalline units are piled on each other. More than 100,000 of these units are necessary to obtain a clay particle 1/10000 of a millimeter in thickness.

THE PLASTICITY OF CLAYS

Numerous interpretations have been proposed to explain the plasticity of clays. Most of these interpretations have ascribed the plasticity of clay to the extremely small size of the particles. On this basis small particles adsorb a film of water which acts as a slipping surface between particles without decreasing the cohesive forces. Hence, a plastic clay would be regarded as an aggregate of rigid spheres of non-plastic material coated with a film of lubricant of suitable thickness. Such a simple

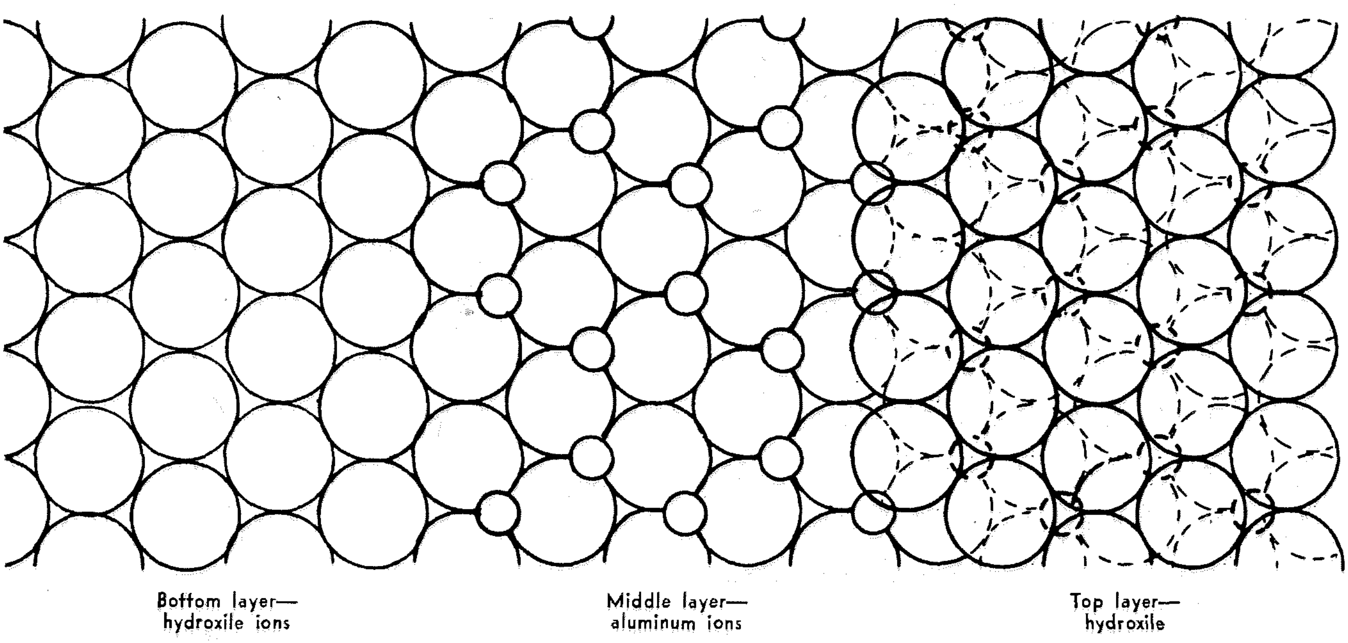


FIG. 2—Crystal structure of Gibbsite.

TABLE NO. I

Hydrated silica:

4-OH
4-Si
6-0

Gibbsite:

6-OH
4-Al
6-OH

Halloysite:

$$\left.\begin{array}{l}\text{Gibbsite}\left\{\begin{array}{l}\text{6-OH}\\ \text{4-Al}\\ \text{6-OH}\end{array}\right.\\ \text{Hydrated silica}\left\{\begin{array}{l}\text{4-OH}\\ \text{4-Si}\\ \text{6-0}\end{array}\right.\end{array}\right\} - 4H_2O =$$

Kaolinite:

$$\left\{\begin{array}{l}\text{6-OH}\\ \text{4-Al}\\ \text{4-O+2-OH}\\ \text{4-Si}\\ \text{6-O}\end{array}\right.$$

Hypothetical Crystal:

$$\left.\begin{array}{l}\text{Hydrated silica}\left\{\begin{array}{l}\text{6-0}\\ \text{4-Si}\\ \text{4-OH}\end{array}\right.\\ \text{Gibbsite}\left\{\begin{array}{l}\text{6-OH}\\ \text{4-Al}\\ \text{6-OH}\end{array}\right.\\ \text{Hydrated silica}\left\{\begin{array}{l}\text{4-OH}\\ \text{4-Si}\\ \text{6-O}\end{array}\right.\end{array}\right\} \begin{array}{l}-4H_2O\\ \\ -4H_2O\end{array} =$$

Pyrophillite:

$$\left\{\begin{array}{l}\text{6-O}\\ \text{4-Si}\\ \text{4-O+2-OH}\\ \text{4-Al}\\ \text{4-O+2-OH}\\ \text{4-Si}\\ \text{6-O}\end{array}\right.$$

concept of the mechanism of plasticity does not explain why a clay particle possesses an affinity for water, and does not explain why other materials like quartz or feldspar of particle size comparable to that of clay do not exhibit any appreciable plasticity when mixed with water.

The knowledge of the crystal structure of clay leads to a more satisfactory explanation of plasticity. It has been shown that water molecules can be absorbed by the crystal. These molecules form supplementary layers between adjacent crystalline units. These layers reduce the cohesive forces and thus provide planes for easy slip by which plastic deformation may occur. Some of the plasticity of clay may also be attributed to the adsorption of water molecules at the surface of the particles. This adsorption is due to the attraction between the outside layer of hydroxiles in a crystal of clay and the water molecules. The crystal of clay is, therefore, surrounded by a film of water as it was supposed in the older hypothesis, but the nature of the bond between the adsorbed water and the clay particle is connected with the crystal structure of the clay. It is then easy to explain why the water adsorbed by very small particles like quartz, for example, will not have the same plasticizing action as when adsorbed by a clay particle. Thus there are two different mechanisms by which plasticity in clays is obtained: namely, absorption of layers of water molecules in the crystal of clay, generating slip planes; and adsorption of a bonded film of water by the particles of clay, producing slipping surfaces.

FIRING OF CLAYS

Many features in the process of drying and firing clays can be explained by reference to their crystal structure. In the drying process, for example, it is rather difficult to expel the absorbed water without partially destroying the crystal lattice. The plasticity may therefore decrease after the clay has been thoroughly dried. The plasticity is completely destroyed when the clay is fired at a sufficiently high temperature (above 550°*C*). Above this temperature the absorbed water is completely expelled and the hydroxile layers also produce water molecules which are removed. As a consequence, the entire crystal lattice collapses. The exact nature of the product resulting from this decomposition of a clay is not known. It is definitely established now that the product of decomposition does not give any X-ray diffraction pattern and therefore does not possess any definite crytsalline structure.

The structural composition of kaolinite after being fired at a temperature above 925° *C*. is well known. It consists of crystals of mullite ($3Al_2O_3.2SiO_2$) and free silica. The latter may be present as amorphous silica, quartz, tridymite or crystoballite. The occurrence of one or several of these forms of silica depends primarily on the nature of the clay. The most suitable experimental method of studying the crystalline forms of silica in fired clay is by means of a dilatometer. Each form of silica undergoes allotropic transformations at certain temperatures. The temperatures of these transformations are different for different materials. These allotropic transformations are accompanied by an expansion.

As an example, the study of the structure of silica in four clays of different origin by dilatometric methods will be briefly described. The results to be discussed were obtained by means of a photo-recording dilatometer, for which the specimens consisted of small bars two inches long with a square cross section 3/32 inch by 3/32 inch. The specimens were cut from a block of fired clay by means of a thin diamond saw. The expansion-temperature curve was obtained with a rate of in-

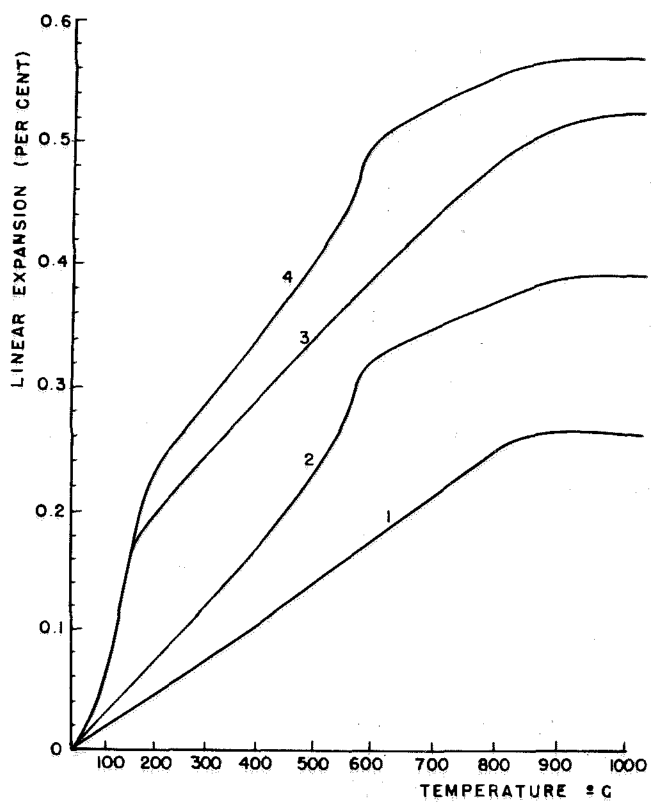


FIG. 3—Thermal expansion versus temperature for four clays of different origin, fired for six hours at 1350 degrees F.

crease of temperature of about 2° *C.* per minute. This slow increase in temperature and the fact that the specimen was of small dimensions resulted in a very small temperature gradient in the specimen, and the allotropic changes took place in a minimum time. Four clays of approximately the same chemical composition but of different origin were fired for six hours at a temperature of 1350° *C.* The four expansion curves are shown in *Fig. No. 3.* Clay No. 1 gave a straight line up to a temperature of about 850° *C.*, showing that no crystalline silica was present. This clay after firing consists of an aggregate of mullite crystals in a silica glass matrix. In clay No. 2 the presence of quartz is clearly shown by the sudden increase of expansion at 575° *C.* In clay No. 3 the change in expansion coefficient takes place around 130° *C.*, indicating the presence of tridymite. The expansion curve of clay No. 4 shows definitely the presence of both quartz and tridymite. All these conclusions were checked by means of X-ray diffraction spectra, which revealed the presence of the constituents indicated by the expansion curves.

