

MAGNESIUM

SOURCE

It is axiomatic that man develops for his use those things which are easy to produce and are most plentiful. As his mental capacities have increased, difficult projects have become easier to develop. This is the story of magnesium.

There are only two structurally important metallic elements in the earth's crust more plentiful than magnesium. These are aluminum and iron. The only other metals more plentiful are calcium, sodium and potassium.

Magnesium is chemically one of the most reactive metals. It is never found as a metal but always combined with other elements, including oxygen, chlorine and combinations of these and other elements. Its reactivity is the reason why this very plentiful element has not been produced as a metal earlier in civilized history, and is also responsible for certain erroneous ideas which tend to limit its commercial use today.

In nature, magnesium is found in many forms. The most important of these, with the average content of the element, are listed in Table No. I.

All of these sources are to be found in the United States, most of them in large quantities. At the present time, all of these materials can be used for the production of magnesium. Five of them are being used either directly or indirectly.

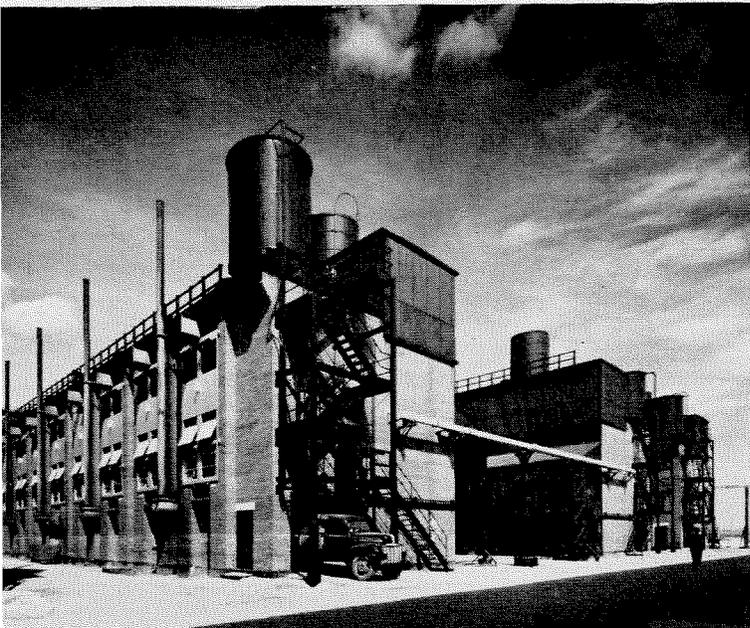
In the relation between sources, distribution of raw materials and processes for production, magnesium stands unique among all metals in world mineral history. It is more universally distributed throughout the whole world than any other metal—its presence in sea water has taken care of that. And even in the present somewhat embryonic state of the development of the industry, magnesium can be produced more cheaply from the widely disseminated and dilute sources such as dolomite and sea water, in spite of the fact that it is

AT LEFT:

FIG. 1—(Upper) Magnesium cells at Defense Plant Corporation's plant at Austin, Texas, operated by International Minerals and Chemical Corporation. The plant produces this lightest of all structural metals from dolomite by the Dow process. The current used for refining the metal is carried through and between cell buildings by a series of bus bars, some of which can be seen in the right foreground. The cell buildings are brick and steel framework and have superstructure covered by asbestos-protected metal.

FIG. 2—(Middle) Dolomite, which serves as the basic ingredient for production of magnesium at Texas plant, is received, crushed and burned as it goes from right to left through the facilities shown here. Note the length of the rotary lime kiln which extends from the base of the crushers to the reinforced structure on the left.

FIG. 3—(Lower) The facilities for converting dolomite into metallic magnesium at the new Texas plant are being used in the open wherever possible. Where character of operations has made it necessary, certain areas of the multi-story reinforced concrete structure have been enclosed with siding of corrugated asbestos.



Metal of the Future

BY PAUL D. V. MANNING

TABLE I

Source	Average Per Cent of Magnesium
Dolomite.....	13.8
Serpentine.....	25.9
Olivine.....	28.4
Magnesite.....	28.7
Brucite.....	41.6
Langbeinite.....	11.6
Sea water.....	.13

present in sea water in the most dilute form in which it is found. About 200,000 gallons of sea water are required to produce one ton of metal. This circumstance is completely novel in the history of metals, having never been met with before. Keep this in mind while we consider one other phenomenon.

