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Critical Materials —A New Dimension

M. A. Siegel
Pratt & Whitney Aircraft,
Government Products Division,
West Palm Beach, Ha.

The decade of the '80s was ushered in with a new dimension for designers, the availability of, and the meteoric cost increases of key materials. Though cost consciousness has always been a materials selection factor, current rates of increase make selection decisions more critical. Shortages of key metals such as cobalt, titanium, tantalum, molybdenum, and columbium, as well as potential problems with chromium and aluminum force the designer to carefully weigh his decisions. Questions of basic raw materials availability, metal conversion capacity, and the increasing influence of raw materials cost upon product cost must be considered. Vehicular gas turbine engine designers must evaluate materials selection decisions based upon these factors, and accompanying manufacturing processes to minimize input material requirements., Achieving high performance, with the required durability, at an acceptance cost is a bigger challenge than ever. This paper provides a view of the critical material situation and outlook, and typical options that are available.

America's industrial might, already threatened by the deepening energy problem, is also threatened by another resource crunch — a metals shortage. The steadily increasing dependence upon imports for basic raw materials of the United States has already resulted in intermittent shortages and spiraling prices. The current import dependence in minerals ranging from aluminum to copper can be seen in figure 1.11] Many of these minerals are primarily obtained from areas of the world that are subject to continuing threats of conflict and strife. For example, chromium, cobalt and manganese imports are largely dependent upon Africa, and an interruption of cobalt flow was experienced in 1977 and 1978 due to strife in Zaire.

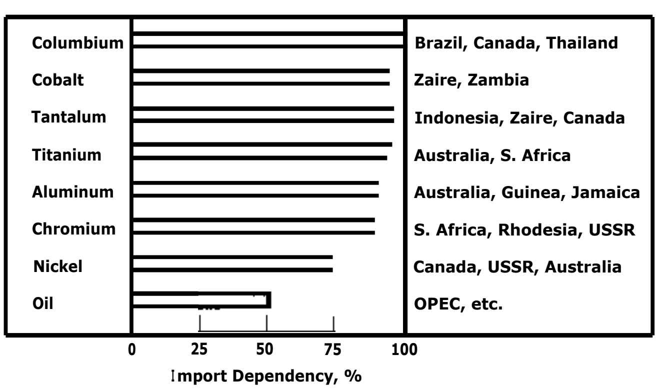

Figure 1. Import Dependency and Sources

In terms of mineral self-sufficiency, the United States and Russia are poles apart. The Soviets are virtually independent of imported supplies, although they are importing some key minerals for strategic reasons. The USSR import reliance of selected materials is shown in figure 2.12]

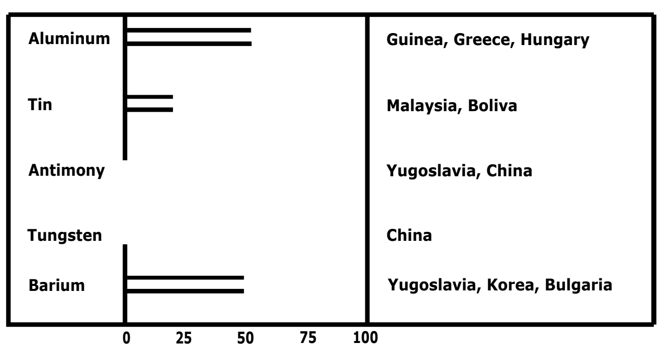

Figure 2. USSR Import Dependency and Sources

The oil embargo of 1973 and subsequent dramatic increases in the cost of petroleum products have made the American public understand the effect of this country's growing dependence on oil. Now the lesson that OPEC holds the whip hand is being brought home again. These harsh lessons are being translated to the potential mineral threats resulting in increased interest in reviving mining in this country, research and development in alternate materials, recycling of scrap, and improved manufacturing technology to minimize input material requirements. However, most of these approaches are of a long-term nature and involve significant technical and economic risk. There is no question that the basic problem and threat will grow, with the possibility of some alleviation through these efforts.

Another worrisome concern is the generalized problem of lack of productivity growth in the United States. This can be specified in many directions relating to the materials problem, particularly in

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the area of industrial capacity. Today, domestic steel and aluminum production is rapidly falling behind demand. Smelting and refining capacity for lead, copper, and zinc is being slowly strangled by environmental regulation. Titanium sponge capacity has been overtaxed, and the basic forging capacity of the United States has been so overburdened that U. S. consumers have been forced to go overseas for forgings. This situation is receiving federal government attention and may cause fundamental changes in the tax structure, loan guarantee policies and other measures to encourage modernization and expansion in the basic metals industry.

On the other hand, we find expanded interest in many of the key materials due to specific requirements and objectives in many industries, such as the chemical processing, aerospace, energy and automotive areas. The use of imported (strategic) materials, as well as expanded use of such metals as titanium and aluminum to enhance durability and life, or reduce weight, indicate the possibility of significant usage growth. In the automotive industry, which is the major user of many key materials in the United States, the emphasis on lighter weight to increase fuel economy is fact. The possibility of alternate power sources such as the gas turbine engine must also be factored into the future picture.

