

• At the American Ceramic Society meeting in Dallas, Texas, this May, Georgia Tech ceramic engineering students took three of the four prizes offered by the Ferro Corp. of Cleveland, Ohio, in its annual National Student Contest in Porcelain Enameling. It was the first time in the 8-year history of the contest—open to ceramic students throughout the country—that any one school has walked off with three of these awards.

First prize of \$500 went to 1956 Tech graduate Henry P. Still, Jr., for his paper on "A study of the oxidation of steel plate as related to the wettability and adherence of porcelain enamel." Second prize of \$300 was awarded to 1957 Tech graduate Edward L. Bradley for his paper, "An investigation of some problems encountered during efforts to heat harden and ceramic coat #420 stainless steel." After a University of Illinois student broke the monotony by taking third prize, 1957 Tech graduate James F. Benzel received fourth prize of \$50 for his paper, "Groundwork on ground coat hairlines." The three papers were the only ones entered by Tech students this year.

Research Engineer J. D. Walton, head of the ceramics research group at the Georgia Tech Engineering Experiment Station, was the only other Tech man to ever win first prize in this contest. Mr. Walton was the winner in the first Ferro contest in 1950. His top assistant, Nick E. Poulos, was the second-place winner in 1952. All three of the 1957 Tech award winners worked with Mr. Walton's group while students at Tech. Mr. Still and Mr. Bradley used a phase of their work at the Station as the subject for their entries in the contest. This is just another example of how Georgia Tech's research organization aids in the proper education of engineers and scientists.

The October issue of this magazine will be devoted in its entirety to the work of the ceramics group at Georgia Tech. We think that you will be surprised at the volume and variety of the work now going on at Tech in this field.

the
record
makers

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the cover

Georgia Tech's new rocket motor, constructed in the Engineering Experiment Station's machine shops, fires up for the first time. The motor is used in testing uncooled rocket nozzles made of ceramic materials. This work and the other subjects discussed in this issue are part of Tech's ceramics research.

Cover photo by Van Toole

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research engineer

TO THE CASUAL OUTSIDER, Georgia Tech might seem at times to be merely a place where football is played exceptionally well and the students walk around a peaceful campus singing "I'm a Ramblin' Wreck" in very loud voices. But when this same outsider is moved into the educational community that is Georgia Tech, he is amazed at the many different activities in which the Institute is engaged.

Today, Georgia Tech's primary responsibility is still the same one assigned to it over 70 years ago—to educate the young in order that they may be more useful to our society—a society that is becoming more and more a technological one. But, over the years, Georgia Tech has shouldered additional responsibilities that have served to make it a much more useful asset to the area.

Probably the best known of Georgia Tech's collateral activities is its research program—one that has made Georgia Tech the leading engineering and industrial research agency in the entire South. Because this program's conduct requires highly trained professional workers and technicians, it indirectly raises the economic level of the entire region and at the same time improves the economic position of the industries and businesses taking advantage of its potential. Research at Georgia Tech is also directly helpful to our national defense effort. But even more significant than these contributions is the one that research makes to the Georgia Tech educational program. A large-scale research program helps us attract and hold top-flight teaching personnel. And as the teacher carries out his research, his grasp of his subject is broadened and his knowledge sharpened, so that inevitably he instills in his students the scientific curiosity that is the basis of learning.

In addition to its regular day school and its Engineering Experiment Station, Georgia Tech operates a large Engineering Extension Division as a campus and off-campus educational service to the people of Georgia. In this division are an evening school offering adult-education and college-credit courses; a short course and conference program; a trade and industrial education program; and Southern Technical Institute, which offers 2-year programs to train engineering technicians in several fields.

As I found out in a few short weeks, Georgia Tech is a large, vigorous, growing educational institution serving a section of the country that is moving ahead at a rapid rate. I am proud to be a part of it.

E. D. Harrison
President

HIGH TEMPERATURE MATERIALS

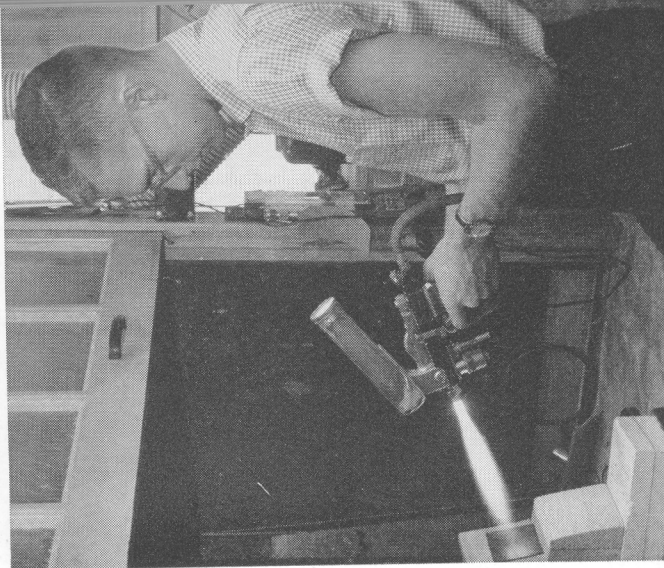
In these early experiments, iron oxide was mixed with leaf aluminum to form the thermite which, when heated to about 1600° F. produced the following reaction:



This reaction produced temperatures within the coating mix of from 2500° to 3500° F.

The second method of applying refractory coatings to metals was to spray the molten refractory directly onto the cool metal substrate. Initial experiments were conducted using an electric arc through which the powdered refractory was sprayed. The powder was melted by the arc and propelled onto the substrate in a molten condition. Because of the high heat capacity of the substrate, the molten particles were quenched without raising the substrate temperature appreciably. Present experiments in coatings applied in

Flame spraying, one method now in use for applying refractory coatings to metals.



THE DEVELOPMENT of jet engines, rocket motors, and high speed aircraft and missiles is being seriously hampered by the lack of materials which will withstand high temperature erosion, corrosion, and thermal shock. With these material limitations in mind, the work on Station Project A-212 (sponsored by the Department of Navy, Bureau of Ordnance) began in early 1955 with 100 per cent emphasis on developing coatings and coating methods to protect existing structural materials. Today the project has expanded to include the development of new, basic structural materials for high temperature applications with special emphasis on the development of a suitable material for the fabrication of rocket nozzles.

Coatings

The early work on coatings consisted of evaluating techniques such as vapor decomposition, sputtering and arc evaporation. Unfortunately, these methods formed coatings at a relatively slow rate, and some new method for applying thick refractory coatings on metals became more desirable. Since the refractory materials which showed the most promise as coatings had a higher melting point than most of the metals to be used as substrates, the problem arose as to how to apply a molten coating to a substrate having a lower melting point than the coating. This problem was attacked in two ways.

First, it was decided that if a thermite mix were blended with the refractory coating, the ignition of the thermite would supply instantaneous heat to melt the refractory particles, but not enough heat to melt the substrate. The basic principle of a thermite is that when a metal oxide is heated with a more reactive metal, usually aluminum, the oxide is reduced by the reactive metal and heat is liberated.

October, 1957



Georgia Tech ceramic leaders: J. D. Walton (left) head of the Engineering Experiment Station's newly-formed Ceramics Branch and Dr. Lane Mitchell, director of the Ceramic Engineering School. Mr. Walton is the senior author of this feature series.

Ceramics—the art that became a science

ONE OF MAN'S OLDEST ARTS has become a science and technology. Ceramics — still defined in most dictionaries as the art of making articles (like pottery) from baked clay—now is more properly known as the science and technology of fabricating useful materials from non-metallic ingredients at high temperatures (generally high temperatures are those above 1000° F.).

Today, ceramic products may be classified into seven broad groups: *refractories* (for the manufacture, pouring, and casting of steel, iron and other metals); *glass* (for windows, TV tubes, optical and electrical uses); *porcelain enamel* or glass-coated metal for decorative purposes, corrosion protection of steel against chemical attack and the protection of metals from oxidation at high temperatures; *Portland cement* (for construction of buildings, bridges and highways); *structural clay products* such as bricks, structural tile and sewer pipe (for the building industry); *whitewares* (for electrical insulators, electronics components and china); and *abrasives*.