In the industrial development of the world, man has always taken the most concentrated deposits of minerals, converted them to his use, and then by his own and natural processes, allowed them to return to the universe in such extremely dilute forms as to make it doubtful that the same metal will ever be recovered. In other words, the normal cycle has been to take the most concentrated form available, purify and use it, and then to allow it to return to nature. As an example, iron is produced from the richest ore deposits, and made into useful objects which immediately begin to rust away, the ultimate process being to deconcentrate an ore to the point where it is scattered beyond use.

But magnesium, after only a few years of commercial production, is being produced from the most dilute form in which it is found in nature, a source which is also the most widespread throughout the world. The development of the magnesium industry is the most outstanding illustration of how an industry should grow.

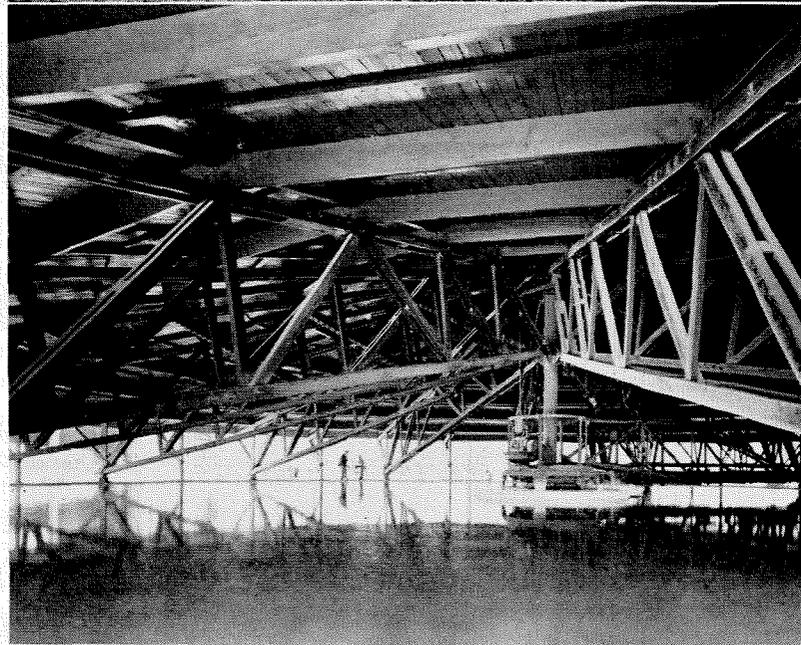
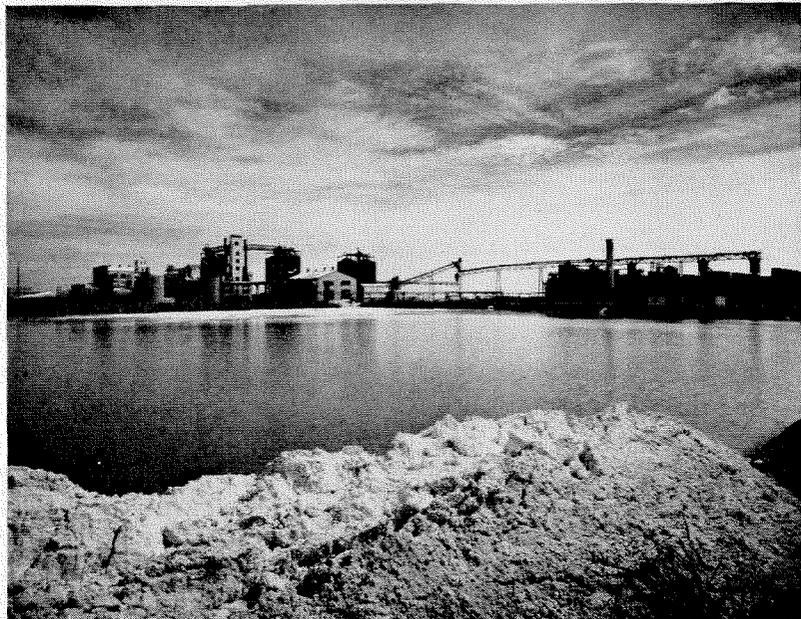
Here we have a metal produced from a source widespread throughout the world, a source that is inexhaustible, right at the start of the development of its usefulness. True, its properties are not all that we would set up if we were to plan our ideal metal, but such an ideal exists in no other metal. But as we learn how to handle magnesium, alloying it with other metals to produce the physical and chemical properties we want, and as we

AT RIGHT:

FIG. 4—(Upper) Looking across a waste disposal pond toward the new shelf dryers (center) and magnesium cell buildings (right) at the new magnesium plant in Texas.