This typical example demonstrates the influence of silica on the average coefficient of expansion of a ceramic body. This average coefficient of expansion is of great practical importance in problems concerned with glazes in porcelain and china ware and also in the making of refractory bricks intended to resist thermal shock.

PROGRESS

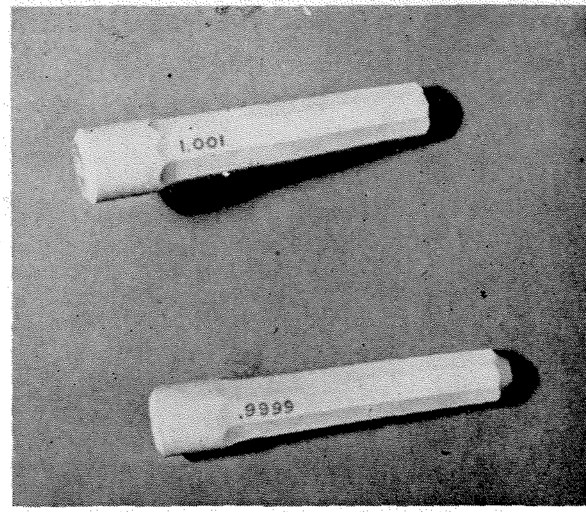
The demands of metallurgy for better refractory materials have been largely responsible for the progress made in the manufacture of refractories. This progress has resulted in a better control of the materials and in the development of new products. Simultaneously, methods have been developed for testing refractory materials under conditions approaching those found in service. Some of these tests, such as the determination of the softening point, the measurement of the load-bearing capacity at high temperature, and the spalling resistance of firebrick, have already been standardized. Other useful measurements, such as the thermal expansion, and the thermal and electrical conductivity, require more elaborate equipment, which is limited to very few laboratories. The resistance of a refractory to erosion and corrosion by a molten slag is of the greatest importance to the metallurgist. Laboratory tests reproducing the service conditions have already demonstrated their value.

Experimental research in ceramics is primarily dependent upon furnaces in which high temperatures can be easily reached with any desired atmosphere. Considerable progress has been made in this direction during the last decade. This achievement, together with the use of the methods of investigation which modern physics has placed at the disposal of the engineer, will greatly contribute to the development of research in the field of ceramics.

CERAMIC GAUGES

By B. W. MORANT

CHANGING conditions of the world have always brought about many new ideas in connection with production and the use of materials. One idea that has turned into a reality is the ceramic type of gauge, the earliest development of which occurred through the use of glass. Chief concern in any volume production program is the life of the tool before it must be taken out of service for replacement or reconditioning. The next concern is how cheaply and how quickly it may be replaced. The ceramic gauge offers a valuable solution for



Ceramic gauge, designed to replace gauges of critical metals.

both of these problems as it is very resistant to wear, and is quickly and cheaply produced and replaced.

While there are many reasons for substituting noncritical materials for those in the more critical classifications, it is unnecessary to analyze the ceramic gauge for anything but its own direct merits. At all times the raw material from which it is made is both plentiful and cheap. The product is very hard and of excellent wearing quality. The rough blank is easily produced by pressure with the minimum of equipment. By varying their composition, ceramic gauges may be provided with a wide range of coefficients of expansion. Oxidation of ceramic gauges does not present any problem, and perspiration does not etch their surfaces. Ceramic gauges do not tend to gall when used with copper alloys. Compressive strength of ceramic gauges can be as high as 100,000 pounds per square inch. Tensile strength, however, will vary from 5,000 pounds to 15,000 pounds per square inch. Similarly the impact strength of ceramic materials is low.

At first glance these last factors discourage industry from the general use of ceramic gauges. However, experts with steel gauges agree that after a gauge has been dropped, it should not be relied upon until standardized. The ceramic gauge is never in doubt because it always dismembers itself or else is picked up in an immediately usable condition. The behavior of ceramics is such that an impact which is sufficient to remove a small chip does not affect the balance of the dimensional characteristics, although intraconchoidal fracture may result on the second or third impact. Therefore, in order to prevent or at least minimize breakage from rough handling, the ceramic gauge should have all exposed edges beveled or finished to a radius.

Briefly, the blank for a ceramic gauge of the type so far considered is slip cast, hollow, and with or without integral handle. It is provided with cast-in-center bores at each end to facilitate the finish grinding. The blank is capable of great accuracy as cast and fired, but the usual finish grinding operations are required to meet the tolerances demanded.

In the above comments an attempt has been made to present some of the factors involved in the use of ceramic gauges, both favorable and unfavorable, in order that the reader may draw his own conclusions as to why after more than a year of general consideration and in

(Continued on Page 15)

Work Simplification in Ceramics

A Case Study in Cooperation between the California Institute of Technology and the Ceramics Industry

By VICTOR V. VEYSEY

"WE practically wear the pottery out dragging it through the shop," stated the factory manager of the Hillmont plant of Gladstone Ceramics Company* in summarizing the manufacturing problems of producing pottery and china in a plant which was not originally intended for this purpose. This frank and critical attitude with which the factory operating man viewed his own work was reflected throughout the entire organization, including top managers, and led the company to the recognition of two facts: *first*, that present methods, although they had been improved from year to year, were not and would never be satisfactory unless improvements were taking place rapidly, and *second*, that ideas and principles developed in other plants and in other industries could be applied to the manufacture of ceramics.

It was with this approach that the officials of Gladstone Ceramics Company turned to the Industrial Relations Section of the California Institute of Technology with the suggestion that a project of mutual benefit be developed from a study of their problem of plant layout and manufacturing methods. It is now possible to review the developments from the perspective of a year of work since the project was undertaken in the spring of 1943, and to describe the problem and its partial solution as a case study in the cooperation of the California Institute with industry in the field of production engineering, including plant layout and improvement of methods.

To summarize the results gained in the year's contact calls for mention of specific contributions, such as a revision of the layout to eliminate several handlings of materials and to effect a saving as high as 50 per cent in material transportation in the plant while developing flexibility of operation; the simplification of a difficult problem of handling materials in the production of cast ware where the installation of a circulating system was the obvious answer; and minor improvements in operations for forming and decorating pottery and china where a slight saving on each operation may be multiplied by the millions of repetitions of the cycle to show substantial annual economies. Not the least important was the development of principles and approaches, outlined in this article, which are applicable in most industry today.

*Fictitious name and location are used throughout for the protection of the company.

FROM THE POTTER'S WHEEL

The manufacture of ceramics is one of the most primitive arts. Much of the production of pottery and china still depends upon the simple principle of the potter's wheel. This is particularly true of the ceramic plants in southern California where the emphasis has been placed on the production of highly styled ware, and on the introduction of a certain peasant quality in the ware by the use of much handwork. The Gladstone Ceramics Company has pioneered in styling and in hand production and decorating methods. There was no thought of producing pottery on a mass production, mechanized basis.

Wall tile, fire brick, and sewer pipe, all construction items, had been the products produced at the Hillmont plant prior to 1934. In that year it was decided to supplement the line with pottery and art ware in order to use plant capacity which was idle because of the general decrease in construction. The pottery line received popular acceptance and the space devoted to its production was gradually increased as new patterns were added. Although good sales outlets were established through higher class stores, the pottery line was still viewed as a fad, and tile was looked upon as the major product; hence the pottery layout was treated as temporary.

In 1940 a line of china was added on a pilot plant basis. Since then the major problems of producing a good quality china have been mastered.

The war brought curtailment in the construction industry and major attention was turned again to the production of pottery, art ware, and china. The sale of these items was stimulated because retail outlets were seeking lines which did not require metals or other

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UPPER:—The first process in jiggering is completed by the "batter out" preparing the clay sheet. LOWER:—A tender brings up and removes the molds.

scarce materials. The problem became that of stepping up pottery and china production to meet the new demand, maintaining the handcraft tradition in spite of wartime labor shortages, and using idle capacity in the tile department without certainty as to when the large-scale manufacture of tile would be resumed.

PRODUCTION METHODS

The production of china and that of pottery are similar as to the sequence of operations employed; the most important differences are in the nature of the materials used and in the care employed in finishing and decorating. Also, china is fired a number of times: in the bisque or unglazed condition, after glazing, and after each color is added in decorating, sometimes a total of five or more times. In contrast, pottery as produced in this plant is fired only once after all decoration has been applied.

Pottery and china may be divided into two groups of products: *first,* flat ware, including plates and platters of all sizes, saucers, and shallow bowls; and *second,* hollow ware, including cups, deep bowls, and pitchers. Flat ware is best produced by the jiggering method, which is a modification of the potter's wheel. A plaster of Paris mold is rotated on a horizontal table, and against this mold a thin sheet of clay in the correct plastic state is pressed to form the inner surface of the plate in an inverted position. The outer surface is formed by holding a template to the rotating clay. After forming and trimming, the plate, still on the mold, is dried in an oven. Great skill is required in jiggering, but considerable speed can be developed by a two- or three-man team: one "batter-out" preparing the clay sheet, one jigger man, and one tender bringing up and removing the molds. Elliptical platters are jiggered on a special table with an eccentric motion.

