Review of Metallurgical Technology

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This REPORT summarizes several technological advancements selected by the Bureau of Mines as being illustrative of the trend in metallurgy during 1960. It is not an all-inclusive list of metallurgical achievements. The authors have drawn freely from personal communications, interviews, papers delivered at technical meetings, and articles from the scientific press.

Metallurgists have contended that the significant advances in extractive metallurgy during the last decade have resulted from the availability, at a reasonable price, of large quantities of natural gas and oxygen. This stand has been strengthened by the activities of the metal-producing industries during 1960.

Steel was the word of the year. The headlines reporting reduced steel production tended to obscure the technological revolution that has been fomenting in the industry. Physical and process metallurgy have been changed and improved.

The announcement by United States Steel Corp. and General Electric Co. of a joint program to determine the feasibility of using low-cost steels in atomic reactors indicated the end of an era. Reactor materials have long been the unquestioned province of exotic metals such as zirconium, beryllium, and columbium. It has become painfully evident, however, that major material revisions must be made if atomic power is to be competitive with power produced by fossil fuel or falling water. Special steels possibly will play the key role in such a revision.

Twenty years ago, a steel with a tensile strength of a quarter million pounds per square inch was almost a rarity, and the few such steels produced were used almost entirely for piano wire and wire rope. More recently, amid the growing realization that dollars spent for steel can buy strength that more than compensates for weight, there has been a reexamination of high-strength steel for use in spacecraft, rockets, turbines, and chemical equipment. Research has shown that yield strengths exceeding 300,000 p.s.i. can be attained by selective additives or by the treatment known as ausforming. One low-alloy steel (a modified 4340) was heat-treated to an ultimate strength of 300,000 p.s.i. and still retained a fair ductility even at liquid air temperatures. This ductility would be of particular value in the structural components of missiles to withstand the stresses imposed by the very low temperatures of outer space. Cleanliness is imperative for the production of steels with strengths above 225,000 p.s.i. Under these circumstances, the dollar-a-pound added cost of
vacuum-melting can be tolerated. In this connection, the world's largest vacuum-melting furnace, capable of making 5,000-pound heats, was put into full-scale operation by Kelsey-Hayes Co. at Utica, N.Y.

Basic-oxygen steelmaking, imported to the United States from Austria in 1954, has been making giant strides toward general acceptance. The principle is simple. Jets of high-purity oxygen are directed onto the surface of molten pig iron and scrap in a pear-shaped refining vessel. Limestone and fluidizers are added to form a slag which removes phosphorus, sulfur, manganese, and silicon. The result is a high-quality, low-carbon steel made in one-half to one-third the time taken by other methods.

The idea is not new; Sir Henry Bessemer suggested the possibility of using oxygen-enriched air when he applied for the patent on his pneumatic steelmaking process in 1856. Economic utilization of the idea, however, required the realization of tonnage production of oxygen at a reasonable price. Now, with more than 400 plants producing 100 billion cubic feet annually at less than 50 cents per thousand cubic feet, the oxygen converter process for steelmaking is here to stay. The oxygen converter doubles or triples capacity by reducing treatment time and decreases investment costs materially. One report is that this process cuts capital costs from $40 to only $15 per annual ingot ton. At Kaiser's Fontana plant, output has been doubled by three new basic furnaces that cost only one-third as much as the old open-hearth furnaces.

This does not mean that all of the open hearths will be torn down in favor of the new equipment. However, some experts predict that by 1965 at least 20 percent of all steel made in the United States will be made by the oxygen-converter process. On the other hand, at least 100 open hearths have been equipped for introducing oxygen to the bath by roof lances. Advocates claim that the results are as good as with the oxygen converter and that the slightly greater operating cost is offset by the utilization of existing equipment, hence eliminating new plant construction. In addition, the Ford Motor Co. recently announced the development of a process that may help remove the threat of obsolescence from the open-hearth furnaces. Burned lime is substituted for limestone, and a mixture of natural gas and oxygen is introduced into the bath through lances. The thermochemical reactions during the initial scrap-melting stage are so increased that production rates can be doubled or tripled, Ford reports. Many producers are dubious about the economics of this technique.