FIG. 5—(Middle) This 100-foot Dorr tank, which functions as a magnesium hydrate thickener, is covered by a wooden roof with a single center support and timber trusses extending from it to the reinforced concrete rim of the tank.

FIG. 6—(Lower) Magnesium chloride cell feed produced from dolomite is distributed from shelf dryers to the cell buildings by means of an overhead conveyor which feeds directly into large bins located above the end of each cell block. The unit shown in the extreme right absorbs and treats the hydrochloric acid derived from the electrolytic refining process.



continue to improve the processes by which it is made, we may expect magnesium to play a part in human life not heretofore found for any other metal.

EARLY DEVELOPMENTS

Sir Humphry Davy first made the metal, in 1808, using potassium vapor. This process of course has not been used outside of the experimental laboratory. Magnesium metal remained a chemical curiosity for almost 50 years, until 1857, when small scale production was begun in France. Seven years later a small plant began operation in England, and about the same time its manufacture was initiated in the United States. Almost the entire production went for flashlight purposes. In this country the manufacture was discontinued in 1892. All of these initial operations were of no importance and it may be said that the industry remained undeveloped until 1896, when the Germans began making the metal on a larger scale, passing an electric current through molten magnesium chloride, a by-product from their operation of the Stassfurt potash and magnesium deposits.

Although the larger proportion of the world's magnesium metal is still produced in a manner that does not differ essentially from the German process, practically the entire credit for the progress of the industry in the United States is due to Dr. Herbert Dow, his associates, and the organization they developed. Dr. Dow noted that the salt brines from wells near Midland, Michigan, contained magnesium chloride and his painstaking work resulted in the commercial production of magnesium.

The story of the industry resulting from this work is one of the most interesting in the history of American enterprise. Established in 1890, the Dow Chemical Company has grown to one of the major chemical producers in the United States, with net sales of nearly \$47,000,000 in 1941. It may be said that this entire development grew out of Dr. Dow's effort to produce magnesium metal from the Michigan brines.

In 1915, the price of the metal was \$5 per pound. United States production in 1918, the final year of the first World War, totaled 142 tons. By 1925, this figure had dropped to 122 tons but the price had been reduced to \$1 per pound.

Although the total production in 1941 was about 17,000,000 pounds, such great progress has been made by the cooperative efforts of those now constituting the producing industry that when present installed capacity is realized, the total annual production in this country should exceed 500,000,000 pounds, an increase of about 30 times the 1941 production.

PRODUCTION PROCESSES

All of the processes in use may be classified into three general methods. Most of the production is accomplished by means of the action of an electric current on melted magnesium chloride. The chloride is decomposed to form melted metallic magnesium and chlorine gas. The former is cast into pigs. The latter is used to produce additional magnesium chloride, using as a raw material, dolomite, sea water, or magnesite. This process is used in the plants operated by the Dow Chemical Company, International Minerals & Chemical Corporation, Diamond Alkali Company, Mathieson Alkali Works and Basic Magnesium.

A second process, depending for its operations on the reduction of magnesium oxide by carbon, was developed by Fritz Hansgirg in Austria. In this process, carbon and magnesium oxide, the latter produced in its American adaptation from dolomite and sea water, are heated together in an electric furnace. There results a gas mixture of carbon monoxide and magnesium vapor. This

is shock cooled, that is, cooled so rapidly that the magnesium is condensed to fine particles of dust before the reaction can reverse to again give carbon and magnesium oxide dusts, which would result if the cooling were carried on more slowly. This cooling was accomplished by refrigerated hydrogen in the original Hansgirg process, but at Permanente, California, where the American modification is in use, the furnace gases are chilled by injection of natural gas, which, after separation of the condensed magnesium powder, is used as fuel.

In a process devised by Dr. H. A. Doerner of the Pullman, Washington, Station of the U. S. Bureau of Mines, the shock cooling is accomplished by the injection of an oil spray which vaporizes and chills the magnesium vapor.

Magnesium dust produced in the Hansgirg process is quite pyrophoric and must be handled carefully. It is distilled into crystals, which are then melted and cast in pigs.