Hollow ware is produced by the casting method. For this purpose a thick solution of clay in water is poured into a plaster of Paris mold having the shape of the outside of the vessel. Water from the clay solution or slip is absorbed by the mold, and a thin layer of clay is deposited against the mold. At the proper time the remaining liquid is poured out. After further drying, the mold can be removed and re-used. Very careful adjustment of the water content of the slip is required for good results; although the slip may be poured, its water content is about the same as that of the plastic clay used for jiggering. This fluidity is accomplished by the carefully controlled addition of certain chemicals.

APPROACHING THE PROBLEM

The problem laid before the Industrial Relations Section was twofold: *first,* the development of a revised layout for the expanded pottery and china departments, and *second,* the improvement of methods of performing the operations and handling of the materials to reduce labor.

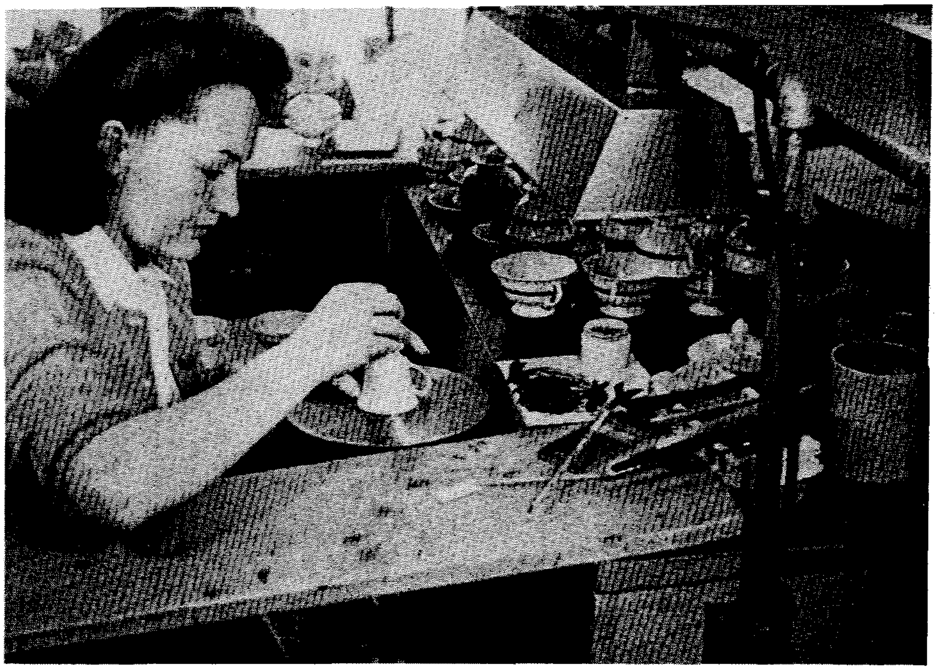
Company officials offered to open the doors of the plant any time, night or day, for Caltech students to familiarize themselves with the problem. They offered to explain operations to the classes and to examine and criticize the finished reports on improvements. At the same time they agreed to use ideas which to them seemed meritorious, although they of course did not pledge themselves to install any given recommendation. Their own competent engineers were engaged in solving the problems at the same time.

The first step in approaching the problem was to obtain complete data. Inasmuch as the bulk of the work on the project would be done by students in courses in plant layout and in methods improvement given at the Institute, it was desirable to record information on the problem in such form that it could be presented readily

Flat ware is produced by the jigger method, a modification of the potter's wheel.

in laboratory. For this reason it was decided to cover all of the major operations in the plant by means of motion pictures taken with a constant speed, spring wound, amateur 16 mm. motion picture camera. The films could then be studied and analyzed conveniently in the laboratory without unduly stretching the hospitality of the company officials. The motion pictures were supplemented with a large number of still pictures to give details of layout, plant construction, and equipment. Additional data were provided on present and planned capacity, distribution of the product among several lines, and on dimensions and layout of the plant.

The bulk of the photographic work was performed by a class of mechanical engineers, seniors at the Institute, who had requested and were given a special course in industrial management with emphasis on motion- and time-study work. It was with some fear that a group of energetic seniors was turned loose with expensive photographic equipment in a pottery plant full of fragile material, but the results were a very pleasant surprise. Far from the "bull in the china shop" outcome which was feared, the men turned in a workmanlike performance, obtained the necessary data with dispatch, and succeeded in producing an edited film of something over 1,200 feet in length which contained more material than could have been recorded in volumes of writing or could have been observed by classes in many field trips. Much of the success of the photographic undertaking was due to the fine cooperation of the company employees. They were not only willing but eager to serve as subjects for the camera. The basic data on this problem have since served with increasing satisfaction as a major problem in four separate courses in plant layout and methods improvement in the Engineering, Science, and Manage-



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Finishing, inspecting, decorating, and glazing operations are similar for all types of ware. Continuous kilns of the type employed for firing tile are used for firing all pottery and china.

ment War Training (E. S. M. W. T.) night school program.

In the course of the work in the plant while taking the motion pictures, a number of facts became evident:

1. Transportation of material in process was excessively lengthy and was sometimes performed the hard way.

2. There was adequate capacity in the plant building for considerable expansion if space were used economically. A number of kilns and other equipment suitable for the manufacture of pottery were idle because of the shortage of orders in tile.

3. The buildings were generally suitable for the uses required. Certain difficulties were encountered because the plant had grown by a series of accretions to an original warehouse structure, but good clear space could be obtained for well-developed lines of flow.

4. Production methods varied throughout the plant from almost primitive methods involving considerable laborious routine work by skilled operators to beautifully mechanized installations for some of the operations.

5. Although there was more than normal latitude provided in rearranging facilities for this layout, certain definite limitations were placed on the problem, due to the importance of flexibility in the plant operations.

Two separate problems had been presented, one, the improvement of the layout and, the second, the improvement of methods in performing the operations, but the two problems were not independent. They would have to be approached simultaneously in the development of new production methods for the company.

PLANNING THE LAYOUT

The problems of methods improvement and the preparation of a layout were divided into the following portions for study by student groups: production of pottery by jiggering method, production of pottery by casting method, production of china by jiggering method, and production of china by casting method. Considerable cooperation was necessary among the several groups because developments and improvements of one group might seriously affect the work of another.

The first step in the procedure was the development of a process flow chart, which is a simple chart showing by means of symbols and abbreviated explanations the sequence of operations, transportations, storages, and inspections which is necessary in the production of the product. In this case four different but related process flow charts were developed, one each for the two methods of pottery manufacture and for the two methods of china manufacture. The drafting of a process flow chart is in itself no contribution to the improvement of methods or of layout, but it has been found both in this case and in industry in general that a complete and definite knowledge of the sequence of operations in performing the work is essential before soundly conceived improvement can be undertaken. It is folly to attempt changes in layout without basing them on thoroughly planned improvement of the flow of work.

Many seasoned production men are inclined to think in terms of an ideal or desired sequence of operations—what is supposed to happen rather than what actually is done. A graphical presentation of performance as given in the process flow chart may reveal the defects in their own operations. The process flow chart serves in three ways:

1. It indicates that the problem of flow of work is critical by bringing defects to light.

2. It facilitates an orderly planning of work and the logical elimination, combination, and improvement of operations.

3. The comparison of an original process flow chart with a process flow chart after the improvements have been made is striking evidence of the worth of the changes.

In this case the development of the process flow chart brought to immediate focus some of the problems in layout. A tabulation of the transportation distances and transportation methods indicated that the factory manager's facetious comment about "wearing the pottery out by transporting it" was not to be taken lightly. The total material handling distance for each group of products was discouraging.

It was further evident from the process flow chart that delays and storages of the material were more numerous than required, leading to the storage in the plant of a very large amount of semi-finished material. This practice was excessively wasteful of floor space, although it had not created any problem in operation, because sufficient space was available for all needs. It did involve, however, a heavy investment in unfinished goods, it tended to cause transportation between operations to be long and to be broken into a series of moves rather than one or two moves, and it was conducive to careless practice in scheduling, production control, and plant housekeeping.

MACHINE CAPACITY

The second step in preparation of the layout was a calculation of required machine capacity to produce the necessary volume of finished material. Furthermore, the capacity of equipment to handle the various operations was balanced so that excessive under-capacity and excessive over-capacity at any point in the flow were avoided. Any computation of machine capacity must be based on some assumption as to the desired volume of production; this assumption depends on business rather than engineering considerations. The uncertainty of the data on the businessman's side of the problem was distressing to engineers who reasoned that they could furnish an economical layout for any given requirement in volume of production but that they must have some guarantee as to what that volume would be. The changeable character of business, on the other hand, made it impossible to guarantee what the volume of production would be next month or next year or how it might be distributed among the several items produced. The businessman desired flexibility to handle the changing situations.

After some study of sales records and due consideration of future possibilities, it was decided to provide capacity for the production of about 30,000 pieces per day in pottery and 8,000 to 10,000 pieces per day in china, at the same time allocating a number of kilns to the production of tile. The estimated distribution of product between cast ware and jiggered ware was: pottery, 35 per cent cast, 65 per cent jiggered; china, 50 per cent cast, 50 per cent jiggered. Machine capacity for each operation was calculated from this assumption. At the same time the future reliability of these estimates was doubtful, so that, although the layout could be designed for this normal output, it was necessary to develop extreme flexibility in the layout even at the expense of efficient operations in order to meet anticipated large swings in volume of business. The major question in developing the layout then became: How can the best compromise be made between efficiency and flexibility?

The third phase of planning the layout was blocking out the required floor space. As it developed in this case the requirements of floor space were not critical, inasmuch as there was idle plant available. Good clear space and a long straight line of flow could be obtained by starting the production of all products at the east end of the plant, where the material could be fed from a spur track which already existed, and by using the full length of all the plant buildings, completing the finished product at the extreme west end of the building and transferring it to the basement for storage and packaging. All important portions of the layout would in this way be located on one floor in a single building and a smooth movement of materials could be accomplished.