Even this cursory list of today's uses of ceramic materials indicates the positive effect that this art turned science has on our very way of living. But it is in tomorrow's world that ceramics will really

come into its own. Today in research laboratories across the Nation, ceramic materials are being developed for tomorrow's use.

Already, ceramic materials are being developed for use in atomic reactors. Power from the atom becomes more economical when reactor materials can operate at higher temperatures, contain higher pressure and resist attack from corrosive materials under these conditions. Components for rockets offer another challenging use for the field of ceramic materials. Our missile program advances when the noses of rockets can resist the intense heat and fantastic velocities encountered as they re-enter the earth's atmosphere. In turn, the rockets can travel further and more accurately if the nozzles can resist the erosion and thermal shock created by the exhaust gases. The aircraft industry is another field in which ceramic materials are playing a big part. Jet aircraft can fly faster and further when the engine components can be made to operate at higher temperatures.

The ceramics groups at Georgia Tech is young with a great potential for growth. And, as the following articles show, it is contributing to the present and future with its expanding research program in many fields affected by ceramics.

research engineer

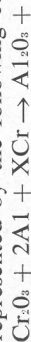
HIGH TEMPERATURE MATERIALS continued

this general manner are being accomplished by using an oxyacetylene flame rather than an electric arc as the heat source for melting the refractory powders. This latter method is referred to as flame-spraying, whereas the first method is referred to as arc-spraying.

Structural Materials

While working with thermites to be used merely as heat sources for firing refractory coatings, it was noted that the thermite reaction products were sometimes in themselves highly refractory materials. This led to the forming of pellets of these thermites to study their characteristics for use as coatings. From the firing of these pellets it was noted that some retained their shape very well, and in addition, had the same composition as "cermets" which are now in use. (The word "cermet" is generally used to describe a material made up of a mixture of a ceramic oxide and a metal, this mixture having been fired to obtain a dense, strong, heat-resistant material.) These observations led to experiments in using thermite mixes to form cermets to be used as structural materials or "thermitic cermets."

An example of the advantage of forming cermets using a thermite reaction can be shown by considering a popular cermet composed of 28 per cent Al_2O_3 and 72 per cent chromium. The cermet is formed by firing this mixture to about $3000^\circ F$. for a total firing time of about 20 hours. This same composition may be formed by heating a thermite composed of aluminum and chromium oxide to $1800^\circ F$. for one hour. Chromium may be added to the original thermite to obtain the desired final composition. This reaction may be represented by the following equation.



$(x + 2) Cr + \text{Heat}$
It should be pointed out that although the above reaction will produce the desired composition, problems such as warping and cracking on firing must still be overcome before this reaction and others

like it may be used to produce cermets for commercial uses.

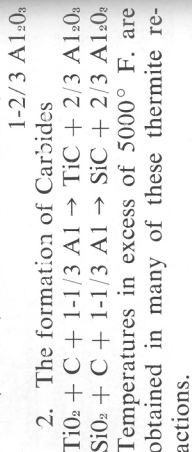
The basic thermite reaction using aluminum as the reducer may be expressed as follows:

$MO + 2/3 Al \rightarrow 1/3 Al_2O_3 + M + \text{Heat}$
where M represents the metal whose oxide is used. While conducting experiments using mixed oxides in the thermite, the following reaction was noted.



Here an intermetallic compound, $ZrSi_2$, was formed.

This led to attempts at producing other intermetallics, and the following reactions have been observed.



Prevent Work

Successful flame-spray coatings of pure oxides such as Al_2O_3 and ZrO_2 have been applied to various substrates including magnesium, aluminum, steel and glass. Coating experiments in progress now are concerned with coatings consisting of mixtures of oxides and other substances. Apparatus is also being constructed to test the oxidation protection of flame-sprayed coatings on molybdenum.

J. D. Walton, at control panel, and Cecil Mason go through start-up check before firing Tech's rocket motor used for nozzle tests.

Because of the almost innumerable possible compositions which can result from thermite reactions, the work on "thermitic cermets" is actually just beginning.

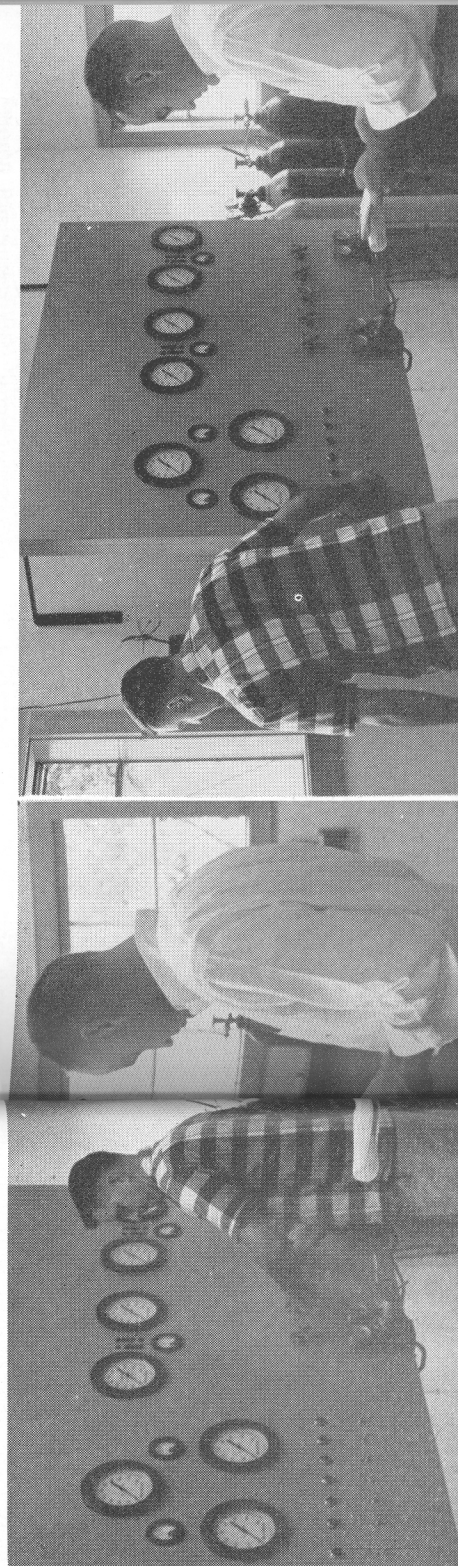
Perhaps the most interesting project now under way is the construction of a small rocket motor to be used for testing ceramic rocket nozzles. This motor uses hydrogen and oxygen as fuel. A removable nozzle holder permits easy changing of the nozzle and provides a rapid method of testing experimental nozzles. The high temperature, high velocity exhaust also may be used as a burner to stimulate re-entry conditions for testing missile nose cones. The basic design of this "micro-motor" and control system was supplied by Battelle Memorial Institute in Columbus, Ohio.

Since this project is concerned with materials to be used in extremely high-temperature service, it would seem an absolute necessity that the materials have an extremely high melting point. Unfortunately, this is not always possible, and surprisingly enough, an extremely high melting point may not even be the most important property in determining the selection of the proper material. Service requiring almost instantaneous heating from room temperature to above a white heat, as in nozzles, requires first of all a material having excellent thermal shock resistance. In some applications, the thermal conductivity, the specific heat, or heat of fusion may be major factors to be considered. Still another factor, the viscosity of the material at its melting point, may be very important.