Another process is being operated on a relatively small scale. This process has been used in principle with different reducing agents in France and elsewhere before the war. It consists essentially in heating magnesium oxide with reducing agent in a vacuum retort, at one end of which is a condenser. In the United States, the reducing agent used is ferrosilicon, calcined dolomite providing the magnesium oxide. The magnesium vapor solidifies on the condenser as magnesium crystals. It is removed by opening the retort. The retort of usual size produces about 70 pounds of metal in eight hours.

Although the Dow Chemical Company is the first commercial producer to start with sea water and make magnesium metal by carrying out the process entirely in one establishment, sea water has been used in this country for many years to produce magnesium hydroxide on a large scale by Marine Magnesium Products Corporation, operating on the shores of San Francisco Bay. Starting several years later, the California Chemical Corporation, now owned by Westvaco Chlorine Products, continuously produced artificial dead burned magnesite from bitterns resulting from the solar evaporation of sea water in the production of salt near San Francisco.

In these two processes, as in the Dow sea water operations, magnesium hydroxide is precipitated from sea water by adding burned lime to it. Both the Westvaco and Dow plants use oyster shells shoveled from marine deposits in bays as a raw material for making the lime. The process developed and used by Marine Magnesium Products Corporation uses a good grade of lime and produces a quite pure magnesium hydroxide.

Working in England, H. H. Chesny, formerly with the Marine Magnesium Products, utilized burned dolomite and sea water to precipitate magnesium hydroxide, this process having the advantage that the magnesium oxide in the burned dolomite adds to that made from the soluble magnesium salts in the sea water. A very good grade of magnesium hydroxide is produced, and in England this process was used to produce magnesium hydroxide, which was sold as a raw material used in making metallic magnesium some time prior to the Dow sea water operations.

The Chesny process is now in use in this country on the Atlantic Coast, producing magnesium oxide for refractories. On the Pacific Coast, magnesium hydroxide lately has been produced from sea water and dolomite, as a raw material for the Kaiser magnesium operations.

International Minerals and Chemical Corporation has developed a new process which is in successful commercial operation in Texas, utilizing dolomite for making

magnesium hydroxide. The primary chlorine requirements for production of the magnesium chloride from this magnesium hydroxide are produced from langbeinite and potassium muriate, mined and processed near Carlsbad, New Mexico. The complex saline brines produced in the Carlsbad potash operations are purified and used to make carnallite, which is then used to make magnesium chloride.

Both the Mathieson Alkali and the Diamond Alkali processes use dolomite, the primary chlorine being obtained from calcium chloride, resulting as a by-product from the manufacture of soda ash by the ammonia-soda (Solvay) process.

Basic Magnesium raw material is obtained as magnesite from the Nevada deposits, the primary chlorine being produced by electrolytic cells.

It will be seen from the above that magnesium oxide in some form is the one primary raw material for all magnesium production in this country, with the exception of part of that produced by the Dow Chemical Company from the Michigan brines.

PROPERTIES, COMPARISON, USES

Magnesium is a silvery appearing metal. It is both malleable and ductile and so light that a cubic foot of it weighs only 109 pounds. On an equal volume basis, it weighs only two-thirds as much as aluminum, one-fifth the weight of nickel, and one-fourth the weight of copper. It is interesting to compare the selling price of magnesium with that of some of the more common metals on several different bases of weight, mol and volume. These figures are given in Table No. II using the present prices. The term "mol" expresses the figures giving weight and cost in ratio of the molecular weights.

These figures are rather startling to those who have thought magnesium an expensive metal. Observe that on the basis of cost per cubic foot, magnesium is more expensive than iron only—cheaper than aluminum and about one-third as costly as copper, while zinc, a metal used for galvanizing steel sheet, wire, etc., sells for nearly 15 times the price of magnesium!

What then needs to be done to get magnesium into the common uses of the metal field? First, we must develop alloys that are stronger and have the physical properties needed to meet the required service conditions. This work has really only just begun.

Metals now commonly alloyed with magnesium include aluminum, manganese, cadmium, zinc and tin. Just as in the early days of the development of steels, no steel could be made that would withstand the pressures required to permit the use of our present high-powered propellant powders in guns or to meet the conditions imposed by our modern internal combustion engines, so we may confidently expect that magnesium alloys will be developed that will give us the strengths required without losing the advantages of light weight. Twenty years ago who would have expected to have steel with a tensile strength of 190,000 pounds per square inch? Ten years ago we could not make a fusion weld of magnesium. We have all of these things and more today.