One disadvantage of the basic-oxygen process is that the converters normally cannot handle more than 20 percent scrap in the charge, since they are dependent on hot metal as a source of heat. Occasionally, scrap steel prices plummet as much as $10 per ton, making it advantageous to use as much scrap as possible. It appears likely, then, that even though the use of basic-oxygen converters is increasing, the industry will keep a substantial number of open hearths to maintain scrap-melting capacity.

During the year introduction of fuel into the bosh of a blast furnace graduated from a laboratory technique to a plant practice. Normally, all of the heat and reducing action in the blast furnace is supplied by
relatively expensive (about $15 per ton) metallurgical coke. Injection of
natural gas or fuel oil into the hot air blast supplies some of
the heat more cheaply and accomplishes a portion of the reduction.
The chief advantages, however, stem from the resulting higher blast
temperature which effects greater furnace efficiency, higher productiv-
ity, and coke savings.

Encouraged by the successful investigations made by the Federal
Bureau of Mines in an experimental blast furnace, U.S. Steel intro-
duced natural gas into one of its big blast furnaces at the Fairless
works. Although the company has not released detailed records on
the full-scale test, it has reported that coke consumption was reduced
from 1,400 to 1,160 pounds per ton of molten iron, while iron produc-
tion was raised more than 10 percent.

The Colorado Fuel and Iron Corp. (C.F. & I.) also ran a success-
ful series of natural-gas-injection tests in one of its blast furnaces
at Pueblo, Colo. As a result, the company will convert all four of its
furnaces to natural gas. C.F. & I. uses as gas-injection rate of about
5 percent of the normal air flow rate and achieves blast temperatures
of 1,250°F.

Pittsburgh Coke and Chemical Co. tried using a 4-percent addition
of waste coke-oven gas to the air stream at its Neville Island plant.
A 12-percent boost in pig iron production and a 12-percent coke
saving were reported.

Esso Research and Engineering Co. announced that it is working
with Dominion Foundries and Oil Co. to perfect an oil-injection
system for Dominion's new $10 million blast-furnace installation at
Hamilton, Ontario. The Federal Bureau of Mines has conducted
limited experiments with injection of solid fuels. Proponents of
natural gas say that oil or coal can introduce unwanted sulfur into
the iron product and point out that in small furnace tests natural
gas injection results in efficiencies superior to those obtained by ad-
ditions of oil, coke-oven gas, or solid fuel. It is conceded, however,
that in some locations natural gas might be at an economic disadvan-
tage. However, injection of some type of fuel into the bosh of blast
furnaces probably will become a standard operating practice within
the next few years.

Linde Co., Division of Union Carbide Corp., an oxygen producer,
developed a generalized computer model of the blast furnace to
help predict the results of operation variables without costly full-
scale tests. Results of tests agree within 4 percent of the predicted
data. On the basis of its investigation, Linde claims that an easy
way to raise blast temperatures is to add oxygen to the air stream
along with natural gas or oil. C.F. & I. reports that it will try
this oxygen-fuel method during 1961.

The drive during recent years to achieve greater and greater blast-
furnace throughput has led to the use of crushed and sized burden
with pelletized fines and to the use of completely pelletized burden.
This trend has given impetus to the continued research to develop
methods of utilizing the low-grade portions of the country's dwin-
dling iron-ore reserves. Current attention is focused chiefly on the
silicious hematitic material known as jasper or semitaconite. This
material although easier to crush than the magnetic taconites, is
more difficult to concentrate because it does not respond to magnetic separation. Yet the mineral association is too intimate for the application of conventional gravity methods of upgrading.

M. A. Hanna Co. constructed a 10-ton-per-hour test plant near Cooley, Minn., to investigate the feasibility of treating semitaconites by roasting and magnetic separation. The Oliver Iron Mining Division of United States Steel Corp. also is looking into the possibilities of this treatment in a 5-ton-per-hour pilot installation completed in November at Trout Lake, Minn. The principle of magnetizing roasting has been known for at least 50 years, and the method was investigated on a pilot plant scale on the Mesabi Range in the early 1930's. Technically, the process was successful, but economically it was disappointing. Hanna and Oliver feel, however, that the process deserves a new look because of technological and economic changes.