At this point a major decision was made. It became evident that an economical type of layout could be achieved by use of the straight line or product type of flow wherein there would be little confusion, back-tracking, or unnecessary handling of pottery, china, or tile as it moved through the plant. At the same time extreme flexibility could be achieved by incorporating many elements of a functional grouping of equipment in the layout, *e.g.*, aligning all kilns for pottery, china, or tile together so that capacity could be swung to one product or the other without moving kilns and without excessive materials handling. This could be accomplished because the processes and equipment used in pottery manufacture, china manufacture, and to some extent tile manufacture were interchangeable. One feature of the existing plant seemed to interfere with this plan: A group of executive offices had been established within the rectangle of plant which would be needed for the layout, producing a narrow point in the flow at precisely the point where the maximum width was needed. The officials agreed, however, that it might be cheaper to build a new office building than to interrupt the flow of the plan.

PLANNING PRODUCTION CENTERS

The fourth step in preparing the layout was that of planning the production centers used in the manufacture of each type of product. By a production center is meant a self-contained unit consisting of a machine and accessory equipment in the work area, working space for an operator or operators tending the machine, space for the movement of materials to and away from the machine, and space for servicing the equipment. A self-contained production center once planned and laid out to scale can be picked up and moved about readily in the reshuffle of facilities which is necessary in planning the complete layout. The production centers were drawn to a convenient scale matching a large floor plan of the

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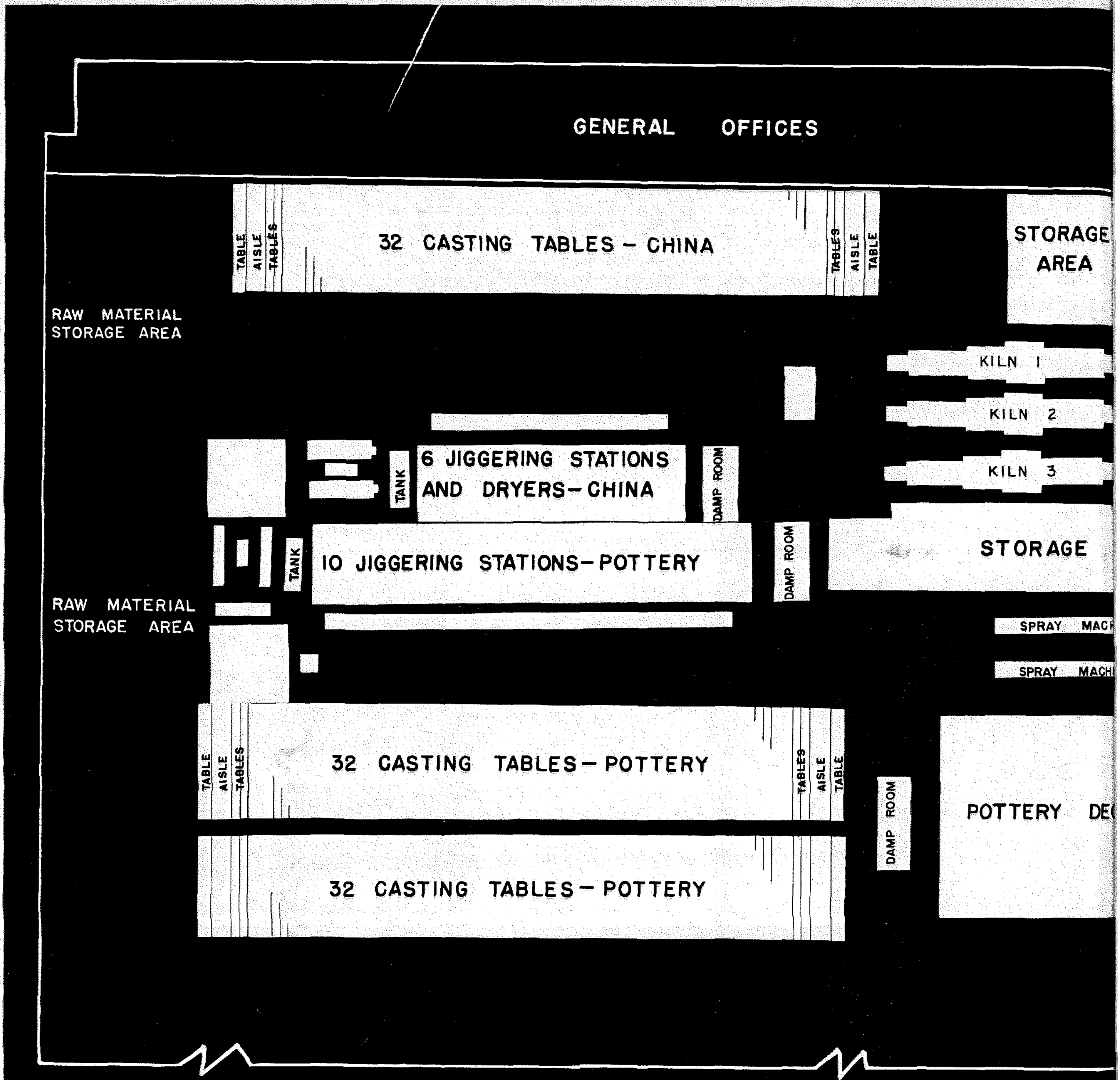
Hollow ware is produced by the casting method. This view shows the plaster of Paris molds for medium-sized bowls.

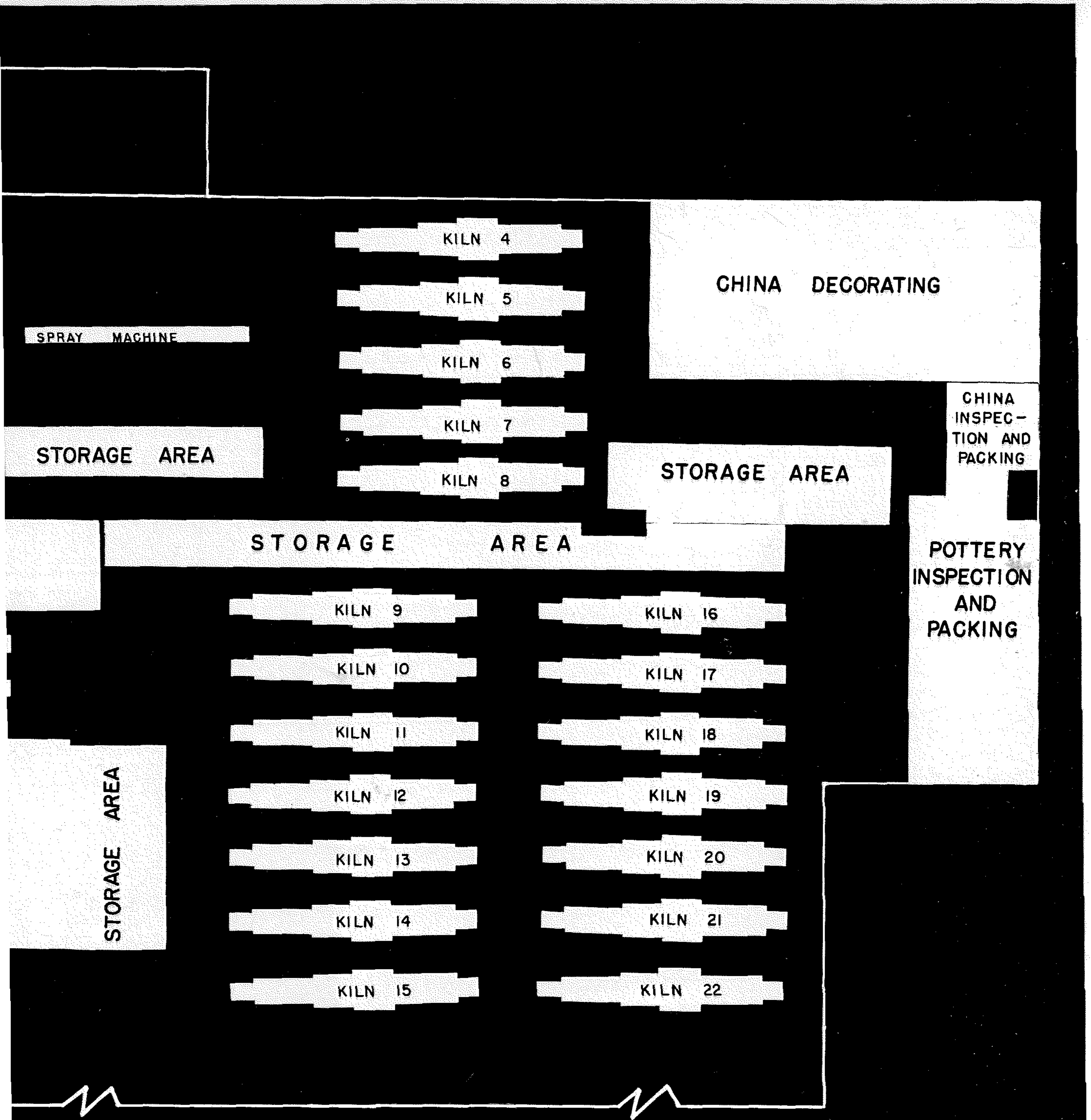


Partially completed plant layout on student layout board. W

plant and were cut out of cardboard for easy handling.

