AVAILABILITY AND INTERCHANGEABILITY OF METALS

Earl T. Hayes

Materials Associates

ABSTRACT

Materials interchangeability is frequently discussed as a method for alleviating shortages. A designer, faced with a scarcity of any desired material, finds a more plentiful alternative to perform the task required. Recycling, conservation, and stockpiling are other policy options frequently considered along with interchangeability. Descriptions of substitution frequently oversimplify the process of replacing one material with another. The technical function to be performed must be defined with precision. Only then can the designer proceed--if at all. Following redesign, often at some sacrifice of product performance, new knowledge of production processes and problems must be accumulated. The example of cobalt--used in alnico magnets, superalloys, cemented carbides, tool steels, ceramics (as pigment) and paints--demonstrates the problems associated with substituting for such specific functions as binding, wear resistance, and drying. Cobalt, a metal used in relatively low tonnages, is a high performance mineral for which substitution and replacement is difficult, complex, and time consuming at best. Thus, in order to achieve any possibility of finding alternatives without severe economic disruption, stockpiles should be built to provide the time necessary to create useful alternative materials.

Introduction

Materials and minerals experts, upon examining either present or potential shortages of minerals and metals, refer to the principle of substitution or interchangeability as a solution. Aluminum replaced copper in long lines for electricity transmission. Plastics are replacing die cast zinc in automobile parts. Examples abound. Substitutions based upon price--or cost effectiveness--in the performance of a specific function have occurred throughout the history of industry. As a design engineer finds that any given material is either unavailable or inordinately costly, he seeks out alternative substances or ways to accomplish the task at hand.

One common lament expressed by materials experts through the years has been that the design engineer didn't consult them soon enough. In the coming years resource people will have their own set of stories about engineers who recommended specific materials without consulting any one about availability. As a case in point, a large American company spent four years developing a thermoelectric refrigerator only to find out at the critical production decision point that there simply wasn't enough tellurium available for the Bi-Te heart of the machine.

The year 1974, with one of the worst materials shortages of any non-war year, impressed the American public that there are capacity constraints and time lags in the supply system of many commodities and even finite limits to specific resources. The production of 11 million automobiles placed severe demands on such items as steel, copper, zinc and lead. A cut of 7 percent in petroleum supplies temporarily demonstrated the vulnerability of the U.S. to foreign supply sources for critical materials. The emergence of cartels like the Organization of Petroleum Exporting Countries (OPEC) which quadrupled the price of foreign oil, the International Council of Copper Exporting Countries (CIPEC) which tried unsuccessfully to control copper prices, and the bauxite cartel led by Jamaica's six-fold increase in severance tax which resulted in a 5% increase in the price of aluminum, came in rapid succession. These were all front page newspaper stories.

The American consumer was hit in a place where he reacts most strongly--the pocketbook. Gasoline went from 35¢ to 65¢ a gallon. Zinc prices spiralled from 30¢ to 90¢ a pound. Copper prices rose from 50¢ to $1.50/lb. The price of automobiles and other consumer products jumped proportionately.

This paper will present a general picture of United States metal use and availability, and some of the steps that must be taken to minimize against future economic disruption. It addresses the naive and erroneous idea that a plentiful material can be immediately and universally substituted for one in short supply. It points out that the only substitution that can be made in our industrial complex is an interchange based on specific functional performance; and this becomes the basic bargaining issue of any change in commodity flow. This is always initiated on the production end by an engineer with a supply problem.

Metals Use

In the boom year of 1974 the United States consumed over $45 billion worth of metals, of which iron and steel accounted for approximately $30 billion. In very round figures the next five were aluminum, $5 billion; copper, $2.5 billion; and zinc, lead and nickel, $0.8 billion each.

Table 1 shows the consumption of 21 metals in 1974.

Table 1

Quantities of Metals Used in the United States in 1974

Metal	Tons	Domestic Availability (Percentage)
Raw Steel	145,000,000	60
Aluminum	6,300,000	10
Copper	2,200,000	90
Manganese	1,500,000	0
Lead	1,600,000	90
Zinc	1,300,000	50
Nickel	210,000	10
Chromium	560,000	0
Magnesium	130,000	50
Molybdenum	76,000	100
Tin	64,000	0
Titanium	27,000	0
Tungsten	16,300	50
Vanadium	14,400	75
Uranium	11,900	80
Cobalt	9,400	0
Silver	7,000	25
Tantalum	1,200	0
Beryllium	210	100
Gold	150	25
Platinum	20	0

Source: Commodity Data Summaries, U.S. Bureau of Mines, 1976.

