GENERAL ELECTRIC RESEARCH LABORATORY

# Skills and Facilities of the Metallurgy and Ceramics Research Department

## Contents



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General Electric Research Laboratory, Schenectady, New York

# Foreword

The Research Laboratory, in performing the research that is its primary function, must often develop facilities and techniques that are new and unique. People skilled in various specialized experimental and theoretical activities are also associated with the Laboratory.

In the Metallurgy and Ceramics Research Department, an extraordinary number of these special facilities and people with unusual skills have been assembled. Sometimes they are not used to their fullest capacity, and therefore, if a critical need exists elsewhere, it is unnecessary for them to be duplicated. This booklet has been prepared to describe such special facilities and activities. I hope that it will prove to be useful.

J. H. Hollomon
*Manager*
*Metallurgy and Ceramics*
*Research Department*


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# Skills and Facilities

As a part of the General Electric Research Laboratory, the Metallurgy and Ceramics Research Department has the responsibility for performing "learning work" (sometimes called "basic research") as well as applied research in the fields of metallurgy and ceramics. Its philosophy is that metals and ceramics can best be studied, not as two separate types of materials, but as solids that are governed in behavior by the same laws, are processed by similar methods, and are capable of performing many similar functions.

The department, with J H. Hollomon as manager, is organized into six sections:

Chemical Metallurgy . . . . D. A. Vermilyea, Manager
Physical Metallurgy. . . .. . . R. W Schmitt, Manager
Ceramic Studies. J. E. Burke, Manager
Alloy Studies. . W. R. Hibbard, Manager
Materials and Processes Studies . . . . . R. L. Fullman, Manager
Materials Application and Evaluation . . . . . . . R. M. Parke, Manager

A description of the activities of these sections is given in a recently issued booklet titled "Metals and Ceramics" (GP-72, 1958). Within these sections, various specialized service groups have been established. For example, the Process Laboratories Unit of the Materials Application and Evaluation Section has facilities for making metal and ceramic samples. Likewise, there are service groups for metallographic examination, x-ray diffraction, chemical analysis, etc. In addition, the individual scientist, when necessary, may duplicate equipment found in the service areas, or may develop special equipment that later finds wider use elsewhere.

The purpose of this booklet is to describe the nature of the Department's skills and facilities. The text is organized as follows:

Metals and Ceramics Processing
Low-Temperature Facilities
Structure and Composition Analysis
Measurement of Properties

# Metals and Ceramics Processing

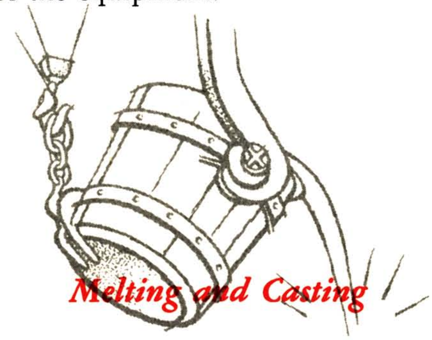
In 1954-55, the Metals and Ceramics Building was constructed to provide unique facilities for scaled-up processing of metals and ceramics. The facilities include five processing areas:

- Melting and Casting
- Fabrication
- Heating and Heat Treating
- Metal Powder Processing
- Ceramic Processing

In this building the staff is provided with an assortment of equipment that is unmatched in any industrial research laboratory. Approximately half of the building's floor space is used to accommodate large, "factory-size" machines, mainly in a high-bay area on the main operating floor (see photo at left). Smaller pieces of equipment can be picked up by overhead cranes and relocated almost anywhere, making possible a wide variety of equipment combinations.

The Process Laboratories Unit (R. K. McKechnie, manager) has the responsibility for operating the processing facilities in the Metals and Ceramics Building, for preparing metal and ceramic samples, and for improving the processes involved. Thus, this unit is concerned with the methods and equipment for processing materials, as well as improvements in the materials themselves.

Technical staff members and technicians provide first-hand supervision of processing, and in many cases participate in the operation of the equipment.




The melting and casting facilities include most conventional as well as many specialized processes and techniques. In many cases, the techniques are being studied as well as being applied, in order to gain greater understanding of the process technology and in order to conduct research on refining, purification, structure control, nucleation, and growth.

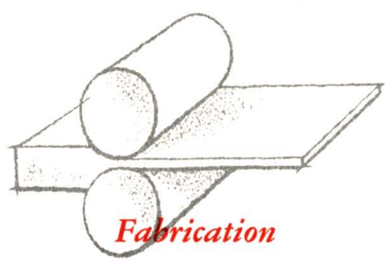
The conventional melting facilities consist of a basic-lined, three-phase arc furnace, a number of air-induction furnaces, and a gas-fired furnace. Melts of varying sizes can be made, ranging from 5 grams to 450 pounds in the air-induction furnaces, as much as 400 pounds in the gas-fired furnace, and from 500 to 2000 pounds in the arc-melting furnace.

The more specialized facilities represent such techniques as vacuum-induction melting, consumable-electrode arc melting, inert-electrode arc melting, atomic-hydrogen melting, and zone melting. In most instances, these facilities have been designed and constructed at the Research Laboratory Melt sizes range from 50 gram lots in the atomic-hydrogen furnace to 8″ diameter ingots in the consumable-electrode melting equipment.

In addition, facilities are in use which include the following practices: sand, permanent, and semipermanent molding; precision casting; centrifugal casting; and special control of structure during solidification.

Most of the common metals and alloys have been melted and cast. In addition, many of the uncommon refractory and reactive metals—such as tungsten, tantalum, zirconium, uranium, etc.—have been processed, using special techniques.

Staff personnel directly responsible for these facilities are: A. J. Kiesler, W. F Moore, and S. J. Noesen. Other technical staff members who often act in the capacity of consultants are H. J. Fisher, J C. Fisher, G Horvay, H. W Schadler, A. U. Seybolt, W. H. Smith, P. S. Swartz, and J. L. Walker.