The aerospace industry has passed through several materials revolutions in this century in making the transition from wood and cloth aircraft to piston-engine-powered planes, to the jet-powered aircraft of today. From an aerospace engineer's standpoint the automotive industry is entering a similar transitory period. We see automakers introducing brand new designed-from-the-ground-up models replacing designs that have been with us from the 70's. Requirements for improved fuel mileage and reduced emissions are driving auto makers towards smaller, lighter weight vehicles with the possibility of alternate power plants such as gas turbines, Stirling cycle engines, and electric drives. What impact will these changes have on materials?

The importance of nonfuels minerals to the motor vehicle industry was revealed by the mines and mining subcommittee of the House Interior Committee recently. This industry uses 26% of the iron and steel, 16% of the aluminum, 12% of the copper, 69% of the lead, 34% of the zinc, 40% of the platinum group metals and smaller amounts of 10 others, such as metals for steel alloying, consumed in the United States.[3]

Plans and forecasts for vehicles capable of meeting the mandated corporate average fuel economy (CAFE) ratings for 1985 of 27.5 mpg indicate some significant changes in materials utilization. A report by Arthur Anderson & Co. of a delphi forecast conducted with consultants from the University of Michigan using automotive industry experts reveals major changes forecast for average car weight and materials from 1980 through 1990 as can be seen in table 1 *14/*

Table 1. Average Car Weight and Materials

	1980	*1985*	*1990*
Average Weight, lb	3300	2900	2500
Steel %	54	55	56
Iron %	16	12	10
Plastics %	6	8	8
Aluminum %	4	5	8

(Source: Arthur E. Anderson and Co.)

One can see the forecast showing increases in plastics and aluminum with an accompanying reduction in the use of iron. Other forecasters show an increased usage of magnesium and higher alloy steels as additional means towards achieving lighter weight vehicles.

While magnesium is not making a strong appearance yet, applications in rocker arm covers and lock cylinder housings are showing in new models. Future uses may include large components such as oil pump housings and transmission cases. Some automotive forecasters indicate that over the next five years the use of magnesium per vehicle could grow from less than a pound today to as much as 4 to 5 pounds by 1985. Julius Harwood, director of Ford's Material Science Laboratories, recently indicated that "when the magnesium to aluminum price ratio reaches 1.5, then one can talk about as much as 30 pounds of magnesium per vehicle in the long-range future.7.57 If one assumed a production rate of 10 million vehicles per year, this would require 50 to 300 million pounds of magnesium per year compared to the 1979 total U. S. consumption of 230 million pounds. It should also be noted that the majority of current consumption is used for the manufacture of aluminum-based alloys, with only 19% used for cast or wrought products.

In a larger material market, aluminum, the automotive industry is also forecast to significantly increase usage. Forecasts range from the current (1979) usage of 117 pounds per vehicle to 200 pounds per vehicle by 1985.16] An increase of 100 pounds would result in an additional demand of 1 billion pounds of aluminum a year based upon production of 10 million vehicles per year. This would be an increase of 12% over 1979 total U. S. consumption. Aluminum's gains are expected to be cast iron's loss, especially in the engine compartment and chassis. The weight-saving potential of aluminum is already being exploited from intake manifolds to cylinder heads. New transmission housings are coming out in die-cast aluminum. Other applications are as diverse as transfer case housings, chain cases, master brake cylinders and steering gear housings. An additional level of interest may result from the plethora of new alloy and processing developments current throughout industry to improve strength and modulus characteristics as well as temperature capability.

Steel has been the basic building material in automobiles since the early days of the industry. Forecasters indicate a shift from mild (low carbon) steels to high strength, low alloy (HSLA) steels through the 80's. If gas turbine or Stirling cycle engines are introduced in this era, the use of superalloys will probably be required. In addition, electric-powered cars may also make an entry, significantly increasing the usage of nickel. The potential combined effect would be an increase in usage of nickel and such alloying metals as cobalt, chromium, molybdenum, columbium, tantalum and tungsten. A summary of the current U. S. usage of these materials is shown in figure 3.[7] Again the production quantities of automotive vehicles is so high that even a minor usage per vehicle can cause significant changes in total U. S. demand.

1978
MILLIONS OF POUNDS

Aluminum	**11,900**
Chromium	**1,200**
Cobalt	**18**
Columbium	**6**
Nickel	**367**
Tantalum	**2**
Titanium	**38**

Source: Bureau of Mines

Figure 3. United States Metal Consumption

On the other hand, the increased usage of plastics and reinforced composites will tend to reduce metals usage. Forecasters indicate that future vehicles will contain as much as 200 to 300 pounds of plasticsJ4J Examples of current applications include Chevrolet Corvette fiber reinforced epoxy leaf springs, nylon see-thru master brake cylinders in many General Motors and Chrysler cars, Oldsmobile Omega's molded urethane front fenders, polyurethane bumpers on Pontiac Grand Prix, and glass fiber reinforced valve covers on AMC cars.