Strategic Metals

In peacetime, Americans paid little attention to sources of supply until the last few years. As a result of events described earlier, many resource papers developed their own priority of importance or strategic ranking of materials. Six of these rankings (Secretary of Interior's 1977 Budget Study, Minerals Availability System, U.S.B.M., BuMines Study of Strategic Minerals 1974, Battelle Study SMMIP, OTA Accessibility of Minerals Study 1976 and General Accounting Office check list) were analyzed by Mr. Al Knoerr of the Bureau of Mines to produce the following composite ranking:

Table 2

Importance or Strategic Ranking Composite

Rank	Material	Rank	Material
1	Aluminum	11	Tungsten
2	Chromium	12	Fluorspar
3	Nickel	13	Lead
4	Tin	14	Columbium
5	Manganese	15	Gold
6	Platinum and palladium	16	Copper
7	Cobalt	17	Mercury
8	Iron	18	Silver
9	Zinc	19	Phosphate
10	Titanium	20	Lead

Source: Personal communication, Al Knoerr, U.S. Bureau of Mines, Washington, D.C.

The stark picture that emerges from Tables 1 and 2 is that the U.S. produces only 10 percent each of two, 50 to 60 percent of zinc and iron and none of the other of six. Although the U.S. has substantial domestic resources of aluminum, zinc, iron, manganese and titanium that could be developed at costs 20 to 400 percent above current trade quotes, this country simply does not have occurrences of tin or platinum. Cobalt, nickel and chromium resources are so limited that they could not be expected to provide much over 10 percent of our requirements even under extreme supply disruption conditions.

Because the U.S. uses over 80 mineral and metal commodities in supplying its complex industrial society, there is no simple across-the-board measure to deal with materials shortages. They must be dealt with on a case-by-case basis with each case being further subdivided according to any metal's specific intrinsic or functional properties. In the past this country has tried a number of options ranging from classical economics through domestic development of mineral resources, conservation, technological development, stockpiling, and interchangeability.

Many persons involved in minerals resource and extraction are hard put to accept the basic economic premise that the law of supply and demand will take care of all shortage problems. Without a constant search for new ore deposits, without technology improvement of extraction methods, the costs of many common materials would be several times their present base. The copper developments in Arizona of the last twenty-five years well illustrate this point. The grade of ore in the United States has gone down, production has more than doubled but in terms of constant dollars, the cost of copper remains about the same.

U.S. industry constantly lives between the options of buying foreign minerals like iron and aluminum ores or developing its own resources. This country has ample clay deposits to satisfy the alumina needs for fifty years or more at costs of one-fourth more than present foreign sources. It has ample iron ore reserves to satisfy all iron and steel requirements at near current costs for many, many years. In both cases plant investment costs outweigh the advantages of a complete domestic production capability.

Potential Solutions

Conservation is offered as one solution to supply problems. At first glance recycling may appear to be the answer to all durable materials supply problems. At some equilibrium state everything that has ever been constructed finds its way back into the production cycle and is born anew. Under such ideal conditions basic industries have to supply new minerals only make up for rust and dust losses. This principle works relatively well for lead due to the present patterns of its use. Over 50 percent of lead is used in batteries, and most of the 120,000 scrapped each day return to the cycle. However, not one iota of the 16 percent of the nation's lead used in gasoline is recovered. Another approach to conservation would be to make automobiles with a 16-year life instead of their present 8. Lacking a complete technological and economic assessment of all the ramifications of this action this country must continue its present use and dispose pattern.

New technology, as another option, has alternately solved and created demands for different mineral resources. The case of World War II development of synthetic rubber is well known. The real significant finding here is that natural rubber could not undersell the synthetic when the war was over. The irony is that synthetic rubber production is based on oil and natural gas. Now 30 years after that interchange this country faces dwindling supplies of petrochemicals. The synthetic diamond development of General Electric over 20 years ago is another excellent example of creating a domestic source of a critical material. Last year this nation produced four tons of industrial diamonds.