## Fabrication

Metal fabrication equipment comprises a large portion of the processing facilities located in the Metals and Ceramics Building. Rod, wire, and sheet products can be fabricated by hot- and cold-working operations. The processes available are rolling, extrusion, forging, swaging, and wire drawing.

**ROLLING FACILITIES** consist of nine rolling mills of various sizes and operating principles, e.g., two-high, four-high, tension, planetary, and multiple back-up (Sendzimir) types. On these mills, it is possible to hot-roll slabs or ingots of many materials into sheet 0.070 inch thick by 12 inches wide. Cold rolling can produce strip or sheet down to 0.010 inch thick by 12 inches wide. Utilizing special techniques, such as tension rolling or pack rolling, metal foil as thin as 0.0001 inch can be produced.

**EXTRUSION** is especially useful for deforming coarse-grained, brittle metals. A water-air, 1250-ton, hydraulic press is available for extrusion, and has been of particular value for initial fabrication of refractory metals such as tungsten, molybdenum, columbium, and zirconium. Billets ranging in size from about 2″ to 5″ can be handled in the extrusion press. The usual product is a rod, and die-openings ranging in diameter from ¼″ to 2¾″ are available, although the degree of reduction that can be made depends upon the material, temperature and related factors. The equipment has been used for extruding copper, aluminum, high temperature ferrous alloys, and refractory alloys difficult to form by other methods.

**HOT OR COLD FORGING**, to accomplish breakdown of coarse-grained cast structures, as well as to obtain finished shapes, is performed on the 250-pound or the 2500-pound forging hammer, or the 2500-pound drop-forging hammer.

**SWAGING** is one of the most widely used fabrication techniques for making metal samples. A series of swaging machines is available for hot or cold working of bar stock from 2½″ diameter down to 0.030 inch diameter wire. Tubing or jacketed bars can also be swaged.

**DRAWING** is an alternate process for making rod and wire. Equipment is available for bench drawing of rigid bars as large as

1″ in diameter and 20 feet long, and for wire drawing to 0.005 inch diameter.

The fabrication facilities are under the supervision of R. C. Leech. C. L. Kolbe and J. R. Hughes are actively engaged in operations in this area. Technical personnel who have specialized in related areas are: L. F. Coffin, W. R. Hibbard, H. C. Fiedler, H. E. Grenoble, and T. A. Prater.

## *Heating and Heat Treating*

Heating for fabrication and heat treating can be accomplished in a wide variety of temperature ranges and atmospheres. When required, auxiliary equipment is available for vacuum annealing, magnetic field treatments, bright annealing, and other special treatment of samples.

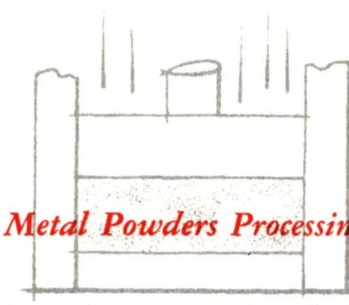
While many furnaces are utilized primarily for heat treating, they may also be used for heating of samples for fabrication. About 20 of the heating and heat-treating furnaces utilize resistance-heating elements, such as silicon carbide, Kanthal, nickel-chrome alloys, or platinum for air treatments up to approximately 1400° C (2550° F). By special arrangement, certain silicon carbide furnaces can be operated as high as 1650° C (3000° F).

Approximately 15 other furnaces using molybdenum heating elements are normally operated with hydrogen atmosphere. In some cases, they can also be used with nitrogen or inert gases, such as argon. The work chamber sizes of these furnaces range from 3″ diameter tubes to a 16″ x 24″ x 10′ hearth. A few of these are capable of attaining 1850° C (3660° F) with a hot zone of the order of 6″ diameter x 12″ long.

Heating facilities also include a molten salt bath and lead pot, two vacuum furnaces—one for use to 1600° C (2910° F) and the other for use to 2100° C (3810° F)—a magnetic annealing furnace, and a small high frequency induction power source.

Atmospheres normally available are hydrogen dried to 95° F dew point, nitrogen, Neutralene (rich exothermic gas), helium, and argon. All atmospheres, however, can not necessarily be used in every type of furnace. Equipment is available for continuous monitoring of dewpoints.

This area is supervised by R. C. Leech. C. L. Kolbe and J. R. Hughes are also actively engaged in operations in this area. Technical personnel who often act in a consulting capacity are J. M. Berry, M. A. Cocca, H. E. Grenoble, D. L. Martin, L. Navias, A. G Pincus, A. U. Seybolt, and W. H. Smith.