The Allis-Chalmers Manufacturing Co.'s grate-kiln pelletizing process for agglomerating iron concentrates made its commercial debut at the new Humboldt Mining Co. plant near Ishpeming, Mich. The Humboldt plant, operated by Cleveland-Cliffs Iron Co., treats a hematite-bearing ore by grinding, desliming, and flotation to produce a plus 60-percent iron concentrate. This product is mixed with bentonite and formed into pellets in a balling drum. The green balls are dried and preheated on a traveling grate and fed into a rotary kiln for final heat treatment at 2,450° F. Less than a month after the Humboldt plant started operating, Cleveland-Cliffs (also operator of the Republic Mine) announced that the grate-kiln system would be included as part of the 900,000-ton-per-year expansion of the concentrating and pelletizing facilities at Republic, Mich.

Improvement of blast-furnace efficiency has reduced effort expended on investigations of the "direct reduction" processes, but interest in them continues. During the last 10 years, spurred on by rising costs and diminishing reserves, industry has spent millions of dollars on research to develop possible substitutes for the blast furnace. The result has been a steady parade of processes but a minimum of commercial applications.

One of the more successful processes has been operated on a 200-ton-per-day scale since March 1958 by Hojalata y Lamina, S.A. (HyL), Mexico's leading steel producer. The company began operating a second 500-ton-per-day unit in late 1960. M. W. Kellogg Co., designer and builder of the two plants, is reported to be negotiating with a Canadian firm to build an HyL plant at Fort William, Ontario. The process, a modification of the Maderas Process tested in a pilot plant by the Federal Bureau of Mines during World War II, involves a fixed-bed batch operation using reformed natural gas as a reductant.

The classic Wiberg-Söderforss process has been used commercially in Sweden since 1938 but has not found acceptance in the United States. By this process lump ore is reduced to sponge iron in a vertical-shaft furnace by a gas composed mainly of carbon monoxide. Another treatment that has found commercial favor in Europe but that has not received much attention in the United States is the 30-year-old Krupp-Renn process. Essentially, this is a semi-smelting operation, uniting ore and solid reductant in a rotary kiln.
The latest installation, a six-kiln plant at Essen-Borbeck, West Germany, has an annual capacity of 500,000 tons of “luppen” nodules containing about 92 percent metallic iron.

Several subfusion reduction processes, using variations of the rotary kiln, have been studied, but that method developed by Republic Steel Corp. and National Lead Co. has received the most notice in this country. The R–N process uses a countercurrent-fired rotary kiln and an excess of solid reductant. Even distribution of heat and controlled reduction are attained by admitting air at intervals along the ore bed. Now in the semicommercial stage, the R–N process has been used successfully since 1954 to treat 3,000-ton lots of a variety of ores.

The Höganäs process is a batch-type, subfusion method that has found limited use in producing special high-purity iron. Reduction is effected by packing ore, coke, and flux in a ceramic sagger and holding the temperature in a tunnel kiln at 2,100° F. for 12 to 36 hours. Originally a Swedish process, it was studied on a pilot-plant scale by the Federal Bureau of Mines in the middle 1940’s. Since then a plant of the Hoeganaes Sponge Iron Co. has operated at Riverton, N.J. to produce iron powder.

Of the fluidized-bed reduction processes studied, only the H-iron process, developed by Bethlehem Steel and Hydrocarbon Research, Inc., has reached commercial operation. The method requires a high-grade feed, free of sulfur and phosphorus, a high reactor pressure (500 p.s.i.) and a relatively low temperature (1,000° F.). Reduction is effected by hydrogen produced by partial oxidation of natural gas. To prevent pyrophoricity of the fine product, it is treated in nitrogen at 1,500° to 1,600° F. before exposure to air. Since early 1959, Alan Wood Steel Co. has operated a 50-ton-per-day H-iron plant at Conshohocken, Pa., to produce a special low-carbon iron powder for the powder-metallurgy market. A second H-iron plant of 110-ton-per-day capacity, was placed in operation to supply melting stock to electric furnaces at the Vernon, Calif., plant of Bethlehem Pacific Coast Steel Corp.