Stockpiling, another option, has been used off and on for 35 years. Up to this point it has always been called a strategic stockpile but in latter years its use has bordered on that of an economic stockpile. Considering the fact that 85 percent or more of the Free World's cobalt, chromium and platinum are in Southern Africa, the U.S. may yet see stockpiles built to protect its best economic interests.

These options then are all just alternatives to the real serious business of alleviating material supply problems through interchangeability based on the function performed. This can take two forms. The first is that change in materials demands brought about by technological development along the lines of Table 3.

Table 3

Examples of Functional Substitution

Function		Yesterday	Today	Tomorrow
Transportation	(1)	Bicycle	Motorcycle	Power glider
	(2)	Train	Automobile	People mover
	(3)	Piston plane	Jet plane	Rocket
Communication		Mail	Telephone	
Lighting		Oil lamp	Tungsten filament	Radiant Screen
Container		Glass	Glass, steel + tin, aluminum, paper, and plastic	Plastic
Paint pigment		Lead oxide	Titanium oxide	
Coinage		Silver	Copper/Nickel composite, brass	Aluminum
Heat		Wood	Fossil Fuels	Solar Energy

These are natural evolutionary developments associated with progress and in general their introduction into the economy covers several years which allows for readjustment to new materials requirements.

Technical Interchangeability

The second form which can be called technical substitution or function interchangeability is the only basic answer to serious supply problems. However, it is completely in the hands of the technologist who has to maintain quality of product as well as supply his particular market. He is the one who has to juggle quality of function, service performance, cost, price and adaptability of his new product with the old in both manufacturing and use.

The complexity of technical substitution is well illustrated in an examination of the uses of cobalt. United States industry used only about 9,400 tons in 1974 but many vital industrial functions are performed because of the presence of cobalt.

Table 4

Functional Uses of Cobalt Metal

Use	Form	Tons*
Magnets	Alnico	2,150
Heat resistance	Superalloys	1,650
Binder	Cemented carbides	1,250
Wear resistance	Tool steels	400
Catalyst	Metal	575
Ceramic	Pigment, frit	585
Dryer	Metal-organic salts	1,700

* Primary uses; does not total 9,400.

Permanent magnets have scores of uses in both dynamic and static applications as represented by small magnetos and loud speakers. They are highly favored over electromagnets because their permanent field does not require an independent power source. Their ratings are almost always based on performance as represented by the product of magnet field strength and the coercive (tenacity) force. Cost per pound then becomes secondary to unit performance. Alnico (24% cobalt) magnets have improved steadily since their invention forty years ago and the better ones have flux densities of over 10,000 gausses. Replacing cobalt with iron or going to cobalt contents as low as 5 percent or oriented ferrites cuts the flux density in half. There are only limited alternatives. The electrical functions performed by cobalt containing magnets could be handled by such magnets but the sacrifice in quality would require change in manufacturing to accommodate more bulky magnets. No doubt many of the present functions would not be performed as well or efficiently.

Cobalt has long been an integral part of some of the best superalloys for high temperature turbine use. Over 25 million vitallium blades were cast in 1944. A whole alloy series of S816, nimonic, and HS alloys containing 40 to 60 percent cobalt (balance largely chromium and nickel) have been developed since that time. Developments of the last decade in nickel base alloys have produced alloys with equal or superior performance. The function performed by cobalt base alloys of producing more efficient jet engines (by operating at higher temperatures) could well be performed by switching to nickel base alloys in most cases.

Some 3 to 15 percent cobalt is used as a binder for tungsten carbide. It serves as both a binder and a shock resistance medium. Cobalt's unique properties of wetability and limited alloying with tungsten carbide have never been matched by any other metal or alloy in the 50 years since these hard cutting tools were introduced. Various carbides involving tantalum, titanium or molybdenum have been developed through the intervening years but they have never had the acceptance of the original tungsten carbide. Chromium carbide with a nickel binder has promises. Replacing cobalt in this application would be extremely difficult. Replacing the tungsten carbide itself would not be as difficult as replacing the storehouse of knowledge built up in the manufacture and myriad uses of tungsten carbide cutting tools.