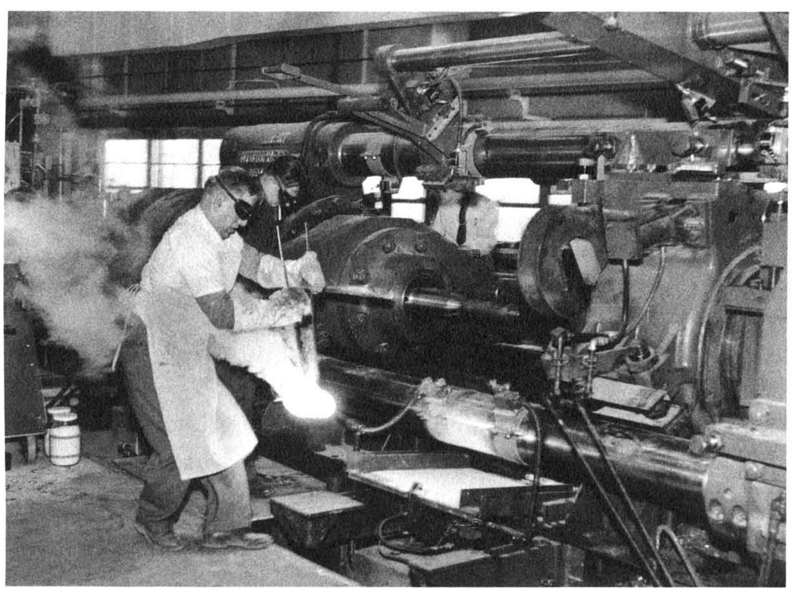


## *Metal Powders Processing*

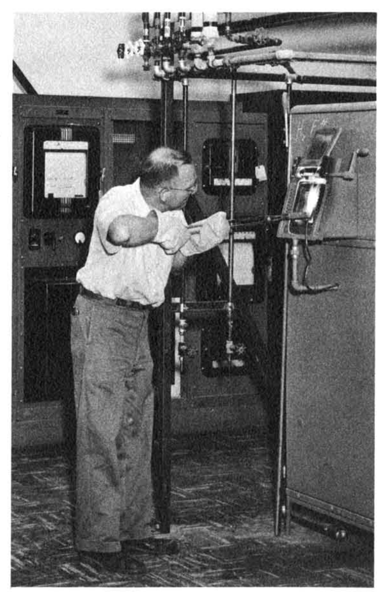
Metal powders processing facilities and services permit the performance of familiar powder metallurgical operations, such as pulverizing, grinding, screening, blending, manual pressing, and atmospheric sintering. More specialized equipment is available for such operations as hot pressing, hot and cold extrusion, infiltration, vacuum sintering, powder rolling, and high-speed automatic pressing. An inert atmosphere box facilitates handling of special materials, such as reactive metals.

General powder equipment includes a jaw crusher, disc grinder, micropulverizer, ball mills, Ro-Tap, and high-speed, twin-shell blenders having capacities up to three cubic feet. An assortment of pressing dies includes

*One example of the special induction melting facilities that are available is shown above.*



*A molybdenum ingot transferred to the 1250-ton extrusion press.*



*A metal sample is placed in a molybdenum-wound hydrogen furnace.*

round dies for wafers up to 7″ in diameter, and rectangular dies for bodies up to 1½″ wide and 20″ long. Manual presses have capacities ranging to 100 tons. Automatic presses include a hydraulic press of 60-ton capacity and a 2-ton toggle press. Hot pressing of samples is possible in air and vacuum.

Small-scale, hot-extrusion operations are possible on a 50-ton press and large-scale hot extrusion of billets up to 5″ diameter is possible on a 1250-ton press. Other specialized equipment includes atmosphere and vacuum infiltration equipment for operation to 1800° C (3270° F), and two cold-extruding machines, an auger type and plunger type, for pieces up to 1″ diameter and 2″ diameter, respectively. Powder-rolling operations yield sheet products up to 5″ wide and 0.060 inch thick.

Sintering furnace equipment provides a variety of atmospheres and temperatures, as well as vacuum treatments. Prefire and sintering operations can be conducted at temperatures from 100° C (210° F) to a maximum of 1900° C (3450° F), depending upon the physical size and configuration of compacts. Other fabrication operations may be performed on equipment such as rolling mills, forging hammers, and swaging machines, which are available to the personnel engaged in powder metals research.

The powders that are normally processed and of which a stock is maintained include all of the more conventionally encountered elements, several alloy and compound powders, and special metals, such as tantalum, titanium, tungsten, osmium and others.

The powder metals facilities are primarily the responsibility of H. H. Hirsch. Because of closely related types of work and interests, staff members such as A. Gatti, A. G Pincus, P. D S. St. Pierre, and E. R. Stover can serve as consultants to this area of research.

## Ceramic Processing

Ceramic processing operations are conducted both in the Ceramics Laboratory area of the Metals and Ceramics Building and in the Ceramic Studies Section. Because it is important that contamination by metallic particles, dust, and vapors be avoided, most of the ceramic processing equipment is set up in a separate area as an individual facility in the Metals and Ceramics Building.

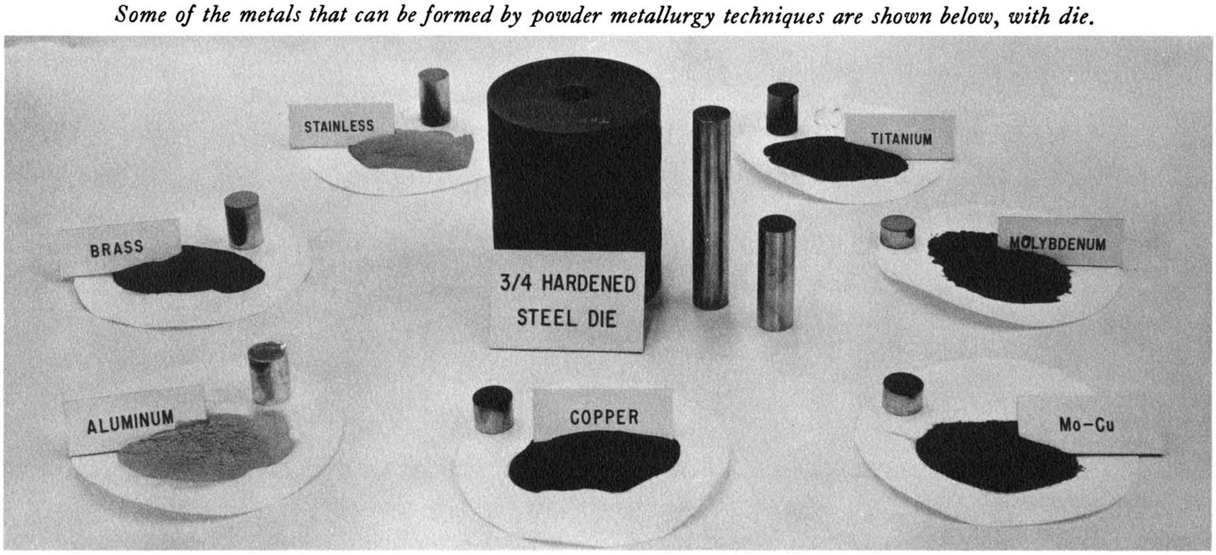
In the Ceramics Laboratory, raw materials are processed into desired shapes by a variety of forming methods, which closely parallel many of the methods used in metal processing. The laboratory is divided into three functional areas a powders room for batch preparation, a press room for fabrication, and a furnace room. A fourth segregated area has equipment and facilities for processing ferrites, uranium oxides, and other materials which might contaminate the "white" ceramics.