The fact that the melting point of a material is not necessarily indicative of

its behavior at high temperatures is clearly shown by considering the behavior of silica when used in the flame-spray apparatus. Alumina and zirconia, melting points $2050^\circ C$. and $2690^\circ C$. respectively, were readily fused and produced successful coatings using the flame-spray gun. Silica, whose melting point is only $1710^\circ C$., passed through the flame-spray gun with no apparent melting, and it produced no coating. This peculiar behavior of silica aroused interest in using silica as a structural material for high temperature applications and led to the present work of fabricating rocket nozzles from fused silica grain. Heretofore the use of fused (amorphous) silica above $1000^\circ C$. was thought to be impossible because it would recrystallize and crack on cooling. The cost of fused silica has been another factor prohibiting its use. A new method of producing fused silica has been developed, through work on another project here in the ceramic laboratory, which will reduce this cost considerably.

Preliminary test results on these nozzles have been very promising despite the relatively low melting point of fused silica. These test results indicate that for this particular application the high viscosity of the molten silica and its terrific resistance to thermal shock more than make up for its relatively low melting point. This thermal shock resistance has been demonstrated by heating the throat of the nozzle to a white heat with an oxy-acetylene torch and quenching it in cold water. This treatment did not affect the nozzle in any way. Tests under actual rocket exhaust conditions are now being performed with the small rocket motor.



Ceramic Molds for Casting Metals

WHEN THE FIRST METAL was smelted in a camp fire, it was perhaps collected in a depression in the sand to form a casting.

Today, the foundry industry moves sand and metal by elaborate machinery with controls for moisture, clay and other binding materials. The sand is selected and mixed and rammed to a definite pressure on a pattern, so that the resultant mold is hard enough to resist the pressure of the hot metal and the sudden development of steam and gas. It also must resist "cutting" or washing by the heavy stream of metal.

It seems simple to just bind and pack the sand as hard as needed, but if the mold is not "loose" enough to let the steam and gases escape, trouble develops. The molder is walking a tight rope between a mold too soft, or not permeable enough, or one that cracks and flakes on contact with the hot metal, or one that allows the metal to soak into the sand. In short, the molder must compromise on surface finish, internal quality, dimensional tolerances, etc., while living with the expansion effects of the sand and the gas-producing effects of the bond.

Considerable time and money has been spent in recent years in an effort to develop molding materials or at least molding techniques which would serve to replace the age-old sand and sand molding. Up to date only minor improvements have been obtained so far as large tonnages of cast metal are concerned. In the field of investment casting or precision mold-



Experimental production and testing of the new ceramics material is done in Tech's labs.

ing, however, considerable progress has been made. In this case, expensive ceramic materials are cast about a wax pattern or precision match plates to provide a mold in which difficult-to-machine metals are cast. In a similar manner, difficult-to-machine shapes are molded from common metals such as iron or steel. The high prices demanded for such items justify the expense in time and materials required for such a casting operation as well as limit the use of such materials and methods to the manufacture of high-priced materials.

A method which was felt by the North Foundry Mold Company to hold promise in breaking through the price barrier of producing a mold to compete with sand casting may be described as follows:

A precision casting ceramic material (fused silica grain or powder) would be used to form a thin shell, backed up by a foamed silica material. It was felt that this combination would provide a permanent mold with either a permanent or renewable liner, depending upon the size or configuration of the piece to be cast. The high cost of the materials in this case would be offset by the fact that several castings could be made with a minimum of time and labor involved.

After preliminary trials, a project was initiated at Georgia Tech with the object of developing a molding system based on the foamed silica and suitable permanent and temporary liner and mold dressing. Immediately a hitch developed in these plans when it became obvious that foamed silica would not be available in any quantities for a long period of time. But traditions out of such unfortunate circumstances comes new developments. In this base, a new, inexpensive method of bonding the fused silica was developed. And the sponsor was inspired to try manufacturing the fused silica himself and producing the entire mold from the bonded fused silica. To develop practical and workable techniques of forming the molds into proper shapes with desired surfaces and strength now became the problem.

Starting almost from scratch with the new source of fused silica, studies were initiated to evaluate the properties of bodies fabricated from this material as a function of particle size, binders, milling and firing conditions. Ceramic bodies were obtained that would repeatedly stand the thermal shock of having molten cast iron poured into them. They also could be formed to dimensional tolerances such as is expected only of investment castings. Expansion is so low that warping, the old bugaboo of ceramic casting, along with thermal shock deterioration, is no longer a real problem.

The new molds will not shock-chill the molten metal, so it will extend the possibilities of permanent molding of simple shapes. It will also be much cheaper than a steel or iron permanent mold or die for short runs. However, the more we change the ancient art, the more it is the same. For the over 15,000,000 tons of ferrous metals and other high temperature metals cast annually in sand, most of the work is too big or not shaped right for a conventional permanent mold. There is locking in the mold, cracking or tearing of the tender hot metal if there is no collapsibility in the mold. To circumvent this problem foundrymen are trying "permanent molds with shell liners" or "shell molds blown into permanent back-ups."

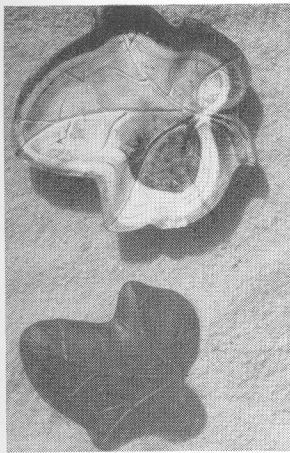


Figure 1—a leaf ash tray made of Tech's new ceramic material and tested cast iron.

The ceramic bodies we are now getting seem to be strong, warp resistant, low in first cost, adaptable to various methods of heating the shell liner, and altogether almost ideal for the back-up. In other words, if we blow a shell around the pattern between it and a back-up, that's a cheap way to keep the metal from sticking in the mold. And we are still sand casting, but the sand is for cores and a thin shell, not for filling big flasks. Sand handling is in pounds, not tons. Back-up is precise and the sand dried to be as strong and as gas free as necessary. Dimensional changes are small and predictable.

The casting into the mold directly, bare or with a thin smooth dressing is not out of the picture altogether. As a thin, one-shot shell mold, or under the various conditions that avoid the presence of oxides or slags to stick, and where shape permits, the mold is easily made with fine detail. With a plaster pattern plate, a mold can be cast on the plaster, removed, dried and fired with a total shrinkage of less than 0.25 per cent. An example of the detail is shown in Figure 1. A leaf ash tray such as ceramic students make in clay was made of fused silica. In it was poured four pieces of iron, one of which is shown with the mold. The bell-like ring of fine china is still obtained by striking this mold, indicating no elastic failure and that the thermal shock could be withstood indefinitely.

And the new method of binding the fused silica has many other applications as you will see in other sections of this report.

PORCELAIN ENAMELED STEEL PLATE

Ceramic materials are coming into their own as coatings to prevent corrosion of a great variety of shipboard components

AT THE PRESENT TIME, exhaust mufflers, snorkel tubes and other shipboard components are frequently porcelain enamelled for protection from corrosion. Although some of these components are made from stainless steels and other corrosion resistant metals, such metals may be curtailed for other uses in the event of a national emergency. The common metals such as rimmed, killed and semi-killed steels in plate thicknesses may cause many defects in porcelain enamel coatings applied to them.

The determination of factors affecting the enameling characteristics of steel plates and welds and the development of a complete and technically accurate description of steel plates and welds of steel plates acceptably receptive to porcelain enamel coatings are the objectives of Station Project A-308, sponsored by the Department of Navy, Bureau of Ships.

Porcelain enamel, a glass coating fused to metal, has a texture between that of a flat paint and a smooth glass. The first step in the basic process of making porcelain enamels is to melt the raw materials to form the desired glass. Enamel glasses are of the borosilicate type. The raw materials for the glass are essentially all inorganic oxides, minerals, fluorides or salts. The materials as used vary from granular to powdered in form. The glass composition as formulated is weighed out in the established proportions and thoroughly mixed. The mixture of materials is melted at temperatures of 2000° to 2600° F. When the melting is complete, the molten glass is poured into a tank of water to break the glass up into a friable condition known as frit.