The fifth step was the essential one of arranging the templates of the production centers on the floor plan to produce a layout. A statement of the step is very simple, but the actual development of a layout in this manner is complex because of the infinite possibilities presented. Every arrangement has advantages and disadvantages which must be weighed in appraising its effectiveness. It is a safe statement that if one worked long enough on the problem of arranging the templates he would produce a layout which is better than any he had previously developed. It must be remembered that all practical solutions to the problem will be only successive approximations approaching the ideal of the "one best way." Although this stage of the process is laborious, it is also profitable. The work is greatly facilitated by the use of the cardboard templates of production centers. It is during this phase of the arrangement of the paper cutouts on the floor plan that minor adjustments may be made both in production centers and in the floor space area to be used. The close association of method and layout requires that adjustments be made in the one to accommodate the other.

The sixth step in preparing the layout was selecting a final arrangement of the templates which best satisfied the requirements. The templates were pinned or pasted



ard templates facilitate improvement of the layout.

in place to produce a working layout. Lines of flow tracing the movement of material from one center to the next were drawn in or outlined with colored thread. The development of these lines of flow was a good check on the layout because it brought to light certain difficult or confused situations indicated by unusually long lines of flow, back-tracking of lines of flow, or the intersection of the lines.

At this point a process flow chart of the improved method of performing the work was drawn and new material-handling distances were tabulated. In this way the exact amount of the improvement in the layout was shown and the quality of the layout from the materials-handling viewpoint was demonstrated. Some of the arrangements developed as solutions to this problem resulted in the elimination of more than 50 per cent of the materials-handling distance in the case of pottery manufacture and an even greater improvement in the case of china.

The seventh and final step in developing the layout was to detail and draw up the layout in good form for blueprinting. This involved drawing in of accessory facilities such as service facilities, auxiliary departments, aisle space, locker room and toilets for employees, and other necessary appurtenances to the actual production process. While the major decisions on layout had been

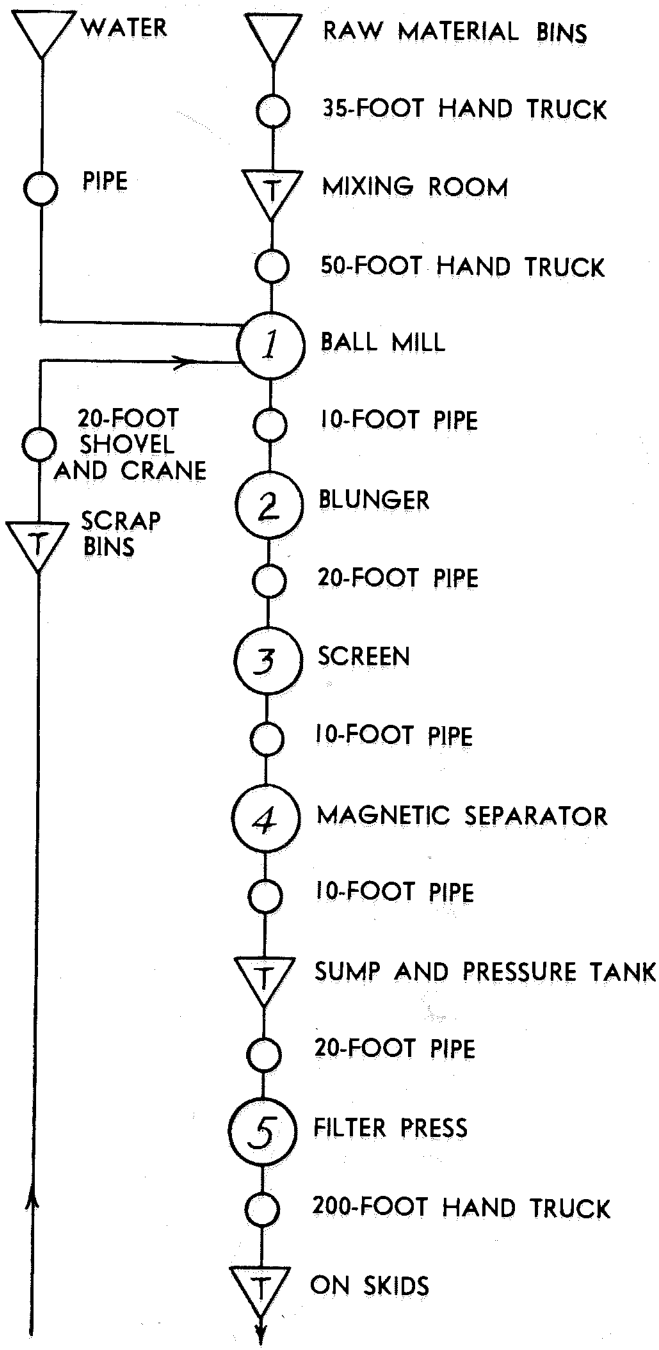


Diagram showing portion of process flow chart for the manufacture of pottery by the jiggering method.

made at this point, it was none the less important to use care in arranging for the details. The quality of the layout may be judged to a considerable extent by its polish and refinement in detail—the hallmark of the competent production engineer. Careful completion of a final report and drawings was required.

METHODS IMPROVEMENT

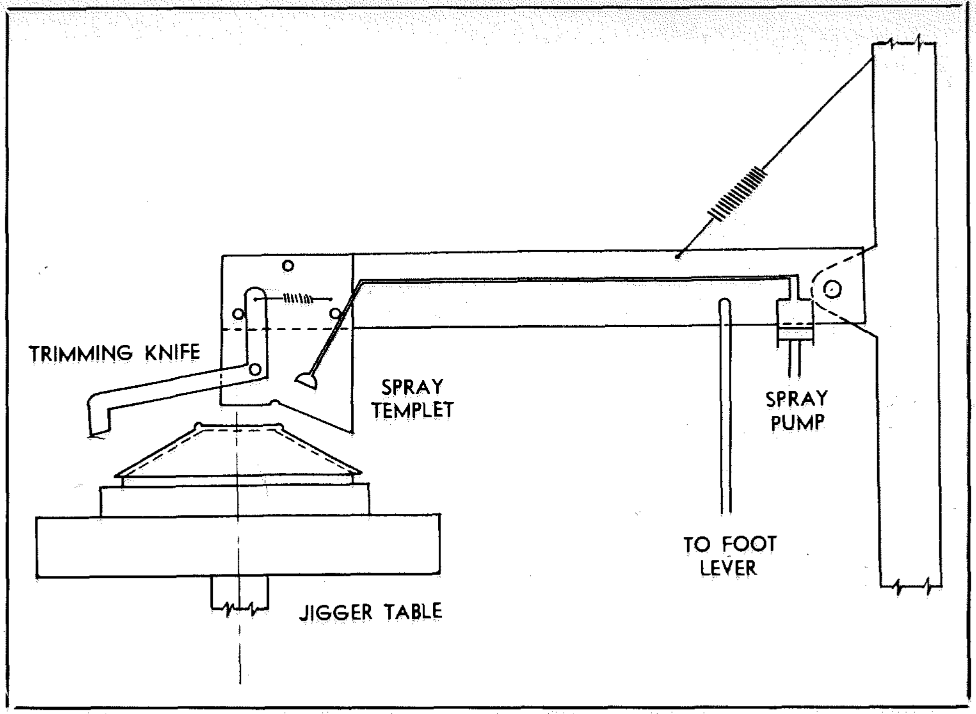
The problem of the improvement of methods in the individual production centers was considered constantly as the layout was being developed. Some of the suggestions for improvement of methods involved re-engineering of equipment, some involved regrouping of men to operate more effectively, and some involved the use of a new pattern of motions in performing the work. It was in the development of new methods that the motion pictures of operations taken in the plant were of maximum usefulness; more detail could be determined about operations by a careful scrutiny of the motion pictures than could be determined even by prolonged observation of the work in the shop. This was true for three reasons: The motion picture focused the attention of the observer on the method itself and excluded other distracting circumstances; the film could be studied in slow motion or frame by frame if necessary to discover exactly how the operation was being performed; and one representative cycle of an operation could be formed into a loop which could be continuously projected, thereby providing a moving picture of the unchanging method for observation.

The approach in developing new methods was first to select the operations wherein improvement could be expected to have economic significance—that is, those operations involving large amounts of operator-paced time on repetitive performance. Operations such as jiggering, casting, finishing, and inspecting of pottery and china were of this sort, since a number of operators were employed on these jobs and the cycles were repeated millions of times in the course of a year. The second step was the preparation of a process flow chart of the detailed sequence of elements followed by the workman in performing the operation. Such a chart is analogous to the larger process flow charts developed for the complete plant, but for this use it is more detailed and confined to a single operation. The third step was a careful analysis of the film in a hand-cranked projector to develop a man-and-machine chart showing against a time scale the activities of the operator and of his various pieces of equipment during the cycle, or a simultaneous motion chart depicting against time the detailed movements of the operator in performing the cycle. By counting the frames required for the performance of a cycle, it was possible to ascertain with good precision a time standard on the job. This was checked against the standard of performance in use by the company for purposes of scheduling and of wage payment.

The next step was the redesign of the work cycle by applying the principles of motion economy to the design of the work place, design of tools and equipment, and to the use of the human body in most effectively performing the work. As in all engineering problems, the engineering of a new method depends heavily on the ingenuity of the man making the design. He has certain rules and principles to follow but his application of those rules is all-important. Certain of the student groups suggested and developed new methods which were clearly improvements. These improvements were not stumbled upon or arrived at intuitively but were developed by careful application of a logical approach to the problem. In order to make the situation as realistic as possible, students were encouraged to estimate a time standard on any improvement which they suggested and to determine the dollars-and-cents saving in a year of operation, testing its practicality as an improvement against the expense of its installation. This demonstration was disillusioning in some cases and gratifying in many.

THE RESULTS

It is difficult to appraise the effectiveness of a project of this type because it is impossible to determine the increment of progress added by the California Institute's participation to what the company would have made in any event. In some cases the suggestions developed at Caltech were new; in other cases they merely supported



AT RIGHT
Diagram showing proposed jigger arm assembly.

conclusions already determined by the company. Many suggestions needed much practical refinement before they were ready for the test of application.