Magnesium and its alloys machine well, are ductile, malleable, can be cast in sand, permanent molds or die cast, can be extruded and rolled as well as hammer and die forged. A number of the alloys respond well to heat treatment.

A recently-developed simple process permits a satisfactory fusion welding even of thin magnesium sheets without the use of a flux. In this method, which is an invention of engineers of Northrup Aircraft, Inc., and the Dow Chemical Company, a tungsten electrode is used with a direct current electric arc, the current passing

TABLE II

Metal	Molecular Weight	Pounds per Cubic Foot	Cost per Pound	Cost per Mol	Cost per Cubic Foot
Iron	56	450	\$ 0.01	\$ 0.56	\$ 4.50
Copper	64	556	.12	7.68	66.72
Tin	119	456	.52	61.88	273.12
Zinc	65	443	.75	48.75	332.25
Magnesium	24	109	.205	4.92	22.35
Aluminum	27	165	.15	4.05	24.75

TABLE III

Metal	Weight per Mile of No. 10 Wire (lbs.)	Base Cost of metal alone per mile of No. 10 Wire	Relative Electrical Conductivity Silver = 10
Iron.....	134.0	\$ 1.34	1.62
Copper.....	165.9	19.90	9.55
Tin.....	136.0	70.80	1.42
Zinc.....	132.0	99.20	2.53
Magnesium.....	32.5	6.67	3.62
Aluminum.....	49.1	7.38	6.18
Nickel.....	157.1	55.10	2.35
Lead.....	211.5	137.10	0.74
Silver.....	195.3	1093.88	10.0

between the magnesium and the electrode. At the same time helium gas pours from the electrode holder, completely blanketing the work and the electrode itself. The equipment is even more simple than that required for the atomic hydrogen welding process in use in welding steel. Helium is inert to magnesium. Its use prevents oxidation and, since no flux is required, the resulting weld is no more subject to corrosion than is the purest metal.

In addition, the use of helium tends to prevent overheating of the metal because of the high specific heat of the gas. For average medium work, 200 cubic feet of helium will give about 35 hours of welding.

In the second place, as an aid in speeding the development of the magnesium industry, we may list the possibility of alloys with lower electrical resistance. Table No. III gives the relative electrical conductivities of several of the common metals in terms of that of silver, which is given as 10.

A magnesium wire measuring twice the circular mils of a given copper wire will have only one-third more resistance than that of the copper wire. It will weigh only 39 per cent as much and the cost of the metal alone would be about 33 per cent less at present prices. As yet we are not ready for high tension transmission lines and bus bars of magnesium alloys. There are several problems to be solved. But there is an eventual possibility of these developments. Aluminum has already been used for both purposes.

Third in the list of major developments required to increase the scope of usefulness of magnesium is the improvement of its resistance to corrosion. Progress along this line is being made by alloying and by protective coatings. Magnesium, unlike aluminum, is highly resistant to alkalis but not to acids or to salts of acids. This explains its corrosion by salt water. However, other metals present in magnesium alloys change the action of many corrosive substances. Protective coatings applied either as by pickling, in which the metal itself plays a part, or as a lacquer or paint are becoming increasingly efficient and it is to be expected that continued progress in these lines will make it possible to use magnesium in places not now feasible.

Pure magnesium metal, while it loses its shine in air, does not otherwise corrode unless salt or acids are present.

The fourth requisite in the magnesium program is the

education of the prospective magnesium user to overcome his fears of magnesium fires. Many years ago both gasoline and kerosene were thought to be so dangerous that neither would ever be commonly used. Today the inflammability of gasoline has been greatly increased and yet it plays a very important part throughout the entire daily lives of all of us. Dangerous? Yes, but only under certain conditions and certainly not when one knows how to handle it.

Most people do not realize that in every magnesium incendiary bomb is some thermite, a mixture of aluminum powder and iron rust. This mixture is first ignited and it is this that sets fire to the magnesium. Magnesium will burn but only if heated to 1,250 degrees Fahrenheit in the presence of air or an oxidizing material.

As to the fields where magnesium may be expected to make its first showing after the war, the following appear most worthwhile considering:

Lightweight household appliances, vacuum cleaners, sewing machines, refrigerators, furniture, folding tables, washing machines, ironers, dish washers and driers, clothes driers, ventilating and other fans, small motors, can all be made of greater usefulness with magnesium. Window shades, screens and frames for the windows themselves are possibilities.