Then the quenched glass (frit) is ground in a ball mill along with water, clay and electrolytes (inorganic salts) to form a water-suspension or slip. The porcelain enamel slip is applied to the metal by dipping, spraying or other techniques after first cleaning the metal by sandblasting or acid pickling. The operation is completed by drying the water out of the coating and firing until the glass fuses to the desired degree, usually in the temperature range of 1300°-1700° F. Porcelain enamel is especially resistant to heat and corrosion and can be formulated to obtain specific properties and uses.

Ordinary porcelain enamel such as that used on kitchen ranges and refrigerators is applied to a special metal known as enameling iron. Problems encountered in these fields have been studied over the years by the enameling industry. In selecting enamels for coating metals for shipboard use, however, many new problems arise which have not received such attention.

Some of the more common defects encountered in enamels are attributed to gases in the metal and in the enamel. The most common defect usually encountered in enameling steel plate of the type to be used in ships is fishscaling. Fishscaling is the fracturing of the glassy coating, exposing the metal underneath. The defect is usually shaped in such a manner as to resemble a half moon or fishscale and is especially bad since it may not show up for days or weeks, and the enamelled article may be put into service before the defect appears.

Analysis of the gases collected from fishscales has shown that hydrogen is the

most abundant gas present. Apparently, the hydrogen is injected into the steel at enameling temperatures by the reaction between the steel and the chemically combined water in the frit. A portion of the hydrogen produced by this reaction is occluded by the steel and subsequently precipitated at the enamel metal interface after the enamel has cooled. It is thought that this reaction will proceed to completion according to the amount of moisture in the furnace atmosphere.

A hydrogen extraction apparatus has been developed to measure the amount of gas injected into the steel under various enameling conditions and with the use of various enamels. This device has enabled us to compare the amounts of gas occluded by steels of different compositions and of those formed by various processes. By comparing the tendency of an enamel to fishscale with the amount of gas extracted from a metal blank which has been coated with enamel and fired under the same conditions, a correlation can be found between the amount of hydrogen occluded and the tendency to fishscale.

Since it seems to be economically unavoidable in normal enameling practice to prevent the steel-steam reaction and the charging of the steel with hydrogen

which later builds up pressure and fractures the enamel coating, some other method of preventing fishscale must be found.

A relationship exists between the structure of an enamel called the bubble film and its tendency to fishscale. An enamel that has large uniform bubbles closely spaced has less tendency to fishscale than an enamel with small poorly defined bubbles. This may be attributable to the fact that the large bubbles provide collection chambers for the hydrogen and/or the large film area provides a stress relief area. Figure 1 shows the desired type of bubble film. Figure 2 shows a poor bubble film. Controlling the bubble film of an enamel in normal enameling practice, however, can be quite a problem since the film depends on many variables, such as firing time and temperature. The firing time in turn is influenced by the thickness of the steel. Since many of the pieces to be enameled consist of both thick and thin sections, suitable control of the firing time of all sections is impossible.

Possibly a better method would be to add a material to the enamel that will replace the bubbles in the system and yet have the same effect.

Figure 1—desired type of bubble film in enamel which has less tendency to fishscale.

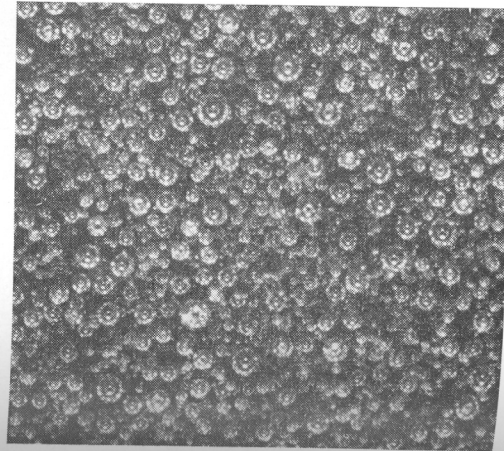
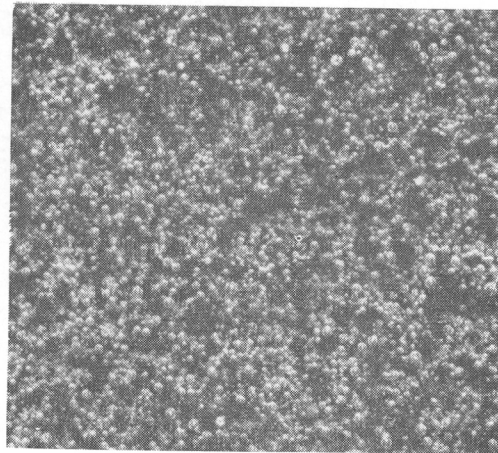


Figure 2—undesirable type of bubble film in enamel with a greater tendency to fishscale.



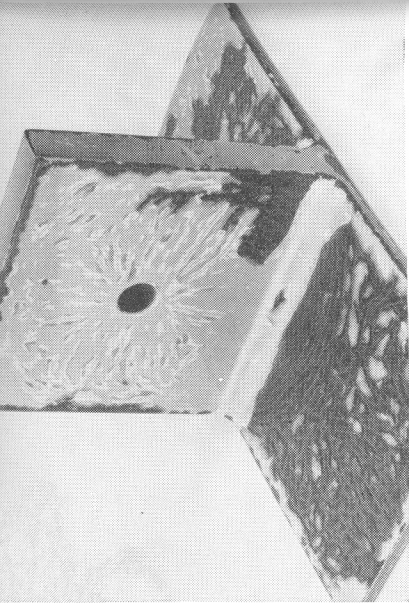


Figure 3—a T-section coated with an enamel having a poor resistance to shock.

It was found that additions of aluminum oxide to the enamel stopped fishscaling or reduced it. At the same time, it was found that these additions also increased the ability of these enamels to withstand thermal shock. (An exhaust muffler on a ship may be subjected to quick changes in temperatures so it is imperative that any enamel developed will have to have good thermal shock resistance.)

It was found that the best enamels procured from the large manufacturers of enamels would not consistently pass the Navy specifications of thermal shock testing. The thermal shock test consists of dropping a large metal sample called a T-section into cold water from temperatures of 650° F., 800° F. and 900° F. A T-section is composed of an eight inch by four inch by $\frac{3}{16}$ inch section of metal to the center of which is welded a four inch by $\frac{5}{8}$ inch section of metal. To pass this test, no cracks or chips which expose the basis metal except within $\frac{1}{8}$ inch of the plate edges can be tolerated. Figure 3 shows a T-section coated with an enamel that has poor resistance to the thermal shock. Future work will be devoted to developing a better thermal shock test.

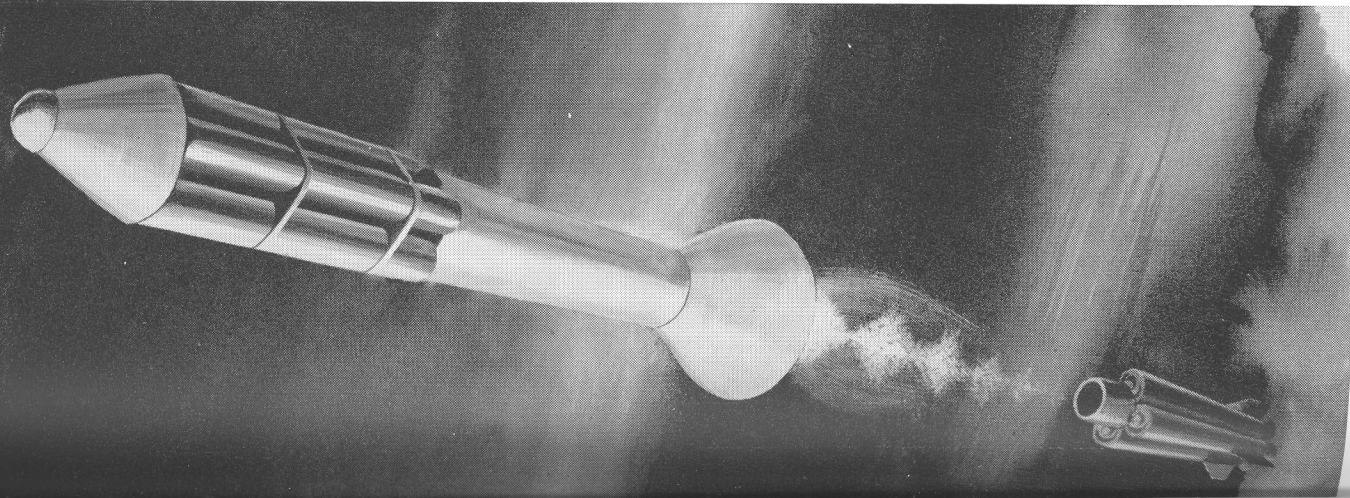
Mill additions of 10 per cent and 20 per cent calcined aluminum oxide gave excellent resistance to thermal shock but left the surface of the enamel with a satin finish rather than a smooth glossy finish. Mill additions of fused aluminum oxide produce the same effects as the calcined oxide, and at the same time, left the surface of the enamel with a glossy finish.