The powders room contains special storage facilities for the raw materials. Batch preparation equipment in use includes porcelain, alumina, rubber-lined, and tungsten carbide ball mills, twin-shell dry blenders, countercurrent batch mixers, filter presses, comminutors, crushers, colloid mills, sieve screens, shakers, wet blenders, and drying ovens.

Equipment for compression molding includes presses with capacities ranging from 6 tons to 100 tons. Extrusions can be carried out either with a 100-gram-capacity chamber, which fits any of the above presses, or with a 1000-gram chamber, in a 30-ton press.

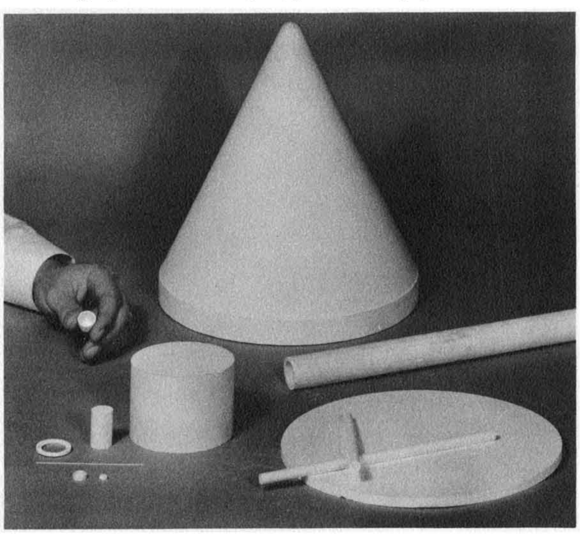
*Ceramic powder is poured into a continuous-mixing, rotating-muffle furnace for purification.*

*Some of the metals that can be formed by powder metallurgy techniques are shown below, with die.*



*Sample is put in high-temperature (2000 C.) gas furnace.*

*A variety of ceramic shapes, produced by powder methods.*



Another type of fabrication process in increasing use is bonding of oxides by small additions of phosphates or aluminates. In addition, mechanical forming (machining, grinding, etc.) equipment and spray drying equipment is available to augment the cold-forming operations. Finishing operations such as metallizing, glazing, spraying, enameling, slurry coating, dipping, and brushing can be performed.

The scale of operations varies from batches of a few grams to two hundred pounds. The number of pieces that can be expeditiously processed varies from several hundred about one inch in size to a dozen in the upper size range of eighteen inches.

In addition to a number of prefiring and drying ovens, approximately 25 furnaces are maintained almost exclusively for the firing of ceramic bodies. About 15 furnaces are of the nickel-chrome, silicon carbide, and gas/air types. The silicon carbide and gas/air furnaces can be used to 1600° C (2910° F) and 2100° C (3810° F) respectively. There are ten molybdenum-wound furnaces which utilize hydrogen atmospheres. These reach maximum temperatures of the order of 1950° C (3540° F) By use of special equipment, including impervious ceramic tubes, these molybdenum furnaces can also be used for vacuum or oxidizing atmosphere treatments.

Quality control equipment regularly in use within the Ceramic Laboratory includes such special items as a Littleton fiber-softening-point apparatus and a petrographic microscope.

A. G. Pincus has the responsibility for the research and service functions for ceramic processing, aided by C. Ryer. Personnel who serve as consultants are C. A. Bruch, R. E. Carter, R. L. Coble, A. Gatti, H. H. Hirsch, L. Navias, P. D. S. St. Pierre, and E. R. Stover.

# Low-Temperature Facilities

The Low-Temperature Building houses facilities for liquefying hydrogen and helium, to meet the needs of the Laboratory and some outside customers. These liquids, supplied by a 40 liter/hour hydrogen liquefier and a 14 liter/hour helium liquefier, can be stored in special containers for many weeks without excessive loss. They can then be transported to the user in 2½, 30, or 50 liter containers.

"Normal" liquid hydrogen is ordinarily supplied, rather than an equilibrium concentration of "ortho" and "para" forms. Equipment for its use must meet minimum safety requirements in design and transportation, and the usual minimum delivered quantity is three liters.

Liquid helium is supplied in "as needed" quantities from liquid-nitrogen-shielded containers of 30 liter capacity

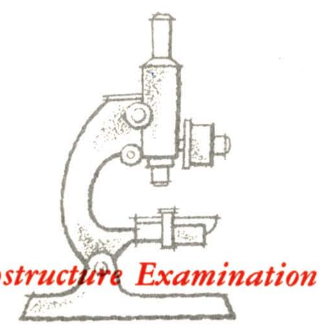
The rapidly expanding application of low temperatures in the investigation of mechanical, electrical, optical, and chemical properties of materials has given wide experience in cryogenics to the staff. In particular, low-temperature experiments in the range from 0.9°K to near room temperature have involved many of the following problems: tensile and fatigue properties of metals; nuclear magnetic, electron spin, and ferromagnetic resonance, magnetism; superconductivity; radiation effects; and thermomagnetics.