Several specific contributions can be listed as representative of the important items:

1. In layout, the idea of combining the efficiency of straight product- or line-flow of materials with the cross-cutting flexibility of functional grouping of major units possesses great merit in this case. While the idea is not new, it has had only limited application; this is a case where it would be applicable.

2. Revision of the layouts achieved over 50 per cent saving in transportation distance, with several handlings of materials eliminated, combined, or simplified. Since materials were heavy or fragile, this was an important saving.

3. Suggestions for the improvement of the jiggering operation varied from designs for new dryers with automatic loading and return systems to suggestions for the combination of applying water to the revolving vessel and trimming it with the action of the template arm.

4. Numerous suggestions for improvement of the laborious hand pouring operation in the casting department centered around pumping the slip to the casting stations. Despite protests that "it can't be done," a fine circulating system is now operating in the plant.

The company engineers and operating men have taken a very broad gauge attitude about accepting the suggestions rather than resenting them as criticisms.

From the view of the California Institute, this problem permitted the development of excellent material for teaching and made for good training in practical problems for the students with an interest in production problems.

The fact that the California Institute, without a separate department of industrial engineering, should be called on to participate in this undertaking to the mutual benefit of both parties indicates the need for specialized training, research, and service in production engineering in the growing industrial community of southern California. Neither industry nor the California Institute will ignore the possibilities of further collaboration on production problems.

Ceramic Gauges

(Continued from Page 7)

the face of severe priority restrictions on critical steel tools the metal-working industry is still hesitating to adopt the newer ceramic materials. The ceramic industry should not be expected to be the one to promote the use of ceramic gauges, because the volume of material involved represents an insignificant percentage of its total product. It has, however, carried on research to increase the mechanical shock resistance of its materials and has been able to present finished surfaces which are "nonfreezing," "nongalling," and capable of resisting the abrasion of anodized and other finishes found on the pieces to be gauged. The gauge industry is inherently conservative, but there seems to be much of future interest in the nonmetallic standard of measurement.

APRIL ISSUE COVER

The April issue of *Engineering and Science Monthly* featured an interesting view on the cover and several readers of the magazine have requested identification of the subject matter. The caption to the illustration reads as follows: "*Birth of a Multiple Contact Plug:* The electric circuit comes into its own in the multiple contact plug. These connectors are specially designed to meet specific and often unusual requirements. Engineers of the Cannon Electric Development Company have designed and manufactured connectors carrying well over a hundred circuits."

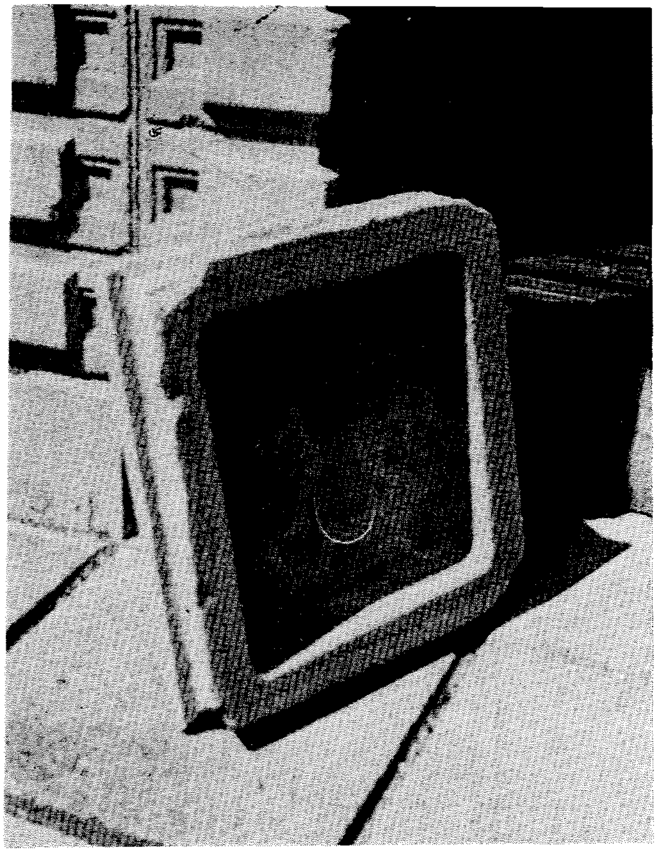


FIG. 1—The cast block is indented on the rear side, thus forming an insulation area when laid up into a wall. The edges are concave, providing a chamber into which concrete is poured around the steel bars. The block is 16 inches square. The terrace and floor of the house are of the same blocks laid horizontally.

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

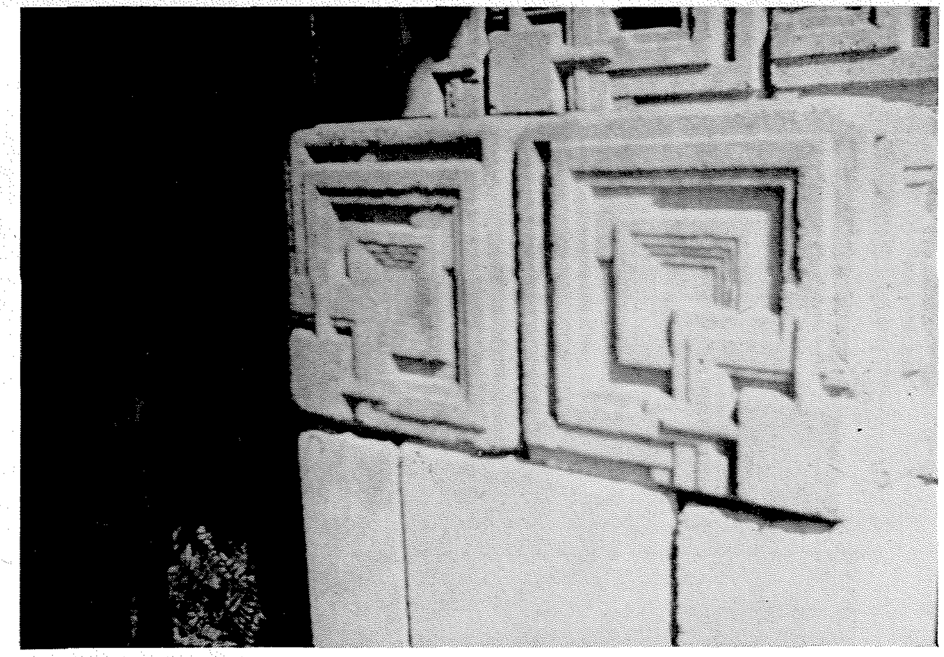
A long list of items was taken under consideration for kitchen equipment: cooking ware, food containers, colorful honey and cheese jars, teapots and teacups, ceramic stoves and small parts like ceramic bottle and jar-closers or coasters for glasses; for the bathroom: plumbing fixtures, handles, doorknobs, 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.

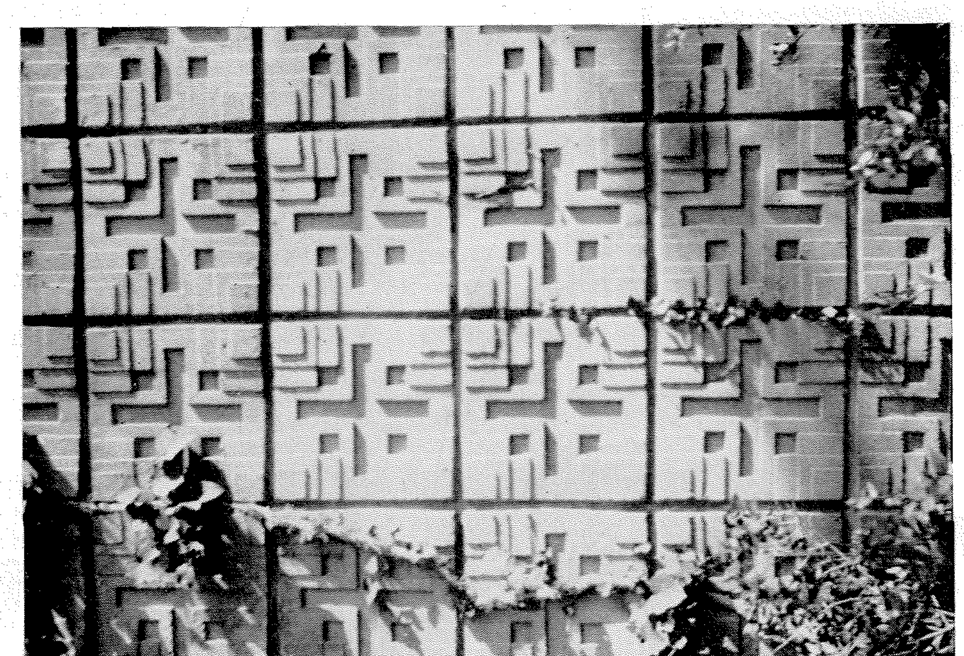


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FIG. 3—The highly textured walls lend themselves admirably to diffusing the brilliant California sunlight, thus reducing glare. Notice in the detail of the blocks the few highlights and shadows with large areas of medium-intensity light reflection.

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.