Another testing method in use for evaluating steels and enamels on steels is the stretch test for adherence. A strip of metal is coated with porcelain enamel and elongated in a tensile test machine a certain predetermined length. The amount of enamel left on the strip is determined by means of a Porcelain Enamel Institute adherence meter. This test gives a good correlation with the thermal shock test in determining if an enamel is suitable for use on a certain type steel.

Another area that gives trouble in porcelain enameling is the differences in hardness, composition and grain structure between the weld and the metal to which the coating is to be applied.

Present work is directed along the lines of discovering the exact cause of defects in enamel on welds and of finding preventive measures for them. Work has shown that some welds containing cavities are more receptive to enamel than sound welds. This could be explained by the fact that occlusions in the bad weld form a reservoir for gases that would otherwise build up pressures that would fracture the enamel.

Results thus far have indicated that glass coated steel plate must be treated as a system, and therefore it is difficult to specify the properties required of the steel if nothing is known of the glass to be fused to it. Such factors as fit, wettability, amount of hydrogen injected into the steel, and firing time and temperature are primarily a function of the properties of the glass.



The U. S. Air Force's "Project Farsides" rocket now undergoing tests in the Pacific islands.

fourth in a special series

High Temperature Electrical Insulation

AS AIRCRAFT and guided missiles reach higher and higher speeds, we run into the problem of the so-called "thermal barrier." This phenomenon results from an increase in friction between the skin of a plane or missile and the air. This friction produces a rise in temperature of the skin. Under these conditions severe service requirements are placed upon electronic components within the missile or aircraft, as well as upon the structural materials.

On February 1, 1957, the Engineering Experiment Station began work on Project A-318, the development of a high temperature electrical insulation material for copper wire, capable of withstanding temperatures up to 1500° F. This research is supported in whole or in part by the United States Air Force under Contract AF 33(616)-3944 monitored by the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

The electrical properties required for this insulating coating include high dielectric constant. The physical properties required are flexibility, impact resistance, thermal shock resistance and corrosion resistance. In considering these requirements, it became imperative that this coating make use of ceramics exclusively or in combination with other materials. Only the flexibility requirement was alien to previous uses of ceramics as electrical insulators. However, if a wire insulation could be developed that was flexible until the wire was installed, there would be no further need for the flexibility requirement.

Continued on page 14

Resins both epoxy and silicone are in present use as insulation for wire up to service temperatures of 600° F. These coatings are flexible and have good electrical properties. Above temperatures of 600° F., however, these insulations will start to burn out and will be almost completely burned out at 1000° F. If these resins could be combined with a ceramic such as porcelain enamel glass and could be fired in service so that the enamel glass would fuse at the time the resin burned out, the problem would seem to be solved. However, at temperatures in the range of 1500° F. the porcelain enamel would be in the form of a very viscous liquid and would act more as a conductor than as an insulator. Tests have shown that the resistance of a typical enamel glass dropped to less than one percent of its original value at room temperature, when heated to 1500° F.

Possibly this problem could be solved by using a nonfusing base coating. Aluminum phosphate is being studied to be applied as a base coat over which the resin-enamel glass coating could be applied. This coating would be flexible and waterproof at room temperatures and would still provide good electrical insulation at high temperatures.

For use in equipment which will be heated only once, the phosphate coating could be impregnated with a resin to give good room temperature flexibility and moisture resistance. However, upon heating, the resin would burn out, leaving a porous structure which would prevent the coating from being useful at low temperatures since moisture could enter

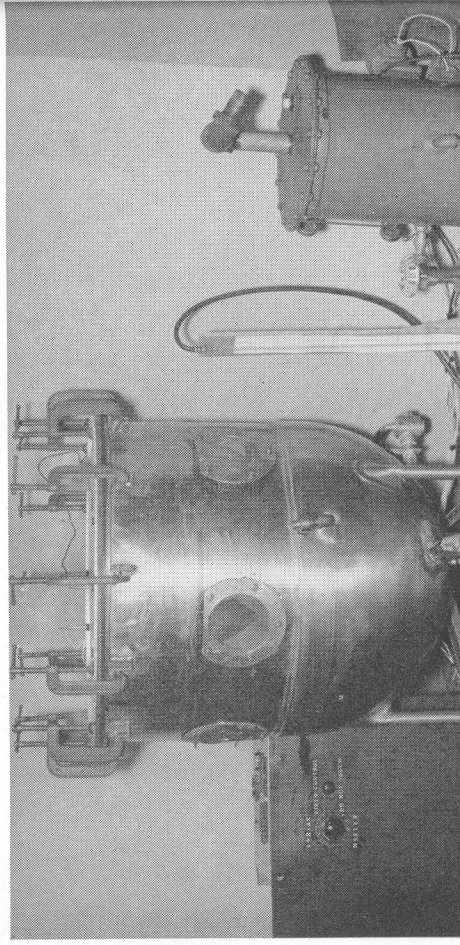
the pores and lower the resistance.

A second type of coating which is being investigated to provide electrical resistance is the use of a refractory anodized aluminum base coat. A coating of aluminum is deposited on copper by electroplating from a lithium aluminum hydride-ethyl ether bath. These coatings can be anodized by any of the common anodizing methods.

Since the aluminum hydride bath must be prepared and used in a neutral atmosphere, construction of a dry box was necessary. The box consists of a stainless steel tank with glove ports and a lucite cover so that work inside the chamber may be observed. A high vacuum pump is used to evacuate the chamber which is then filled with nitrogen. The current source is supplied by a 14-28 volt DC motor-generator set. Control of the system is provided by a central panel. See Figure 1.

At the present time a gradient furnace is being constructed. The temperature within the furnace will vary from about 900° in the front to about 1500° F. in the rear. It is constructed to allow a coated metal strip ten inches long to be placed in it. This type furnace eliminates the necessity for firing many individual plates at different temperatures. It also eliminates the possibility of missing a reaction that might take place at a temperature between arbitrarily set increments. The furnace will have ten thermocouples equally spaced so that a temperature distance plot may be drawn and the exact temperature determined at any spot in the furnace.

FIGURE 1 — TECH'S DRY BOX FOR PREPARING ALUMINUM HYDRIDE BATH.