The cryogenic (low-temperature) engineering consulting services of the Research Laboratory have been utilized by many Company components, including: Light Military Electronic Equipment, Heavy Military Electronic Equipment, Ordnance, Missile and Space Vehicle, Aircraft Gas Turbine, Large Steam Turbine-Generator, and General Engineering Laboratory Loyd B. Nesbitt, cryogenic engineer in charge of the liquefaction plant, and other staff members, including M. D. Fiske, R. W. Schmitt, R. H. Pry, J. W. Corbett, and W DeSorbo, are available for this service.

# Structure and Composition Analysis

The properties of metals and ceramics are dependent upon their micro- and atomic structures and the chemical composition of the phases of the material. In order to understand and to control the properties of such solids, it is therefore necessary to examine and measure their structures and compositions. Extensive facilities for such work have been assembled within the Metallurgy and Ceramics Research Department.

Determination of *structural characteristics*, such as grain size and orientation, particle size and distribution, atomic arrangement, crystal defects (dislocations), magnetic domains, etc., requires light and electron microscopes, x-ray and electron diffraction apparatus, and other analytical equipment. *Composition analysis* facilities for rapid determination of carbon and sulfur and for the determination of any of 50 other elements have been established. The facilities available for both types of analysis are described below in three sections: microstructure examination, atomic structure and crystal orientation, and composition analysis.



## Microstructure Examination

The facilities and services for microscopic examination of metals and ceramics are similar, but are described separately in this booklet under the headings of metallography for metals, and ceramography and petrography for ceramics.

**METALLOGRAPHY:** Most of the equipment for optical and electron microscopic examination of metal samples is centered in the General Metallographic Laboratory of the Alloy Studies Section. Conventional and specialized techniques for mounting, polishing, etching, and examining specimens are utilized. Thus, chemical, electrolytic, and diamond polishing methods, and chemical, electrolytic, and vacuum cathodic (ion bombardment) etching methods are available for preparation of the wide variety of metallic, ceramic, and plastic materials that are submitted for examination.

Some of the special metallographic techniques and equipment that have been used are interferometry, color photography, micro-autoradiography, phase contrast examination, stereo-electron fractography, stereo-macrography, and Berg-Barrett x-ray diffraction microscopy.

The metallographic facilities include three metallographic microscopes, several desk microscopes, and special equipment such as micro-hardness testers for measurement of hardness of micro-constituents. Most of the common metals and alloys, as well as many of the uncommon ones, such as tantalum, rhenium, and boron, have been studied.

The electron microscope is used for the examination of metals and ceramics and is being utilized more and more as its special usefulness is recognized. It has a much higher resolving power and greater depth of focus than the optical microscope. It also has the important advantage that it can be used in transmission through thin sections to study the interior of materials (e.g., to observe dislocations), and by means of selected area diffraction to identify phases present.

A Philips EM-100 electron microscope has been in use for several years as a research tool. Recently, a new Seemens electron microscope of very high resolving power has been added, to broaden the range of observation almost to the atomic scale.

Experience has been gained in many of the electron microscopy techniques and continued effort is being made to use and develop new and unique techniques. For example, carbon and plastic replica techniques, extraction replicas, thin film techniques, and dispersed powder techniques have been used. Stereo microscopy has been used for fracture studies.

The metallographic facilities are operated by a group of skilled microscopists under the direction of V. A. Phillips. A. S. Holik acts as leader of the microscopy group and also as the primary service electron microscopist. The high technical competence of the group is indicated by their success in winning 15 awards (seven were judged Best in Class) in the last three ASM National Metallographic Exhibits.

J. B. Newkirk, Anna Turkalo, and D. L. Wood are particularly qualified to act as metallographic consultants because of their experience.

**CERAMOGRAPHY & PETROGRAPHY:** Many studies of the physics and chemistry of ceramic systems are greatly aided by the use of optical microscopy In the Ceramic Studies Section, facilities are available for the routine identification of phases and the microstructural relationship of phases by both transmitted and reflected light techniques.

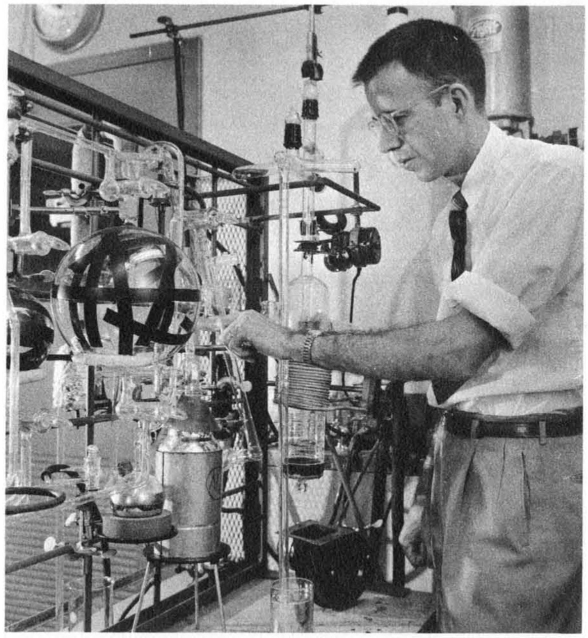
Transmitted light petrography using polarized light is most useful for identification of phases and for determining the orientation of these phases from their optical behavior This technique is used on samples ranging in thickness from about 10 microns to 1 mm. Such samples might result from experiments in phase equilibria, crystal growth, or sintering. Three transmitted-light microscopes are available within the section for classical thin-section studies. Small accessory stages for studies from liquid nitrogen temperature up to 1500° C (2730° F) are available for use with these microscopes.