In the field of transportation, by airplane, by automobile and by train, magnesium undoubtedly will fill a tremendous demand. Its use in airplane construction is increasing, and the per cent of the total weight of the plane that is magnesium continues to increase in present manufacturing practice. The advantages in airplane, rail and ship transportation obtained by use of light metals and alloys are quite obvious.

In the field of automobile manufacture, with continued high gasoline taxes it seems quite probable that the need for higher gasoline mileage to guarantee economical transportation will require lightweight cars.

In commenting on various possible uses for magnesium, Dr. Colin G. Fink suggests the use of magnesium for coins. Speaking of magnesium instead of copper pennies, Dr. Fink says, "There are approximately 1,000,000,000 copper pennies in circulation equivalent to 6,600,000 pounds of copper. The peacetime production cost of copper is six cents per pound as against about 14.5 cents for magnesium. For the same sized coin, the magnesium penny weighs but one-fifth the weight of the copper penny. In other words, 1,320,000 pounds of magnesium pennies at a base cost of \$191,400 would replace 6,600,000 pounds of copper pennies at a base cost of \$396,000. There is only enough copper in the world to last industry 40 years as against 10,000 years for magnesium."

In considering the possible future uses for magnesium and light metal alloys, it is difficult to find applications in which they cannot serve.

The Electron Microscope

(Continued from Page 13)

positive means of identifying the material. The microscope combined with the diffraction attachment becomes a research tool that is particularly advantageous for pigments, dusts, and various chemical preparations. Its usefulness in varied fields of research may lead in the future to an instrument in which individual particles only 50 atoms or so in diameter can be singled out of a sample of powder, photographed and then identified by "Submicroscopic chemical analysis," either by the diffraction method or by an analysis of the velocity of the electrons that emerge from the particle.

Windowless Factory

(Continued from Page 8)

volt equipment is supplied through 50 kilovolt-ampere, 440-120/208 volt, three-phase, air-cooled transformers installed at regular intervals throughout the plant. In general, each serves three multibreaker panel boards from which current is extended by conduit or through the underfloor duct system which is extended throughout most factory areas. Balance is maintained as closely as possible between phases.

CONCLUSION

To evaluate a "controlled conditions" plant properly in relation to traditional factory construction requires exhaustive analysis beyond the scope of this article. Certain advantages, however, are obvious. First, product quality and uniformity have a better chance of being maintained at a high level. Second, and especially in a severe climate, employee comfort and efficiency are greatly improved. Third, inaccuracies due to expansion and contraction can be held to a minimum. This is very important as assemblies of light metals get larger and larger, and for accurate machining of large light structures. Fourth, corrosion from both atmospheric conditions and handling is reduced.

The only serious disadvantage which has become apparent is that of increased investment and operating cost. This is a disadvantage only when full production is not maintained. In this respect it may be compared with a high-production special machine tool versus a less expensive but more common type.

For mass production, the special tool and the "controlled conditions" factory both have an outstanding place in the future of industrial development.

The Month in Focus

(Continued from Page 3)

that the public may be assured of safety. Another civil engineer may be concerned with the construction of channels, involving a knowledge of hydraulics as well as features of construction. Such differences may be cited in other branches of engineering. Thus it is apparent that the complete unification of engineers into a single professional group is difficult and that there are major barriers to the realization of this ideal. Some fields of engineering have been legally professionalized by several states in requiring licensing of those who wish to practice publicly. It is probable that more extensive developments will take place along these lines which will place the various fields of engineering on a professional basis in the eyes of the public.

Those who read "Mechanical Engineering" may have noted in the May issue the article by Hans Ernst on "High-Speed Milling with Negative Rake Angles." These developments originating on the Pacific Coast have led to greatly increased rates of production in milling operations. In this work, carbide-tipped cutters have been and are being operated at cutting speeds in excess of 500 feet per minute and with unusually high feeds. Some of the advantages obtained with these methods are higher production, improved finish, and less distortion of work due to heat. Naturally, these developments present many problems which require research to establish the soundest procedures. As a part of a program of studying milling operations under these new conditions, California Institute of Technology is conducting certain studies which will be interesting to watch. In his article in "Mechanical Engineering," Hans Ernst presents some interesting data in this connection.