Exploding meteors offer good examples of the re-entry problem. Shown the Great Bolide of 1923, one of the best-known.

fifth in a special series

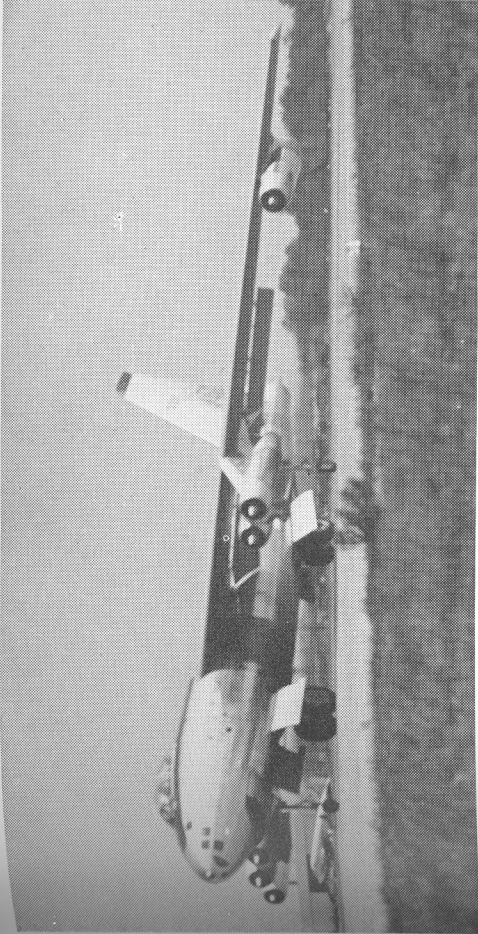
CERAMIC NOSE CONES FOR ROCKETS

WITH THE ADVANCES of rocket power technology, the speed and range of rockets has been increased to the point where space flight is now within the grasp of man. One of the major problems facing our rocket developers is known as the re-entry problem. It is created by the rocket's return to the earth's atmosphere at speeds that can be obtained only where the air is so thin that there is effectively no drag on the rocket. The velocities attained by a rocket upon re-entry into the earth's atmosphere are reported to be as high as 15,000 miles per hour. The temperatures developed on the nose of the rocket under these conditions may reach 4000-5000° F. Similar conditions exist when a falling star enters our atmosphere, and the burning of the star allows us to see it. In the case of a star, the burning reduces it in size until only a fraction of the original mass hits the earth, and thus the earth's atmosphere acts as a protective

shield. But, in the case of our rockets, it is essential that they return to the earth with little or no change resulting from the re-entering.

On April 1 of this year, a project was initiated at the Engineering Experiment Station to develop materials for resistance to high velocity erosion at high temperatures. This research is being sponsored in whole or in part by the U. S. Army Ordnance, Redstone Arsenal, Alabama, under Contract No. DA-01-009-ORD-548.

Again, ceramic materials appear to be the choice for a coating or layer to protect the nose of the rocket from destruction. The conditions here, however, require a close examination of the properties desired of the ceramic material. Since the temperatures reached on the nose of a rocket during re-entry are developed instantaneously and last for less than a minute, the primary requirement for the ceramic material is thermal shock resist-



HIGH LANDING SPEEDS ESTABLISHED A NEED FOR NEW BRAKE MATERIALS.

sixth in a special series

Aircraft Brake Friction Materials

WITH THE ADVENT OF THE JET AGE the trend toward high landing speed, high density, supersonic aircraft has outpaced the development of suitable brake friction materials. Friction material failure or malfunction is the most frequent cause of brakes failing to meet specification requirements. Present day friction liners are composed of several materials utilizing an organic resin for a binder. These organic bound friction liners are thought to be operating now at about their upper temperature limit of 1800° F. Current needs exist for friction liners which will withstand service temperatures of 3000° F. It is apparent that new materials must be found to satisfy high energy, high temperature braking requirements for modern aircraft.

The ceramic group of the Engineering Experiment Station has been engaged in the study and the development of high temperature materials for various activities. The experience gained from this work should be invaluable in the performance of a project initiated in April of this

year and sponsored by the United States Air Force under Contract No. AF 33 (616)-5191 monitored by the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

Since the first days of this project, the effort has been directed toward becoming familiar with the properties required of aircraft brake friction materials and tests used to measure such properties. Literature surveys and visits to manufacturers of friction liner materials were made to become more familiar with the problem. As a result of the inspection of the various testing devices, a design of a laboratory testing device was evolved and is currently being manufactured in the Station shop. Dr. J. P. Vidossich and Professor R. A. Trotter of the School of Mechanical Engineering have been directing the design and engineering of this testing device.

The testing device is composed of a 7½ HP motor which turns a flywheel on

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this type we find we are often misled by consulting handbooks for data which was obtained under equilibrium condition.

With thermal shock resistance as the prime requisite of a nose cone material, it was decided that fused silica (amorphous silicon oxide) would first be evaluated for its possible use as a rocket nose cone material.

The fused silica used in this case was obtained in granular form, the intention being to mill it in water to form a finely ground suspension from which suitable shapes could be cast. In this instance it would be cast in plaster molds as conventional ceramic clay body slips have been cast for years.

The primary problem has been one of determining the particle size distribution, mill additions and milling conditions which would provide the desired slip. With the conventional clay slip systems the clay acts to suspend those components of the suspension which would otherwise settle out like silica. However, clay mixed with fused silica would lower the melting point and reduce the thermal shock resistance. Therefore, it has been an objective of this project to slip cast pure silica bodies.

Progress has been made in milling studies to the point where a test nose cone of the type shown in Figure 1 has been successfully cast in a plaster mold.

Items so cast exhibit the excellent thermal shock resistance characteristics of fused silica. The size or shape of the article does not limit its ability to withstand severe shock. Such an item can be heated to 2000° F. and plunged into cold water with no deleterious effect.

The intense heat of an oxygen acetylene flame directed on a plate cast from fused silica only serves to fuse the surface without the thermal cracking which is so typical of usual ceramic materials.

Recent efforts have been directed toward the development of techniques which will allow the fused silica grain to be pressed into the desired shape. Such a process would allow articles to be more easily and cheaply mass produced from this material.



Figure 1—rocket nose cones of Tech's new ceramic material successfully cast in molds.

ance. Other desirable properties are high melting point, low thermal conductivity and the ability to withstand the high velocity erosion.

When considering these properties, however, we must keep in mind the service conditions. For example, a handbook lists the melting points of zirconium oxide and silicon oxide as 4800-4900° F. and 3100° F., respectively. But when both materials are subjected to sudden heating to 5000° F., such as would be the case when fine grained powder is carried through an oxygen acetylene flame in a flame-spray gun, we find that the zirconium oxide grains are fused unaltered. Thus, when approaching a problem of

a shaft whose end contains a steel disc. When the flywheel attains a desired speed and kinetic energy, the motor drive is disengaged from the flywheel through a magnetic clutch. The friction material, which is mounted opposite the steel disc, is allowed to make contact with the steel disc by the use of an air cylinder, thereby producing the necessary braking action. The device is so designed that the kinetic energy can be varied by adding discs to the flywheel and by a change of RPM. Ground speeds of fully loaded planes traveling from 0 to 125 mph can be duplicated with this apparatus. Instrumentation will be provided for measuring various parameters, the most important being a torque-time measurement.

Because of the load imposed at high temperatures and the limited opportunity to dissipate heat, the physical properties of the brake materials are of primary importance. In this case the materials must be selected on the basis of the physical properties which are most desirable for high temperature friction materials. These high properties are: (1) High coefficient of friction. (2) High melting point. (3) Good thermal shock resistance. (4) Good wear resistance. (5) High compressive strength.

While most ceramic materials have high temperature resistance and compressive strength, many of them do not have the combination of properties listed above. The following materials appear to have a high probability of meeting requirements for a high energy aircraft braking application and will be among the first to be evaluated upon the completion of the test apparatus.

cermets

1. Conventional Cermets

A cermet is a composition of ceramic and metal particles. In considering materials of this type we assume uniform distribution of ceramic and metallic phases. All of the desired properties are theoretically obtainable with cermets; the problem would be obtaining the degree to which each property was found to be required. The design factors involved in the actual braking system would dictate the

properties which would be required and determine to a large extent the success of these materials at the required temperatures.