The Nu-Iron process, developed and piloted on 2-ton-per-day scale by U.S. Steel, is a fluidized-bed method using hydrogen as a reductant. Operating conditions call for 1,300° F. and about 20 p.s.i. pressure. The pilot plant was technically successful, but owing to the present cost of hydrogen believed to be uneconomic in the United States. A similar process, that of Esso Research and Arthur D. Little, Inc., employs a three-stage, fluidized-bed reactor with a mixture of hydrogen and carbon monoxide as a reductant. The process operates at 1,450° to 1,650° F. and at 1 to 4 atmospheres pressure.

Two new processes involving pelletizing, prereduction, and electric furnace smelting were announced by industry. The OreCarb process, developed by the Swindel-Dressler Corp., includes preheating of ore and flux, mixing with coal fines, and pelletizing in a rotating retort. The pellets are prereduced to 25 percent metallic iron content in a rotary kiln at about 1,800° F. Final reduction and smelting are achieved in a conventional electric furnace. The Dwight-Lloyd-McWane method includes preparation of ore-coal-flux nodules in a “flying-saucer” pelletizer. These are treated on a downdraft sintering
machine to obtain 50- to 70-percent reduction. Smelting to pig iron is effected in a submerged-arc electric furnace.

The Strategic-Udy process continues to attract attention. Essentially, the system comprises kiln prereduction with a solid reduction, followed by open-top electric smelting. Several projects incorporating the S–U system have been announced by industry but two are receiving more attention than the rest. Zechendorf Steel Co., a division of Webb and Knapp, Inc., has arranged for the installation of an S–U plant to treat copper smelter stag at Anaconda, Mont., for the production of semisteel with copper and zinc byproducts. The company has contracted for powder at an attractive price and reported that it negotiated contracts to supply steel to customers in the Northwest beginning in 1963. In Canada, New Mylamaque Explorations, Ltd., has contracted for Koppers of Canada, Ltd., to build an S–U plant at Kingston, Ontario, to treat a titanium-bearing iron ore; construction is scheduled for 1961.

In the United States, none of the direct-reduction processes is likely to supplant the efficient and reliable blast furnace, in spite of the high capital cost and inflexibility of operation that has earned it the name of “metallurgical monster.” Yet under certain conditions, such as low-cost power and fuel, high-cost metallurgical coke, and a local but limited market, direct-reduction processes appear economically attractive. It is not improbable that future blast-furnace production will be supplemented by substantial production from direct-reduction units.

The biggest contender with iron and steel for headlines during 1960 came from aluminum. The first news story of significance appeared in late 1959 when a chemical journal reported that the Federal Bureau of Mines “with eternal optimism” was investigating a two-stage leaching process for recovery of aluminum oxide from ferruginous bauxites.

About midyear it was reported that a plant would be erected near Powhatan, Ohio, to recover 40,000 tons of aluminum sulfate annually from coal-mine waste by a newly developed North American Coal-Strategic Minerals leach process. The ultimate aim would be to produce alumina and, eventually, finished metal. However, the perennial problem conversion of sulfate to oxide, has not been solved. Researchers of the Commonwealth Scientific and Industrial Research Organization at Melbourne, Australia, also developed an acid route to producing alumina from clays and aluminous laterites.

Industrywide interest was sparked greatly in August when word leaked out that Canada’s Aluminium Company of Canada, Ltd. (Alcan) was developing a method to eliminate the alumina-from-bauxite stage in the production of aluminum. Almost simultaneously it was announced that France’s (and Europe’s) major aluminum producers, Compagnie de Produits Chimiques et Electro-Metallurgiques (Pechiney) and Soc. d’Electro-Chimie, d’Electro-Metallurgie et des Acieries Electriques d’Ugine (Ugine) had joined forces to investigate similar processes to produce aluminum directly from bauxite. Past research to accomplish direct production always had bogged down in mechanical failures, but the dream still has persisted. Such a process possibly could lower appreciably the capital outlay for
plant construction and permit significant reduction in operation costs. The mineral industry recognized the significance of the news that Alcan and Pechiney were reinvestigating the direct-reduction routes.