Reflected light microscopy using conventional polishing techniques and, often, less conventional etching techniques reveals the relationship of structures both between and within crystals. Thus, in a polycrystalline aggregate, the grain boundary and pore structure can be seen, described, and perhaps related to a property of the material. Similarly, twinning structures and other imperfections can be studied by this method, which may be called "ceramography"—metallography applied to non-metallic materials. The standard Bausch and Lomb Metallograph is the principal instrument used, but three smaller desk microscopes are also available in the section.

Measurements of hardness and porosity are also performed. Hardness can be measured from 3 to 9 Mohs, and porosity measurements can be made from zero to 50%

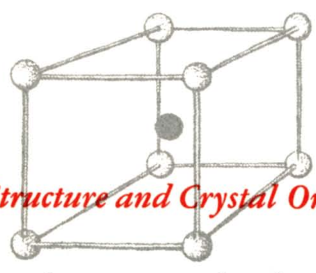
The materials that are ordinarily encountered and for which techniques have either been established or are under study are ferrites, ferroelectrics, electric porcelain, and special refractories.

There is a continuing interest in the development of new techniques for examination and interpretation of the microstructure of nonmetallic materials. R. L. Coble and R. C. DeVries are responsible for the ceramographic and petrographic facilities.



*A platinum bath can be used in the rapid chemical analysis of high-temperature metals and alloys.*

*The electron microscope is being used more and more as its special advantages become apparent.*

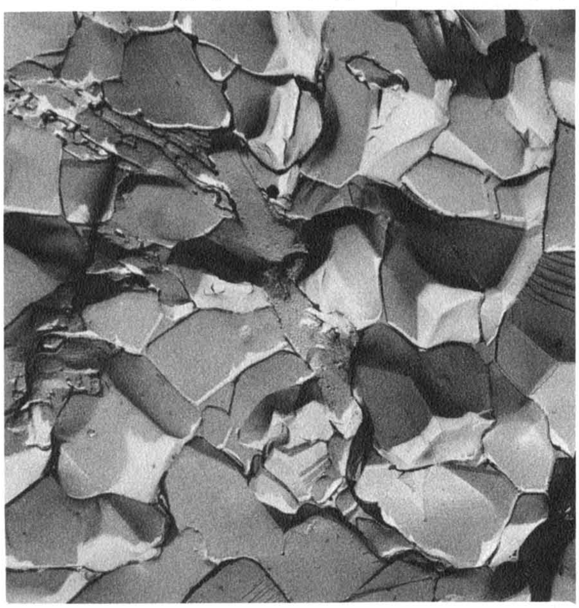


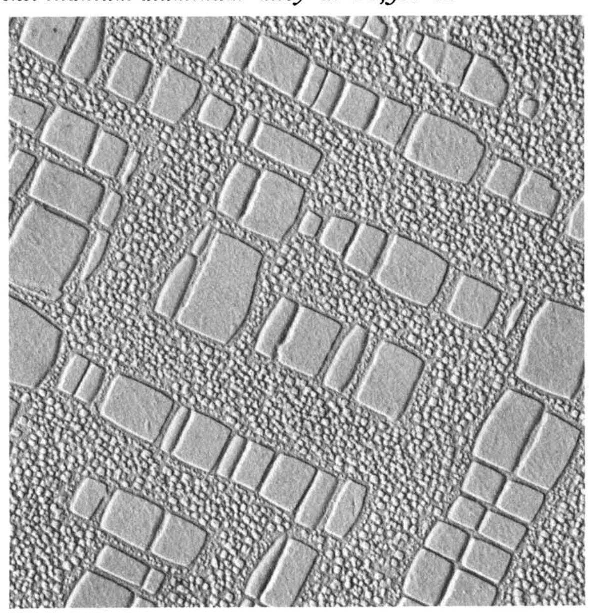
## Atomic Structure and Crystal Orientation

Many studies require the determination of crystal orientation, identification of phases, measurement of particle size and lattice

*Crystal structure of alloys can be studied by means of a special high-temperature x-ray camera.*

*Two electron photomicrographs are shown below. At the left, the fracture surface of $Al_2O_3$ (alumina) at a magnification of 7500 x. At the right, a nickel-titanium-aluminum alloy at 12,500 x.*





parameter, and evaluation of similar characteristics, for metals and ceramics. To meet these needs, x-ray and electron diffraction service facilities have been established.

For x-ray diffraction work, equipment available includes powder cameras of the Debye Scherrer, Seeman-Bohlen, and Laue type; a Unicam high-temperature camera (1450° C, 2640° F) for phase diagram and melting point studies; an automatic pole figure recorder; and a Hilger microfocus x-ray generator Most of the x-ray generators are of the General Electric XRD type.

For electron diffraction studies a General Electric transmission-reflection type diffraction instrument is used.

Practically all of the normally encountered crystalline materials have been studied. Sample and specimen sizes are usually very small—of the order of grams or milligrams—and in the form of wire, powder, sheet, whiskers, or rod, depending upon the technique and equipment to be employed.

The x-ray and electron diffraction laboratories are a part of the General Metallography Laboratory under the supervision of V. A Phillips. Mrs. R. DiCerbo acts as leader of the x-ray group. Consultants to these activities are B. Decker, J. Kasper, J B. Newkirk, B. W. Roberts, W. L. Roth, and M. L. Kronberg.

## Composition Analysis

In the course of planning the extensive facilities of the Metals and Ceramics Building it was apparent that the need existed for analytical chemistry facilities to provide the rapid analyses often required at intermediate stages of the processing work. Further, because of the unique nature of many of the materials being studied, it appeared advantageous to have analytical chemists available who would be familiar with the technical problems of the staff, and who could conduct research and development work on new analytical methods. The Analytical Chemistry Laboratory was consequently established in the Metals and Ceramics Building, as part of the Materials and Processes Studies Section.

Carbon and sulfur equipment is available for control analysis while a heat is being made. Low-carbon analyses (less than 0.015%) are normally made each Tuesday, but for process control, twenty-four-hour service is available.