2. Cermets from Thermite Reactions

These materials are presently being developed in our laboratory. The process used is one whereby the components of a thermite are pressed into a desired shape, using powder metallurgical techniques, and ignited to form a cermet. The primary advantages found to date are low ignition temperatures, high reaction temperatures and the fact that a controlled atmosphere is unnecessary. Since such high temperatures are developed through this process (5000° F.) it is felt that higher melting point cermets may be developed than can be obtained by conventional techniques.

porous structures

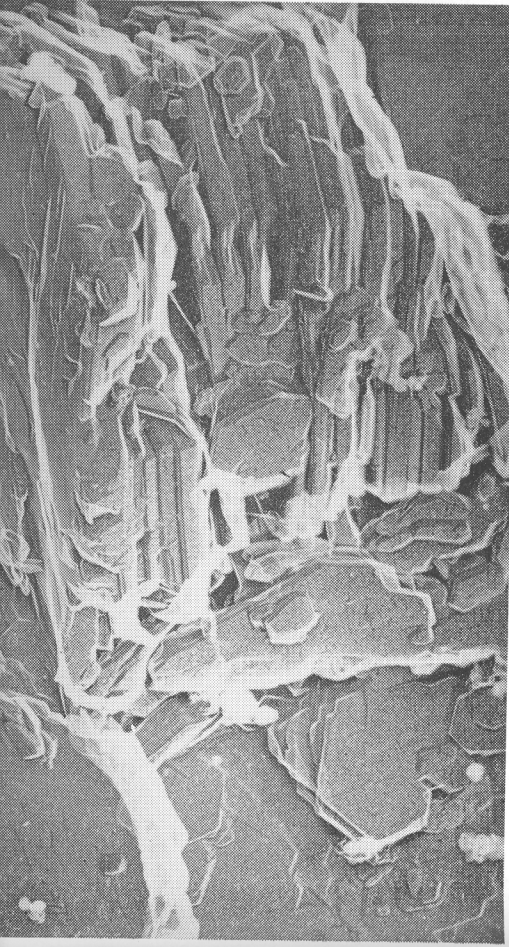
This would permit the use of materials such as fused silica, whose melting point is lower than many ceramic materials but whose other physical properties make it a highly desirable friction material. These materials could be fabricated into porous structures and infiltrated with low temperature materials. The heat developed as a result of the friction would go to melting and/or vaporizing the low temperature infiltrate rather than raising the temperature of the part itself.

flame sprayed coatings

Coatings of this type may fuse much above the melting point of the material to be coated, thus a braking surface which is capable of withstanding extremely high temperatures could be put on a metal with very high thermal conductivity. This combination might not necessitate such a high melting base metal as would otherwise be required.

Another possible advantage of such a coating would be the ease with which a coating could be applied in the field, thus facilitating maintenance.

However, considering the best probability of success, preliminary studies will be directed toward the evaluation of cermets from thermite reactions and porous structures infiltrated with low temperature materials.



A micrograph of Georgia kaolin deposited on glass. The magnification is 36,000 times.

seventh in a special series

CLAY MINERAL RESEARCH

KAOLIN, commonly known as white clay, is Georgia's principal mineral product. Today, Georgia is the Nation's leading producer of the type of kaolin used in the paper industry, an industry which consumes about half of the State's total output of kaolin (estimated for this year at \$30,000,000).

The rubber industry consumes about 12 per cent of Georgia's kaolin. Refractory manufacturers, making fire brick and other heat resistant products, use 10 per cent. The pottery industry, including all porcelain and china goods of all kinds, also consumes about 10 per cent. The remaining 18 per cent is consumed by the adhesive, cement, insecticide, linoleum, oil cloth and paint industries.

Several years ago, the Georgia Tech Engineering Experiment Station initiated a project to study Georgia's principal mineral. As a result of this sponsorship by Tech, it now has clay research facilities which excel any other school in the Southeast. Several of the clay producers of Georgia have sponsored or are sponsoring work here at the Station, and these facilities are a great aid in their studies.

Tech's facilities for this work include up-to-date ceramic and optic labs, electron microscope, electron diffraction, X-ray diffraction, differential thermal analysis, surface area determination and other general lab equipment such as pH meters, viscosimeters, particle size determination apparatus and high temperature fusion apparatus.

These facilities are just tools used to study the behavior of clays when they are subjected to certain prescribed conditions, i.e., a kaolin from x deposit is a good coating clay, and a kaolin from y deposit is not, but both clays appear to be identical outwardly. The use of these facilities could indicate the difference between these two clays and this knowledge could possibly lead to a method of processing the y clay to make it a good coating clay when it may otherwise be useless for this use.

Georgia Tech is acquiring new equipment in an effort to conduct better studies, requiring less time, on this valuable mineral called kaolin. As this research grows, so will grow the value of Georgia's principal mineral product.

A new president for Georgia Tech

A new director for the station



rose to the rank of commander. After completing his Navy service, Dr. Harrison taught at a preparatory school and at Virginia Polytechnic Institute. He received his Master of Science in Mechanical Engineering from VPI in 1948.

In 1952, Dr. Harrison received his doctor of philosophy (mechanical engineering) from Purdue University. He returned to VPI and was made assistant to the dean of engineering. In 1955 he went to Toledo as dean of engineering.

Dr. Harrison and his wife, Dorothy, and two sons—Bob, 13, and Rick, 5—moved into the president's house in early August.

Talking about Georgia Tech and the Engineering Experiment Station, Dr. Harrison said, "Tech is a big engineering school—one of the largest in the country. It is in a section of the country that is moving ahead fast. It has tremendous research organization. You know, every once in a while you hear an educator complaining about applied research in a university. I am not one of them. I not only like research for its own sake, but I feel it is one way to attract a well-rounded, competent faculty. You find your pace-setters in the research groups—people who know what's going on in the industrial world today as well as some who know what will go on in the future. You turn out better engineers because of research, for through it you get a better faculty."

The young educator realizes full well the tough job he has ahead of him. "I bruise easily but I bounce back," is one of his favorite expressions. "I expect to do a lot of bruising and bouncing within the next year," he said. "But I know now that I have a strong administrative set-up and faculty to help me through the transition period. Georgia Tech is a growing thriving institution, and I am right proud to be a part of it."

ON THE SAME DAY that Dr. Harrison was appointed president of Georgia Tech, the Board of Regents approved the appointment of Dr. James E. Boyd, long time Tech teacher and research administrator, as director of the Engineering Experiment Station. Dr. Boyd assumed his new duties on July 1, replacing Dr. Paul K. Calaway, who accepted the post of director of the School of Chemistry at Texas A & M College.

A native of Tignall, Georgia, Dr. Boyd received the Bachelor of Arts in Mathematics from the University of Georgia in 1927. He received his Master of Arts in Mathematics from Duke University in 1928, and the Doctor of Philosophy (Physics) from Yale University in 1933. While at Yale, he was a graduate assistant and held a Loomis Fellowship. From 1933 thru 1935 he headed the Department of Mathematics and Science at West Georgia College in Carrollton, Georgia.

He joined the staff at Georgia Tech as assistant professor of physics in 1935. He was appointed associate professor of physics in 1937. In 1942 he took leave of absence to serve in the United States Naval Reserve where he served as a lieutenant and lieutenant commander in the Radar Section of the Research and Development Division of the Bureau of Ordnance. In 1945 he served in the operational Characteristics Branch of Electronics Division of the Office of the Chief of Naval Ordnance as a commander.

He returned to Georgia Tech in 1945 as a professor of physics and as a research associate directing radar and microwave propagation projects. In 1950 he was named chief of the Physical Sciences Division. In 1954 he became assistant director to the Station, in charge of research. He was named associate director of the Station in 1955.

Dr. Boyd agrees with philosopher A. N. Whitehead's statement in *The Aims of*

Education that "universities are schools of education, and schools of research . . . the proper function of a university is the imaginative acquisition of knowledge." In Dr. Boyd's own words, "I believe that a campus research center can strengthen research and teaching by (1) hiring competent and enthusiastic young research faculty members and encouraging them to teach part time and (2) encouraging the teaching faculty to research part time. How better can we provide the needed teaching staff in our 'exploding universities' and be sure that they will be imaginative?"

Dr. Boyd, one of the prime movers in the development of Georgia Tech's nuclear program, has been chairman of the Tech Nuclear Science Committee since its organization in 1955. He is a member of the Georgia Nuclear Advisory Commission and chairman of its Research Reactor & Industry Committee. Since 1949 he has been commanding officer of the Naval Reserve Research Company in Atlanta.