Aluminium, Ltd., announced plans to construct an 8,000-ton-per-year experiment plant at Arvida, Quebec, to use its “radically new” process. The plant, due to be completed in 2 years would cost only as much as a conventional Hall plant of the same size. Pechiney and Ugine countered by revealing that they already have started construction of a semicommercial facility that is expected to be operating on a 3,000- to 5,000-metric-ton-per-year basis by early 1961.

Neither company released any details about its methods, so interested parties have had to read the recent patents and assemble educated guesses about who was doing what. Alcan probably will use a variation of the Gross sub-halide method, sometimes referred to as the disproportionation process. In brief, instead of purification in an alumina-extraction step, the metal is reduced directly from impure bauxite and distilled away from the impurities. The company has not revealed the method for reducing bauxite, but it is generally assumed that it is a carbothermic technique. The reduced mass is contacted with aluminum trichloride, (AlCl₃) at 1,000° to 1,200° C. and 1 atmosphere pressure. The volatile monochloride (AlCl) is formed, leaving the impurities behind. The AlCl is cooled in a condenser by a shower of molten metal at about 700° C., and the reverse reaction occurs—metallic aluminum and aluminum trichloride are formed. The latter is recycled. An interesting engineering feature is Alcan’s method of maintaining the 700° C. temperature of the molten metal bath in the condenser. A connecting compartment contains a floating bath of molten salt—sodium and aluminum chlorides—that absorbs heat from the metal and, in turn, is cooled by water coils.

Pechiney’s only statement about its process is that the method to be tried involves “two-stage carbothermic reduction of bauxite.” The company patents indicate that bauxite will be reacted with carbon and nitrogen to form aluminum nitride (AlN), followed by thermal decomposition of the nitride to yield aluminum and nitrogen. The second step is difficult because the nitride always is contaminated with unreacted carbon and alumina. These impurities, when present in the thermal-dissociation step, form aluminum cyanide (AlCN) and aluminum suboxide (Al₂O), both of which may react with metal vapor to form several undesirable side products. The Pechiney process meets the problem by the reaction of the nitride product in a vacuum at 3,100° F., followed by a multistep condenser system. The vapors pass through a heated graphite trap where the aluminum cyanide is removed as carbide and nitride sinter. The aluminum metal condenses in the center of a differential-temperature condenser; the suboxide decomposes to form metal powder and trioxide on the condenser walls.

However, not everyone is convinced that the Utopian route to aluminum will avoid the time-honored Bayer process for producing aluminum oxide from bauxite. Several alumina producers are spending their research and development dollars on plant and equipment improvement in an effort to increase efficiency and minimize costs.
Recent examples of these efforts are embodied in the Kaiser Alumi-
num & Chemical Corp.'s new alumina plant at Gramercy, La.

The aluminum industry always has been highly successful in find-
ing new and expanded uses for its product. Recently 5 firms an-
nounced that they have adopted all-aluminum, standard 6-ounce
containers for frozen juice concentrates to be packed during 1961
under their 12 house brands. This is estimated to be 110 million
cans or one-fifth of the concentrate industry's requirements for cans
of this size. Additional concentrates will be packed in cans with
aluminum bodies and tin-plate ends. Aluminum has entered the
can business solely because its light weight results in substantial
savings in freight. The tinplate suppliers profess unconcern about
the drop-in-the-bucket loss of business; however, there is some worry
about how far the aluminum-container trend may extend.

Copper producers, like steelmakers are investigating the advan-
tages of oxygen. For example, the use of oxygen-enriched air shows
promise in roasting sulfide ore; the operation is speeded, fuel cost is
reduced slightly, and an exhaust gas is produced that is high in sul-
fur dioxide and that is suitable for processing to sulfuric acid. The
International Nickel Company of Canada, Ltd. (Inco), adopted
oxygen roasting at its Sudbury, Ontario, plant in 1957. Kennecott
Copper Co. is making small-scale studies of oxygen-enriched air in
the reverberatory furnace to reduce the volume of waste gases and,
hence, heat losses. In Japan, the Nippon Mining Co. Ltd., is reported
to be enthusiastic about an oxygen-converter smelting operation in-
stalled at the Hitachi mine in 1958. Sulfide concentrate is pelletized
and dried. A small fraction of the concentrate is melted in a blast
furnace to form a matte which is charged with the remaining dry
pellets into a converter. Oxygen-enriched air reacts with the sulfide
with sufficient heat to enable a direct conversion of the copper
concentrate to blister copper and slag.