The Laboratory has had experience analyzing for the elements listed below:

| | | |
|---|---|---|
| Aluminum | Iridium | Rhenium |
| Antimony | Iron | Rhodium |
| Argon | Lanthanum | Scandium |
| Arsenic | Lead | Silicon |
| Barium | Lithium | Silver |
| Bismuth | Magnesium | Sodium |
| Cadmium | Manganese | Sulfur |
| Calcium | Molybdenum | Tantalum |
| Carbon | Nickel | Thallium |
| Cerium | Niobium | Thorium |
| Cesium | Nitrogen | Tin |
| Chromium | Osmium | Titanium |
| Cobalt | Oxygen | Tungsten |
| Copper | Palladium | Vanadium |
| Gold | Phosphorus | Zinc |
| Hydrogen | Platinum | Zirconium |
| Indium | Potassium | |

The technical staff member responsible for the service and research work conducted in this area is D. L. Wilkins. L. E. Hibbs is also engaged in research in this area.


6

# Measurement of Properties

In metals and ceramics research, there is a continuing need for testing facilities to measure properties. Although the individual scientist often maintains his own facilities when his needs justify them, the Metallurgy and Ceramics Research Department has several centralized testing services to meet the more generally encountered needs of scientists. In the testing laboratories, experienced personnel make measurements and devise improved equipment and techniques.

Within the Materials and Processes Studies Section, two laboratories have been established: an *Electrical Measurements Laboratory*, which is equipped to conduct magnetic, dielectric, and electrical measurements; and a *Mechanical Testing Laboratory*, which maintains extensive facilities to measure a wide variety of mechanical properties.

## Electrical Measurements Laboratory

One service function of the laboratory is to make measurements of common magnetic phenomena over a wide variety of conditions. D-c hysteresis loops can be drawn semi-automatically with samples of several shapes and sizes. From these, one can calculate permeability, energy product, or hysteresis loss, and read directly the coercive force, induction at various fields, and squareness ratio. Saturation magnetization can be measured on samples of a particular shape.

Torque curves can be drawn semi-quantitatively. This test is a rapid means of obtaining the peak torque and peak ratio, which can then be compared to a single crystal for evaluation of the degree of texture.

D-c magnetic measurements can be made on sample shapes as a function of temperature, from that of liquid nitrogen up to 1000° C (1830° F) Curie point apparatus is also available, but is usually set up to meet the requirements of a particular experiment.

A-c magnetic test equipment includes a single-strip watt loss tester for measuring losses at various inductions, and an Epstein berth for measuring losses and permeability of a two-pound sample. An a-c loop tracer is available for plotting hysteresis loops at 60 and 420 cycles with both high and low impedance drive.

In the area of dielectric measurements, bridges are available for measuring capacitance and dissipation factors from 20 cycles to 10 megacycles at 1 kmc., 3 kmc., and 8 6 kmc. At frequencies up to 10 megacycles, these measurements can be made from room temperature to 1000° C (1830° F), and equipment has been installed to measure samples at microwave frequencies to 500° C (930° F) Automatic equipment is in use for continuously plotting capacitance and dissipation factor as a function of temperature at 1 kc. and 10 kc.

An admittance bridge is available for measuring piezoelectric properties of ferroelectric materials.

Samples for dielectric property determinations usually come in the form of ceramic buttons or disks, to which electrodes are applied on the two planar surfaces. Specific dimensions and electrode materials must be worked out to meet the requirements of the measurements. Special sample shapes are required for microwave measurements.

Resistance from $10^{-4}$ to $10^{13}$ ohms can be measured with the use of three bridges. Jigs and fixtures are available for making measurements as a function of temperature up to 1000° C (1830° F).

P G Frischmann is directly responsible for the service facilities and equipment in this laboratory Many of the technical staff are engaged in activities which are closely related to this type of work and thus serve as consultants to this laboratory area. Some of these are C. P Bean, J J Becker, G. Goodman, I. S. Jacobs, W. H. Meiklejohn, S. P. Mitoff, L. Navias, and R. H. Pry.

## *Mechanical Testing Laboratory*

Mechanical testing equipment is available to perform tensile, creep, and rupture tests at temperatures from that of liquid helium to 1200° C (2200° F), in normal and inert gas atmospheres, as well as in vacuum. Fatigue tests are made using either axial loading or cantilever-type machines at temperatures to 1200° C (2200° F) A Chevenard dilatometer is used for automatic thermal expansion work and a Burger type dilatometer for the high magnification, controlled-atmosphere tests. Hardness testing equipment includes normal Rockwell, superficial Rockwell, Vickers, and a hot-hardness machine designed to determine hardness up to 1000° C (1830° F).

Three types of tensile testing machines are used, each having unique features: a 60,000-pound machine with a hydraulic universal system for tensile and compressive tests, a 20,000-pound machine having a total travel of two inches and deformation rate from 6 inches/minute to 0.0001 inch/minute, and an Instron testing machine, which is extremely versatile and widely used. On the latter, loads from 10 grams to 15,000 pounds can be applied and measured. Predetermined loading rates from 2 inches/minute to 0.002 inch/minute are available. Sensing devices allow recording of load vs. time and load vs. strain.

Other accessories that permit a wide variety of tests include. a 5-ft. straining frame, silicone oil immersion bath (temperatures to 250° C, 480° F), extension and gage length dials and controls for automatic extension cycling, load-maintaining and load-cycling control cams, quick-change chart drive (factor of 10 speed change), crosshead and bearing take-up system to permit 15,000 lb. tension to 15,000 compression range without null point, liquid helium and hydrogen test apparatus for strip and button-head specimens, multiple furnace changer, capsule mechanisms for vacuum testing to 1200° C (2200° F), fixtures for testing of wire strip and button-head specimens in air, liquid bath and high temperature furnace (1200° C, 2200° F), bend test fixtures for all test conditions, and a 5000-lb. compression test fixture.