Automotive power plants are receiving considerable attention as a means for meeting future emission and fuel economy requirements. A recent study by the Jet Propulsion Laboratory of the California Institute of Technology evaluated the potential of several conventional and alternative power plants. According to this study, both Stirling and gas turbine engines should meet the emissions research goal of 0.4 g/mile of NO_x and Otto-engine equivalent performance in both small and full-sized cars, while maintaining their adaptability to various types of fuel.[7] The studies further indicated that diesel engine usage may be restricted and subject to limitations of currently unregulated emissions. They also indicate that the cost premium for a gas turbine engine can be acceptable, but that Stirling's higher costs could delay or even prevent its introduction. Other studies indicate that the emergence of the electric vehicle will improve overall CAFE values. For CAFE purposes, an electric vehicle will probably be assigned an equivalent of 180 mpg according to some forecasters, although that figure is an early estimate.

The introduction of the gas turbine would most likely require superalloy combustors and turbines as well as aluminum compressor components. The electric vehicles batteries will require as much as 500 pounds of nickel for batteries per vehicle.

Sudden changes in the usage and demand of raw materials can cause significant shortages. It was recently reported that the raw material requirements for the proposed MX missile include 10,000 tons of aluminum, 2500 tons of chromium, 150 tons of titanium, and 890,000 tons of stee1J8] Other proposed systems ranging from fusion reactors to solar collectors also require significant new quantities of materials beyond normal industry forecasts. Changes in usage in small metals markets like cobalt, columbium, tantalum and titanium are particularly critical because of the difficulty in achieving significant expansions. However large markets, such as aluminum, are also somewhat imperturbable due to the capital investment and energy requirements for expansion. The cost of many of these materials has risen with availability and demand. Cost factors also reflect increases in energy cost, mining in lower grade ore deposits, and some trader control of the market. Figure 4 shows some of the price increases for representative metals.

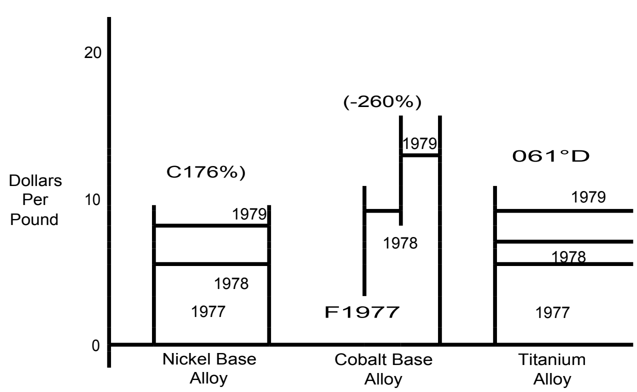

Figure 4. Aerospace Materials Costs Are Rising

From an aerospace viewpoint, the automotive industry evolution into new materials raises particular questions about future availability. For many years, aerospace products, particularly gas turbine engines, have been the major user of such elements as titanium (60%) and cobalt (30%) with a wide diversity of uses in the remaining portion. The total usage of these elements in the United States is comparatively low, i.e., about 50 million pounds of titanium metal and 20 million pounds of cobalt metal a year. A sudden surge in demand could not easily be met either in raw material availability or processing capacity.

An increasingly important factor in the materials situation is the recycling of scrap. There are about 200 auto shredders in operation in the United States. It is estimated that 60% of all deregistered cars are processed by these shredders, and the number is expected to increase. However, the major factor in auto scrap recovery today is the ferrous content which will decrease as the lighter cars of the future appear. Scrap content will feature HSLA steels, zincs and galvanized irons, aluminum, magnesium and plastics. A shift in emphasis and technology will be required to recover and recycle these materials.

On the positive side, research and development efforts are being focused on new material systems which offer the potential for significant reductions in critical material usage, and high strength-to-density ratios. Besides the extensive plastics and composite system efforts previously mentioned, rapid solidification of metal alloy systems offers the promise of a new generation of materials with improved strength, temperature capability, and minimal critical materials content. While new superalloy systems are emerging as the initial efforts in this area, advanced Aluminum and Ferrous alloys are also being developed. Ceramics for high temperature application in gas turbines are also being developed and tested with significant performance improvement capability, but have the drawback of low ductility.

Specific decisions regarding materials selections will require not only basic traditional parameters of strength, weight, corrosion characteristics, repairability, and cost, but the new dimension of materials availability and processing capacity. Again, the volume of application in the automotive vehicle industry can severely tax the supply and processing base of this country. Although aluminum, magnesium, plastics, HSLA's, superalloys, and other glamour materials may offer significant improvements in automobiles, the high volume requirements of the industry may limit their maximum usage due to availability and cost escalation.

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