High cobalt alloys containing of the order of 50% cobalt, 1 to 2.5% carbon and balance largely chromium and tungsten, have been used on a specialty basis for many years. They perform a number of functions. As cutting tools they are intermediate between high speed and cemented carbides; they are used as lathe tools, milling cutters and special shop tools; in hard facing applications, ranging from dies and gages to earth moving equipment leading edges, they are unexcelled. In this last function they may increase part life 3 to 6 times. Strictly speaking, these functions of metal removal and increased wear resistance could be carried out by other hard metal combinations or a number of chromium-nickel-tungsten-molybdenum alloys. However, each specific use noted above has evolved over a period of 40 years. The same functions would not be performed as well by the alternates. The same analysis as that of cemented carbides would have to be applied to this group. Again, one of the principal casualties would be accumulated knowledge of shop know-how in fabrication and use.

Cobalt is probably next to platinum in importance as a metal catalyst. It has many uses in the world of organic synthesis, oxidation and reduction reactions, desulfurization of petroleum and production of hydrogen. Catalysis functions defy simple solution and replacement of cobalt in this area would be slow, difficult and, in most cases call for radical revision in process flow sheets.

The use of cobalt as a blue pigment for ceramics has been known for a long time and this intrinsic property can not be matched. The use of cobalt in base frits has decreased through the years.

The last major category of cobalt use is in salts and dryers. In essence it serves to oxidize or catalyze the polymerization of oils in paint-like coating materials. It would be easy for a physical metallurgist to decide this was a nonessential use. Time, convenience, and properties of the coating would all have to be weighed against alternative dryers.

This cursory exploration of seven major categories of cobalt use obviously doesn't result in many conclusions of how to interchange materials to perform the same functions. Each of the seven functions can be divided and subdivided into specific end uses. Alnico magnets, for instance, have wide applications in magnetos in airplanes, trucks, tractors, outboard motors, lawn mowers and small d.c. motors. They are used in telephone receivers, tachometers, meters and even for games, toys and bulletin boards just to name a few. Obviously the telephone receiver needs a small magnet, and toys can use ferrite magnets, but who decides the relative importance of the in-between uses? Alternate materials (in most cases other Alnico series) for a number of applications are shown in tabular form in the Metals Handbook:

Metals Handbook, Permanent Magnet Materials, p. 891.
American Society for Metals, Metals Park, Ohio, 1961.

The other six divisions have a similar breakdown; some of the functions could be done easily by other metals or alloys. Some like the blue ceramic enamels are non replacable.

From a functional performance application there are only 2 ways to interchange cobalt. The first would be by decree, as was done in World War II and the Korean War, and allocate cobalt strictly on a defense priority system. The second would be in the economic marketplace as is done today. Faced with a long period of supply disruption, industry would have to devise new systems involving different functions or develop alternate materials to provide the same function now brought about by the presence of cobalt. In many cases these alternate materials would be nickel or chromium, two other minerals which offer very limited domestic availability.

Research, development and engineering just to replace cobalt in 5 or 10 of its several hundred applications would be time consuming and expensive. The U.S. does not have national resources to prepare a complete source book for a low tonnage use metal like cobalt, let alone chromium and nickel. Only industry and the production engineer can make the decision on a case-by-case basis as the specific need arises. This country certainly needs a stockpile of such metals to carry over the several years required for interchangeability.

Summary

The problems of cobalt and the development of alternatives to replace that material apply to almost the entire spectrum of metals. Interchangeability or substitution then is not a simple task performed easily and quickly. It is technologically demanding and time consuming at best and sometimes virtually impossible to accomplish. Replacing one material with another in the performance of specific functions implies identification of the new substance, creating new designs consistent with the total range of properties inherent in the new substance, and creating a complete body of knowledge for all workers -- from the scientist and engineer to the production worker -- to insure the success of the replacement.

The application of the interchangeability principle then demands technology, knowledge, resources and time. The usefulness of this principle, therefore, must be based upon the effectiveness of a stockpile which is large enough to buy the time required for technological substitution.