In the creep and stress rupture laboratory, there are 41 machines with various atmosphere controls. Temperature can be controlled to ±1° C and load to less than 0.1%.

The pneumatic and Sonntag fatigue equipment has been modified to permit testing at elevated temperatures and in controlled atmospheres. Pneumatic fatigue stress levels can be held to ±2%, and temperatures to ±5° C (±10° F) The pneumatic machine vibrates the specimen at its natural frequency The Sonntag machine is an 1800-cpm machine with a capacity of 50 lb. A BJL-1 axial loading machine is available for use at room temperature.

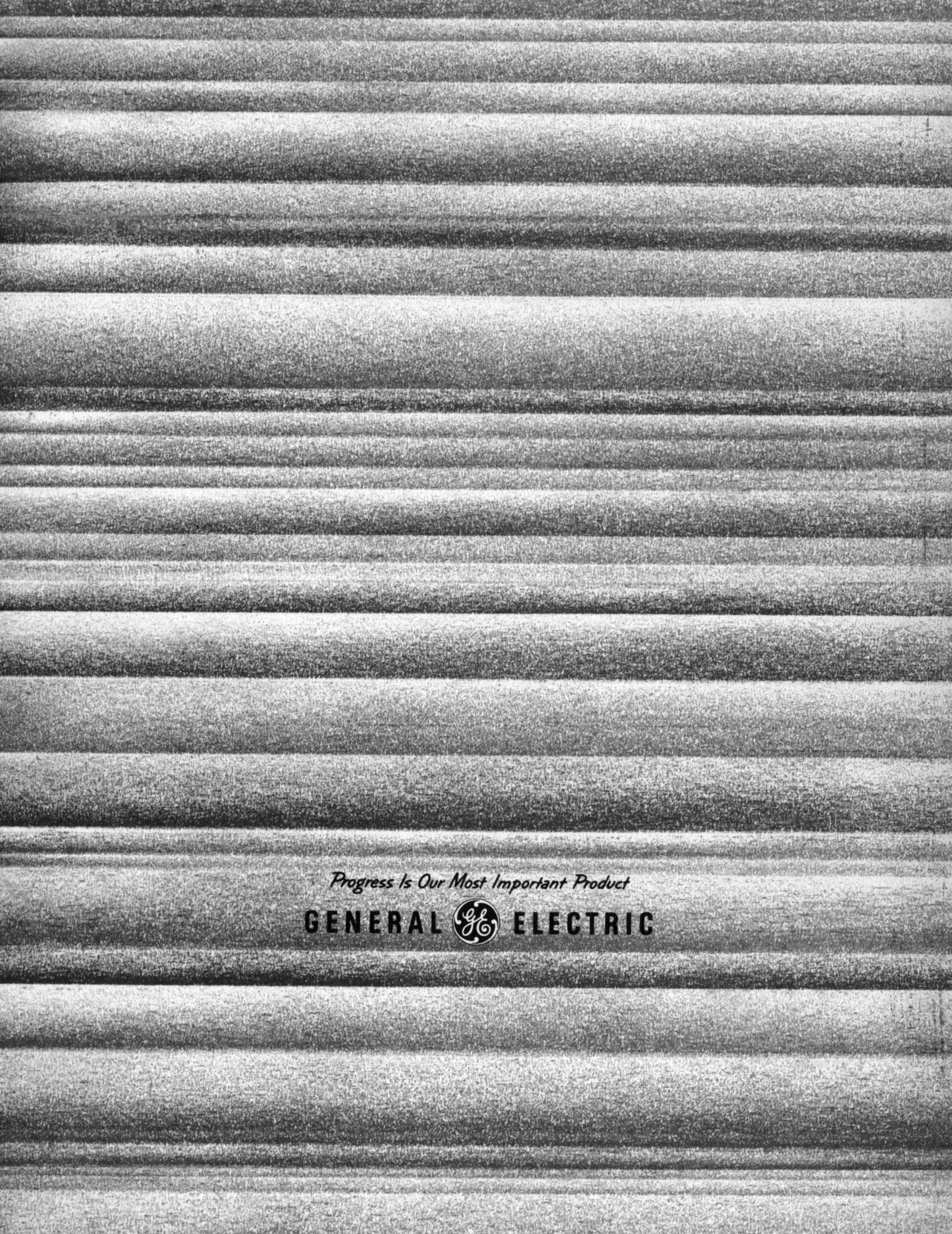
Dilatometric measurements can be made from liquid nitrogen temperature to 590° C (1100° F) in controlled atmospheres.

The use of Ni/NiMo thermocouples in many of the tests has resulted in a need for thermocouple calibration apparatus. Standard melt samples have been obtained from the Bureau of Standards and are available for general use.

Experienced personnel are available in the laboratory area for the design and construction of special apparatus, as well as for conducting tests. The area is supervised by R. F. Berning with the aid of J H. Steadwell. Many technical staff personnel are available as consultants in this area, including H. E. Grenoble, J R. Low, T A. Prater, L. F. Coffin, R. W. Guard, R. E. Keith, J. J Gilman, M. L. Kronberg, J H. Westbrook, and E. R. Stover

# *Liaison*

The Research Liaison Section (C. G. Fick, manager), has the broad function of establishing and maintaining communication between the Research Laboratory and the rest of the Company. The liaison scientists in the metallurgy and ceramics area are J. H. Keeler, D. L. Martin, and J. F. Youngblood. They are responsible for interpreting the work of the Department and for being familiar with the Company's scientific needs, engineering plans, and manufacturing methods. The liaison scientists help to establish contacts between Company components and the Research Laboratory personnel who are best qualified to provide assistance.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