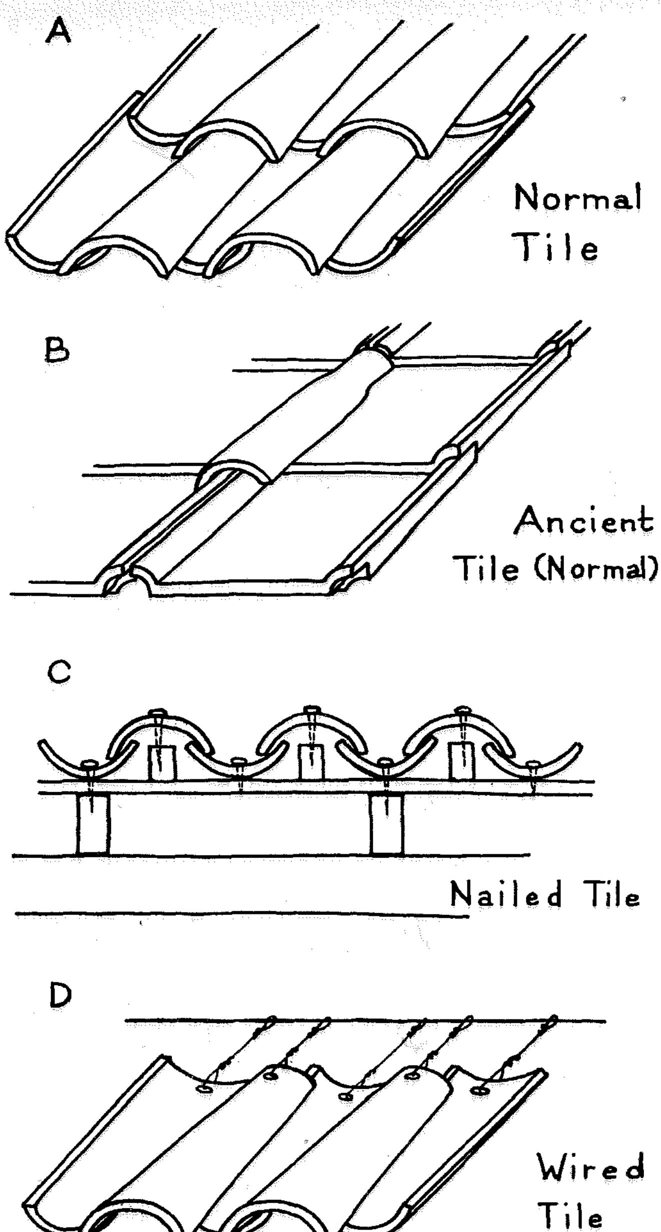


FIG. 4.

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.

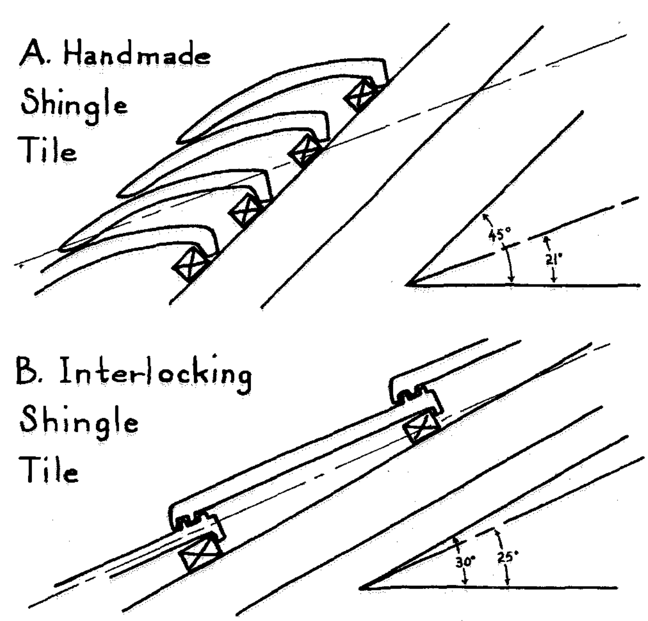
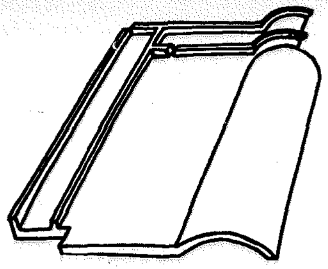


FIG. 5.

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.

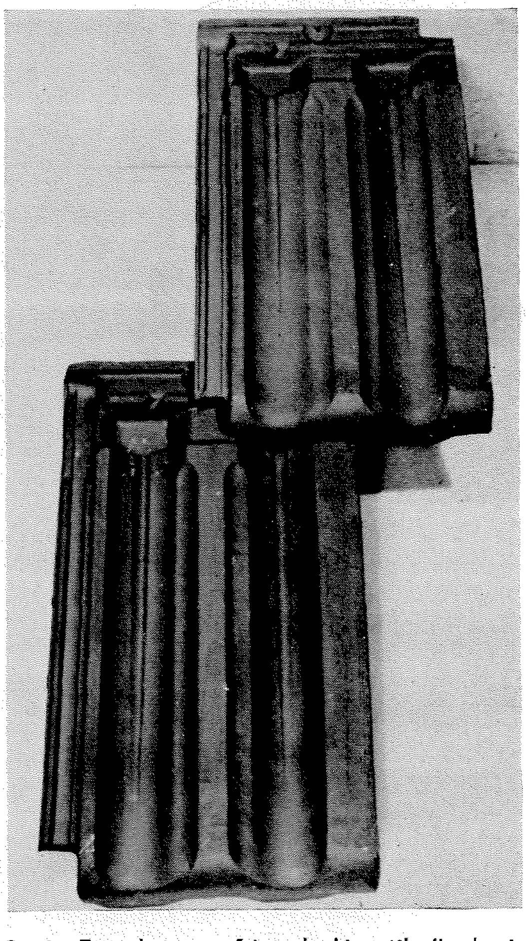


FIG. 7—French type of interlocking tile (Ludowici).

PERSONALS

1914

VIRGIL F. MORSE is with the Aero Crafts Corporation in Los Angeles making tools for aircraft fabrication. He has one son, Robert, who is with the Navy at Pearl Harbor.

1920

DONALD D. SMITH and GEORGE O. SUMAN, who were close friends during their years at Tech, attended the wedding on April 22 of Mr. Smith's daughter, Aileen, to Mr. Suman's nephew, John Sparling. The bride is a sophomore at Pomona College and the groom is a cadet with the Army Air Corps at Santa Ana. The wedding was at the North Hollywood home of Mr. Smith.

1922

JOHN E. SHIELD is a major and has returned to the United States from overseas duty.

1924

MAX W. MOODY is a commander in the supply section of the Navy.

W. LAWRENCE HALL is a lieutenant colonel in the Coast Artillery Corps, now commanding a searchlight battalion recently stationed in the Los Angeles defense area.

1925

MICHAEL BRUNNER is a lieutenant colonel stationed at Fort Belvoir.

1926

ORRIN H. BARNES is now a major.

LIEUTENANT COLONEL JOE MATSON, Jr., of the Engineer Corps, visited the campus recently while on leave. Prior to the war he was engineer for a sugar plantation in Hawaii. He is married and has three children.

WILLIAM S. KINGSBURY, Jr., has been in England with the Army Engineer Corps since July, 1943. He took his basic training at Camp Claiborne, La., and is now a staff officer and plans and operations officer for his regiment.

1927

JAMES BOYD is now a colonel and is in Washington, D.C.

V. WAYNE RODGERS is a major in the Corps of Engineers, Washington, D.C.

BORICE Z. BORIS has been transferred from the position of chief electrical engineer of the San Diego Division of Consolidated Vultee Aircraft to the post of plant engineer of the new Consolidated Vultee Aircraft manufacturing plant at New Orleans. This plant is one of the largest in the deep south and is engaged in the manufacture of "Catalina" patrol planes, which have made a name for themselves in all theaters of operation. Mr. and Mrs. Boris live in one of the new housing projects and find the houses quite satisfactory.

1928

JULIEN PHILLIPS, ex-'28, is still employed as chemical engineer in the research department of the American Potash and Chemical Corporation at Trona. He has one daughter one and one-half years old.

KENNETH M. FENWICK is a lieutenant commander in the Navy.

1929

LIEUTENANT COLONEL BILL MOHR is now at Camp Van Dorn, Miss.

DR. DUANE E. ROLLER is now in charge of the physics department at Wabash College, Crawfordsville, Ind.

ALBERT E. MYERS is living in Berkeley and is employed at the San Francisco office of Shell Oil Company. On January 18 his second daughter, Caroline, was born, weighing nine pounds 10 ounces.

H. M. O'HAVER is the division sales supervisor, eastern division, of the Southern California Gas Company, and is living at San Bernardino. He has a daughter, Sharon, seven, and a son, Michael, four.

1930

MAJOR ROBERT H. BUNGAY has been transferred from the Signal Corps to the Engineer Corps and has been assigned to a project in British Columbia.

ROSCOE P. DOWNS has been at the Muroc Air Base while employed by the firm building a concrete runway at the Base.

1931

CAPTAIN CHARLES K. LEWIS has been active in the Italian invasion.

MYER S. STEIN has been a tooling engineer for Douglas Aircraft Co., Inc., since April, 1943. He is married and has one child two years old.

LAVERNE D. LEEPER has graduated from Officers Candidate School at Fort Belvoir, Va., and is now a second lieutenant assigned to Camp Claiborne, La. He was recently married.

WINTON C. HOCH is a lieutenant in the Navy, located at Washington, D.C. He recently visited the Muroc Air Base.

LUCAS A. ALDEN was married on March 8 to Rita Coté of Bethesda, Md. They are living in Washington, D.C.

1932

WORRELL F. PRUDEN is now assistant manager of the naval ordnance division at the Maywood plant of Consolidated Steel, where five-inch Twin Mounts for the Navy Department are being built. It is a strictly mechanical job, somewhat out of his original line, but work that he finds very interesting.

LIEUTENANT WILLIAM J. THOMAS is an engineering officer in the Navy.

JOHN H. A. BRAHTZ is a lieutenant commander.

MAJOR STUART L. SEYMOUR is at the Muroc Air Base.

1933

ART MATHEWSON, formerly a staff engineer at Lockheed, is now a lieutenant (j.g.) stationed at San Diego.

LIEUTENANT PHILLIP H. CRAIG, former football captain at Tech and a three letter man, is now a flier for the Navy in the South Pacific. His wife lives in Alhambra.