Removal of oxygen from molten blister copper prior to casting
into anodes has traditionally been accomplished by inserting a green
log into the refining furnace—a processing step known as poling.
Recently, the Phelps Dodge Corp. eliminated poling at its Douglas,
Ariz., plant by substituting an injection of reformed natural gas.
Kennecott is conducting research on a similar scheme that combines
natural gas and steam in a lance injection, and hopes to eliminate the
cost of a gas-reforming plant.

In 1958 and 1959 the segregation process for the recovery of copper
was studied on a small continuous basis at the Federal Bureau of
 Mines' Tucson, Ariz., Metallurgy Research Laboratory. In this proc-
ess ore mixed with carbon (coke or coal) and salt is heated in a gas-
fired kiln at 700° C. Copper, gold, and silver are reduced to the metal-
lic state and deposited on the carbon; they are subsequently recovered
by flotation. During 1960, the process was applied commercially to
a mixed oxide-sulfided ore. Transarizona Resources, Inc., treating
1.6-percent copper ore from the Lake Shore claims near Casa Grande,
Ariz., used the method successfully to produce 58- to 60-percent
copper concentrate with recoveries averaging about 88 percent. As
a result, the company is installing two new furnaces to raise plant
capacity to 500 tons per day. A segregation process pilot plant oper-
ated at Sana Roselia, Mexico, until midyear with similar results. Ninety-percent recoveries were obtained on straight oxide ores. The Lampa Mining Co., Ltd., of Peru has successfully operated a 1-ton-per-hour segregation pilot plant to recover copper and silver from a manganiferous ore containing 1 to 2 percent copper and 5 to 20 ounces of silver per metric ton. Average recoveries of 80 to 85 percent of the copper and 70 to 75 percent of the silver were reported; the concentrate grade varied from 40 to 60 percent copper and 200 to 500 ounces of silver per ton.

Beryllium continued to command the greatest interest of metals in the space-age category. Pechiney of France announced that it was prepared to supply commercial quantities of beryllium as electrolytic flake. The purity of this material was such as to command a premium price over the normal magnesium-reduced material produced by two United States companies.

The lack of transverse or biaxial ductility seriously restricts the forming of beryllium by normal methods. Hogging or machining of parts from a beryllium block is one of the most commonly employed methods, but the high-circulating scrap-load adds to the high cost of finished beryllium products. So far, neither casting nor any of the usual methods for producing semifinished or finished shapes has been very successful.

The problem of purity versus ductility of beryllium has been a moot question for many years, but this year the hopes of metallurgists that purity was the answer were raised again. Small amounts of zone-refined beryllium exhibited reasonable ductility at room temperatures.

Nationwide research was started or accentuated on such problems as the production of beryllium by the iodide process, the evaluation of beryllium metal made by various reduction methods (including the electrolytic flake produced by the Federal Bureau of Mines at Boulder City, Nev.), and the development of analytical methods for determining trace impurities in the metal. This latter point is not to be minimized because the low atomic weight of beryllium imposes several restrictions on conventional analytical tools, that is, a normal spectrographic analysis.

Demand for this metal, other than for the traditional beryllium-copper uses, came from both nuclear energy and missiles or space-flight operations. One B-70 bomber requires 900 pounds of finished beryllium parts. The Brush Beryllium Co. produced the biggest hunk of beryllium ever made in response to request for a piece approximately 6 feet in diameter and 3 feet thick and with a weight of about 9,000 pounds. There is no doubt that the reawakened interest in this light, stiff metal will lead to extensive examination of the extractive metallurgy processes and to a critical appraisal of the beryllium resources of the world.