He is a member of the American Physical Society, Gamma Alpha, IRE, Phi Beta Kappa, Phi Kappa Phi, Sigma Xi and other scientific and professional societies. He is the author of a number of scientific articles and reports.

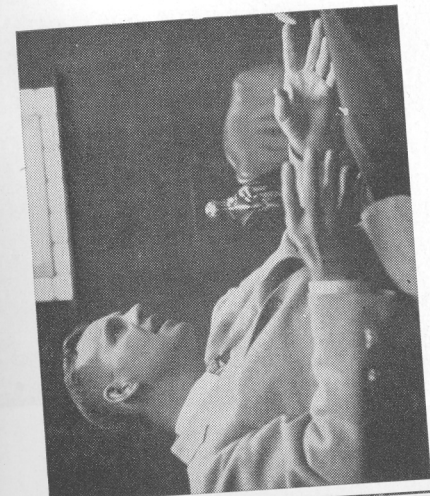
Dr. Boyd is married to the former Elizabeth Reynolds Cobb. They reside with their two children—Betty, 17, and James, 14—at 926 Lullwater Road, N.E., Atlanta, Georgia.

ON JUNE 26 the Board of Regents ended a search of 17 months and 3 days when they named Dr. Edwin D. Harrison, above, dean of engineering at Toledo (Ohio) University, as the sixth president of Georgia Tech. Dr. Paul Weber, dean of faculties, has been acting president since the death of Dr. Blake R. Van Leer on January 23, 1956.

Dr. Harrison, who took over his new duties on August 15, was first contacted early in May by Chancellor Harmon Caldwell of the University System and Executive Secretary L. R. Siebert of the Board of Regents. "They came by my office in Toledo and talked to me about the problem at Tech and asked me if I knew of any qualified men who might be interested in the job," Dr. Harrison said. "I gave them a list of names and then promptly dismissed the subject from my mind. To my surprise, they called me back on June 14 and asked me to come down and look over Tech. It was the first inkling I had that they were considering me for the vacancy."

"I came to Atlanta the week of the 17th of June and was impressed with both Georgia Tech and the people I met," the personable 41-year-old educator continued. "I came back to Atlanta the night of June 25, and the next day they told me I was the new president of Tech."

Born in Evadale, Arkansas, Dr. Harrison received his bachelor of science degree in 1939 from the Naval Academy. He served through 1945 in the Navy and





Governor Griffin grants \$2,500,000 to Georgia Tech for a nuclear reactor

GOVERNOR MARVIN GRIFFIN pledged \$2,500,000 on August 20 to construct Georgia Tech's proposed high-flux research reactor.

The pledge was made at a luncheon meeting of the Georgia Nuclear Advisory Commission immediately after Dr. Walter H. Zinn, internationally known nuclear physicist, outlined the conceptual design for the Georgia reactor. The design was carried out by the General Nuclear Engineering Corporation of which Dr. Zinn is president.

In making the pledge, Governor Griffin said, "I am convinced that the multi-purpose research reactor explained here by Dr. Zinn will be a real asset to the State and region as well as to Georgia Tech. I am also convinced that at Georgia Tech we have the talent to make the best possible use of this reactor. After a great deal of study on this project, I have

concluded, with the help of many of the Nation's outstanding experts in this field, that we must take immediate action on this project or we will certainly be sorry in the future.

"If the Board of Regents of the University System will put in a budget request for \$2,500,000 for the Georgia Tech reactor project, I will be happy to sign it."

The Governor's pledge gave the final green light to a three-phase expansion program in the nuclear field at Tech.

The first phase, the nuclear graduate program, got underway in the fall quarter of the 1956-57 scholastic year. In 1956 Governor Griffin appropriated \$300,000 to the Regents for phase two of this program—the construction of a Radioisotopes Building on the Georgia Tech campus. The building, now valued at \$500,000 as a result of additional grants from



the National Institutes of Health and the Board of Regents, will go under construction this fall. It will provide laboratory space and facilities for courses taught in connection with the nuclear graduate program as well as for research.

Beginning with the formation of a Nuclear Science Committee in January, 1955, Georgia Tech's program has moved steadily forward through the addition of new courses to the curriculum and of nuclear scientists to the faculty and staff. Tech has received a grant from the Atomic Energy Commission for equipment and special supplies to be used in nuclear science and technology courses. Georgia Tech also has taken advantage of the AEC's educational support program to acquire 5500 pounds of uranium and a neutron source for use in a subcritical assembly construction at the school and now in operation.

The new reactor will be a heavy-water-moderated, heterogeneous, enriched-fuel type, similar to the CP-5 now in operation at Argonne National Laboratory and Cambridge, Mass. The reactor will be used in a broad and intensive program

of research in physical and engineering sciences. It also will contribute to research in biological, agricultural and medical sciences in the region, as well as make more comprehensive and effective the Georgia Tech graduate program in nuclear science and engineering.

In his discussion of the Georgia Tech reactor, Dr. Zinn said, "With the reactor, Georgia Tech scientists and engineers will be as well equipped as those in any university in the entire world. This facility will permit work in every important phase of nuclear development. The Tech people will not be able to do every type of nuclear research anyone has ever indulged in, but they will be able to play a full part in many important areas. The Tech reactor is a general purpose machine—one not designed to favor any specific type of nuclear research. It will have built into it facilities for materials testing, but it will also have facilities for many other kinds of research—facilities that can be used by physicists, chemists, biologists, and various disciplines of engineering. It will also contain facilities for experimentation and treatment of cancer with neutron therapy.

"This reactor will be planned, constructed and operated under strict Federal supervision and licensing through the Atomic Energy Commission," Dr. Zinn continued. "It is, in my opinion, the very best research reactor that can be built for the multi-purpose needs of Georgia Tech, the State and the area for the amount of money that will be available to construct it."

Present estimates on the capital investment cost of the reactor run from three to four million dollars. Georgia Tech expects to secure the balance of funds needed from Federal agencies.

Other speakers at the meeting of the Georgia Nuclear Advisory Commission, which is headed by Frank H. Neely, were Dr. James E. Boyd, director of the Georgia Tech Engineering Experiment Station and head of the campus Nuclear Science Committee, and Dr. William B. Harrison, III, the director of the research reactor project at Tech.

• Since the last issue of this magazine went to press a great deal has happened at Georgia Tech.

After a 17-month search, the Regents named Dr. Edwin D. Harrison, a 41-year old engineering educator as the sixth president of Georgia Tech. On the same day, June 26, the Regents approved the appointment of Dr. James E. Boyd as director of the Engineering Experiment Station. We have departed slightly from our original plans of an all-ceramics issue of the magazine to bring you a short profile of both of these men. Otherwise, as you can see, the issue is devoted to a report on the ceramics research program now in operation at Tech.

As you will notice in reading this series on ceramics, a great percentage of this research work has been undertaken during the past year. This great increase in sponsored work in ceramics has forced J. D. Walton (see cover) and his group to expand in every direction possible. Today, ceramics work is being carried out in the hallways of the main research building and in a newly erected Butler building in Research Area 2, which is located on Atlantic Drive a few blocks northwest of the main Tech campus.

Oddly enough, the group's major new contribution, a new and cheaper method of producing fused silica (see article on page 8) was developed using a Rube-Goldberg-type, home-made device in the aforementioned hallway. Which we suppose once again proves the adage that "there is no substitute for the brain of man."

The other important recent event concerning Georgia Tech was the announcement that Governor Griffin had pledged \$2,500,000 for the construction of the Georgia Tech Research Reactor. Because of its real news value, this story has also been inserted into this issue of the magazine.

The January issue will be devoted to the third progress report of Tech's nuclear program—providing, of course, that events don't pop during the next three months as they did during the summer just past.

the
changing
Tech



Governor Griffin
and Tech's program
see page 2