GROVER SECORD recently returned from the South Pacific rubber survey for the Naval Bureau of Aeronautics.

JOHNNY SHARP, ex-'33, is now back in the United States after having spent a year in London with Douglas Aircraft Co., Inc.

1934

LIEUTENANT COLONEL JOHN D. HARSHBERGER, U.S.M.C., is a flier in the South Pacific. His wife and baby daughter are living at Laguna Beach, Calif.

LEE P. MORRIS, a lieutenant in the Navy, has seen considerable action.

ED DOLL has done some work on the Muroc Air Base. Since the start of the war he has traveled about 50,000 miles.

1935

J. H. WAYLAND spent a year in Washington on war research work at the Naval Ordnance Laboratory, was attached to the Navy Degaussing Station at San Pedro as District Degaussing Consultant until January, 1944, and is now engaged in war work at the Institute.

EUGENE C. MILLER was a victim of the American Air Lines crash on February 10 near Memphis, Tenn. At the time of his death he was chief estimator for Consolidated Steel Corporation, Ltd., Wilmington, Calif., and was on his way to Washington, D.C., on business.

ARTHUR ENGELDER is a captain in the Medical Corps of the 354th Infantry at Camp Roberts, Calif. He entered the service in June, 1942.

ROBERT P. JONES is a lieutenant (j.g.) in the Navy and has been stationed in Washington, D.C.

JOHN R. ROSSUM is the sanitary engineer of the California Water Service, San Jose, Calif.

1936

WILSON H. BUCKNELL is an engineer with O'Keefe and Merritt Company.

HAROLD J. ALWART is with Clayton-Mark and Company, Evanston, Ill. He has an eight-months-old daughter, Sharon Jo.

LIEUTENANT (j.g.) RAYMOND H. F. BOOTHE is with the Seabees Maintenance Unit, New Guinea, as the executive officer of the unit.

SAMUEL C. EASTMAN, executive partner of Dozier-Graham-Eastman, recently completed an extended survey trip throughout the central and eastern United States compiling information for use in certain production processes of the war program. Manufacturing centers visited on the six-week survey included Chicago, Detroit, Cleveland, and New York. A considerable period of time was also spent working with various government agencies in Washington, D.C. While making the trip, considerable data were also gathered on post-war industrial trends which will be of value in guiding merchandising programs of western industries through the reconversion period to peacetime activities.

LUTHER P. SPALDING is employed by North American Aviation, Inc., and recently went to the east on a business trip.

VICTOR V. VEYSEY is the father of a son, John Charles, born March 26.

1937

JOE MAUK SMITH received his Ph.D. degree in chemical engineering from the Massachusetts Institute of Technology in May, 1943. He is now an assistant professor of chemical engineering at the University of Maryland, and is also doing government research work at the Bureau of Mines located at the university. He was married on December 23, 1943, to Miss Essie McCutcheon of Frederick, Md.

V. TULAGIN is employed by General Aniline and Film, Easton, Pa.

1938

JOHN L. MERRIAM is in charge of the soil conservation service office cooperating with the Yucaipa Valley Soil Conservation District. He and MARTIN J. POGGI, '37, have bought an 11 acre farm and a cow. Last fall John fell from a ladder while working on the house and fractured two vertabrae, but is now recovered. He has been reclassified in Civil Service from assistant civil engineer to assistant soil conservationist but still does some engineering.

SAMUEL H. KELLER is a lieutenant (j.g.) and on duty in the South Pacific area. He enlisted two years ago.

1939

PAUL O. ENGELDER was promoted from captain to major in the U.S. Marine Corps. He is attached to the headquarters staff at Washington, D.C.

FREDERICK C. HOFF has been assigned to the production staff of the Naval Ammunition Depot, Hastings, Nebr.

ALEX M. SHIELDS, ex-'39, is with the Merchant Marine.

LIEUTENANT CHARLES CARSTARPHEN, U.S.N.R., has been at the Puget Sound Navy Yard but is now in Hawaii.

ROBERT W. WINCHELL is a major at Bradley Beach, N.J.

1940

ROBERT B. MEYER is in charge of process engineering at Bendix Aviation, Pacific division. He has a son, Billy, two and a half years old, and a daughter, Irene, one year old.

CAPTAIN GILBERT VAN DYKE is now with the regional weather control in Great Falls, Mont. He was sent to Alaska in September, 1942, returning in February of this year, when he saw for the first time his 13-months-old son.

DWIGHT H. BENNETT is the father of a baby girl born in February. He is employed by the Consolidated-Vultee Aircraft Corporation in San Diego.

DONALD E. LOEFFLER is photographic officer at the Palm Springs Army Air Field.

1941

PAUL R. FREEHAFER died suddenly on March 25 while visiting his sister in Payette, Idaho. He was employed as a research chemist with an engineering corporation in Los Angeles.

CHARLES T. HIGHT has been overseas for the past two years. Until March he had been in meteorology work in North Africa.

LIEUTENANT GLYN FRANK-JONES is with the Royal Navy Volunteer Reserve Special Branch.

1942

E. J. GENTLE was recently promoted from senior design engineer to special projects production engineer at Lockheed "B."

ENSIGN WARREN GILLETTE recently qualified as a full fledged Submariner and was awarded his Dolphins. He is in the Atlantic theater.

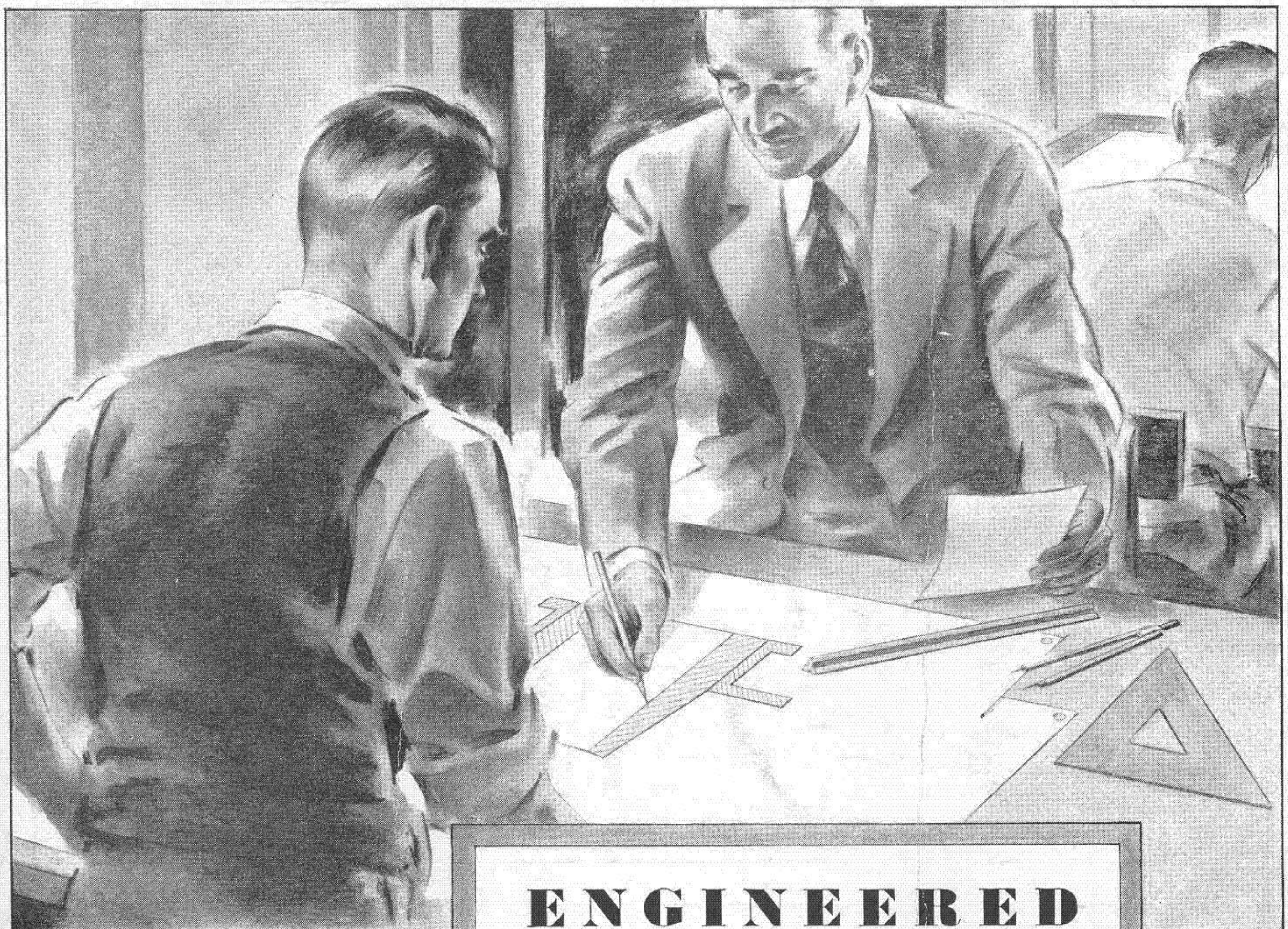
THOMAS D. ELLIOTT is now an ensign in the Navy, stationed in the Pacific, and would enjoy hearing from his friends. He has a five-months-old son, Thomas, Jr.

1943

LIEUTENANT CLAUDE CARTER received his commission in January after completing his training program at Yale, and he has been assigned as an engineering officer to an Army bombing squadron now training in Kansas.

ENSIGN GEORGE GRIFFITH and ENSIGN BILL HALPENNY reported for engineering instruction at the University of Arizona after their graduation from Caltech, and they are now inspectors with the supervisor of shipbuilding at the Brown Shipbuilding Yard at Houston, Texas.

RONALD RAU and Miss Maryjane Uhrlaub, niece of Stuart Mackeown, recently announced their engagement. He is engaged in war work at the Institute.



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