In the field of high-temperature-strength materials, two columbium-base alloys were developed that are regarded as having outstanding characteristics. Armour Research Foundation announced one containing 20 parts vanadium, 5 parts titanium, balance columbium; Union Carbide Metals Co., Division of Union Carbide Corp. made one which was essentially 50 weight-percent each of vanadium and columbium. Both showed strengths of the order of 35,000 p.s.i. for
100 hours at 2,200° F. Although such alloys exhibit excellent chemical corrosion resistance properties, they still deteriorate rapidly at high temperatures. Most of the applications at the extremely high temperatures encountered in rocket propulsion belong to the realm of tungsten and its alloys, so the best possibility for use of these vanadium-columbium alloys is in aircraft turbines. However, they are up against fierce competition by the nickel- and cobalt-base “super-alloys” that have been developed in the last few years.

The nickel-base alloys are essentially a nickel-chromium solid solution with addition of high-temperature strengtheners such as tungsten, molybdenum, and vanadium or columbium. The cobalt-base series contains 20 to 25 percent chromium, about 1 percent carbon, and a carbide precipitant. Over a dozen super alloys are available commercially that are capable of operating for 100 hours at a 15,000-p.s.i. stress level. Five of these can tolerate similar conditions at 1,800° F. or above.

Titanium the original glamour metal of the era, saw a little of the tarnish removed from its record this year.

The revival of the B-70 bomber program and the continued missile development combined to bring about a mild recovery in the ailing titanium industry. New and better alloys based on higher additions of vanadium and chromium extended the usefulness of the metal to higher temperatures and new uses. There were no radical changes in the production or fabrication of titanium, and the price of sponge seems to have reached a low of $1.60 per pound.

Most researchers realize that the lead time between discovery and production is decreasing rapidly; this is well illustrated by the case history of synthetic diamonds. Research, started in the early 1950’s culminated in an announcement by General Electric Co. (G.E.) in 1955 that synthetic industrial sand-size diamonds were available for sale. During the past year the wraps of technical secrecy were removed to disclose that a metal catalyst is the key to producing synthetic diamonds in available equipment. Without the catalyst, pressures of 3 million p.s.i. and temperatures above 3,500° C. (7,000° F.) would be required; with the catalyst, diamonds are grown at pressures of the order of 1 to 2 million p.s.i. and at temperatures of 1,200° to 2,500° C. (2,200°–4,400° F.). In practice, pressure from hydraulic jacks is transmitted to a pressure cell of pyrophyllite by tungsten carbide-faced dies. The high temperatures are attained by passing high-amperage current through a carbon or metallic resistance.

Only 5 years after the original G.E. release, De Beers Consolidated Mines, Ltd., the world’s largest producer of natural diamonds, announced that it had its own diamond-making process. A Dutch firm of diamond cutters was reported to have perfected still another process. In effect, what required a century to realize initially took only 5 years to parallel.

Diamonds were not the only material studied in these new high-pressure, high-temperature machines. Battelle announced that it had produced a new form of uranium oxide (a gamma U308) in such a device. Dr. H. Tracy Hall, one of the inventors of the original G.E. process and now Director of Research at Brigham Young Univer-
sity, announced that the compressive strength of silicon carbide subjected to 200,000 p.s.i. and 10,000° C. improved 30-fold. He also reported having made chromium and manganese oxides and zirconium and titanium borides with similar high compressive strengths. The equipment could handle 10 cubic centimeters of material, and Dr. Hall believed this could be readily scaled up to 250 cubic centimeters.

The establishment of three Materials Research Centers by the Department of Defense was destined to widely affect U.S. metallurgy in 5 years or more. Centers were established at Cornell, Pennsylvania, and Northwestern Universities, and five more may be established in 1961. About $15 to $17 million went into the initial grants; operational funds are guaranteed for 4 years. In 1959 Congress authorized the Atomic Energy Commission to construct two similar centers, in addition to existing centers at California and Iowa State.

The establishment of such centers was dictated by the reasoning that this country desperately needs materials engineers and that these can be obtained only by training men in the combined fields of physical metallurgy, ceramics, plastic chemistry, and solid state physics. Only time can tell whether this fusion of disciplines will accelerate the solution of the materials problems of the space age.