Chapter 6

Impacts of Materials Substitution on the Basic Metals Industries

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Chapter 6

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FINDINGS

The U.S. steel and aluminum industries are currently undergoing a substantial restructuring process caused by large increases in world supply and decreases in per capita demand. Overall, materials substitution has been only a minor factor affecting the demand for these metals in the past decade. However, the importance of substitution by alternative materials is likely to be significantly greater in the next 10 to 20 years.

The materials likely to have the greatest impact on the aluminum and steel industries are unreinforced plastics, polymer matrix composites (PMCs), metal matrix composites (MMCs), and high-strength concrete. Ceramics and ceramic matrix composites (CMCs) are not expected to have a significant impact on steel or aluminum use in the next 20 years.

The threat of substitution has stimulated improvements in metals technology, e.g., high-strength, low-alloy (HSLA) steels, aluminum-lithium alloys (A1-Li), and rapidly solidified metal alloys. This makes the pace of substitution difficult to predict.

An analysis of the end uses of these metals indicates that substitution is likely to be most important in four markets: aircraft, automobiles, construction, and containers. However, OTA finds that by far the greatest volume of metals will be displaced by relatively low-performance materials, such as unreinforced plastics, sheet-molding compounds, and high-strength concrete, rather than by so-called advanced materials.

As new materials are increasingly adopted, a variety of secondary industries, such as adhesives, coatings, and weaving industries can be expected to grow. The recyclability of the new materials could become a major factor affecting their use.

INTRODUCTION

With the development of new materials such as structural plastics and composites, engineers now have many more options available for designing products. These new materials can offer performance advantages over such traditional materials as aluminum, steel, and concrete. How will these new materials affect the traditional manufacturing industries? What new industries will develop to support the use of these materials? The answers to these questions are important to an understanding of the factors that will influence the evolution of U.S. manufacturing industries in the 1990s and beyond.

This chapter outlines the effects of materials substitution on the U.S. aluminum and steel industries.[1] An analysis of the major markets for these two metals suggests that the most significant possibilities for substitution will be in aircraft, automobiles, construction, and containers. In the following section, materials substitution is considered in the context of the many factors affecting supply and demand within the basic metals industries.

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[1] This chapter draws heavily on "Impacts of New Structural Materials on Basic Metals Industries, " by Steven R. Izatt, a contractor report prepared for the Office of Technology Assessment, April **1987.**

HISTORICAL SUPPLY AND DEMAND FACTORS FOR STEEL AND ALUMINUM

supply

The supply of steel and aluminum worldwide has grown substantially in recent years. Major factors that have affected the supply of steel and aluminum in the United States are: the present U.S. overcapacity for steel and aluminum; the worldwide overcapacity for steel and aluminum; government ownership of foreign production facilities; volatile and depressed prices for steel and aluminum; imports of steel and aluminum, the growth of steel mini-mills in the United States; restructuring of the steel and aluminum industries; domestic scrap recovery of aluminum; and a shift to fabricated shapes in aluminum.

- ***Overcapacity:*** The main factor affecting the supply of steel and aluminum in the United States is the current domestic and worldwide overcapacity.
- Foreign government ownership: Abroad, many foreign governments own the national production of steel and aluminum. These governments thereby control commodity price, and this can lead to overproduction.
- ***Steel and aluminum prices:*** Prices are depressed for these commodities; often they are highly variable. This can be as damaging as continuous low prices, since fluctuating prices prevent long-term planning.
- ***Imports:*** Large volumes of foreign steel and aluminum are imported that are of good quality and of lower cost than can be found in the United States.
- ***Mini-mills:*** These smaller, more efficient steel mills are servicing some of the markets previously held by the larger integrated steel mills. This is very significant in product lines such as bar, rod, and wire, in which increased supply from mini-mills has caused overcapacity in the integrated steel mills.
- ***Restructuring:*** Both the aluminum and steel industries have been undergoing restructuring; for instance, the U.S. steel industry is evolving with the growth of mini-mills. Within individual steel and aluminum companies, restructuring is also taking place; for instance, the large U.S. aluminum producers are diversifying into other materials, particularly advanced materials, for their future business. This factor tends to reduce U.S. primary overcapacity.
- ***Scrap recovery:*** Recycling of aluminum has played a large part in its competitiveness. However, large amounts of recovered aluminum scrap also displace primary aluminum in several applications,
- ***Shift to fabrication:*** There has been a shift to supplying fabricated shapes rather than producing large units of steel (e.g., billets) to be shaped by the purchaser. This has little effect on total supply, but tends to favor industry restructuring toward mini-mills and away from integrated steel manufacturers.

Demand

The per capita demand for steel and aluminum has been continuously decreasing in the United States since its peak in the early 1970s.[2] The factors that have tended to decrease demand are: shifting consumption patterns, market saturation, more efficient use of materials, and materials substitution.

- ***Consumer preferences:*** Over the past 10 years, there has been a shift in consumer spending away from durable goods to services (table 6-1). This switch in spending preference is reflected in the decrease in the manufacturing sector's contribution to the national income since the late 1960s (down to 22 percent in 1983 from 30 percent in 1965[3]), and thus the decrease in per capita consumption of steel and aluminum.
- ***Market saturation:*** Analysts have observed that as a country matures past the rapid growth phase of its industrial development, the majority of the primary industrial infrastructure has been built. This results in a de-

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[2] Bureau of Economic Analysis, U.S. Department Of Commerce, *World Almanac and Book of Facts, 1985,* p. 152.

[3] Ibid.

Table 6-1 .—U.S. Personal Consumption Expenditures for 1978 and 1983 (billions of dollars)

	1978		1983	
	Expenditures	% of total	Expenditures	% of total
Durable goods:				
Motor vehicles & parts	$ 95.7	7.1	$ 129.3	6.0
Other	104.5	7.8	150.5	7.0
Total durable goods	200,2	14.9	279.8	13.0
Nondurable goods.	528.2	39.2	801.7	37.2
Services	618.0	45.9	1,074.4	49.8
Total personal consumption expenditures	$1,346.4	100.0	$2,155.9	100.0

Between 1978 and 1983, personal consumption of services increased by nearly 4 percent, while consumption of durable and nondurable goods decreased by about 2 percent.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, The *World Almanac and Book of Facts, 1985,* p. 165.

crease in the ratio of materials consumption to per capita gross national product (GNP). In the United States, this ratio peaked for steel around 1950 and for aluminum in the mid-*1970s,* and is now declining.[4]

- *Efficient use of materials:* The use of a material becomes more efficient when a higher performance per pound of material is achieved. Producers have devoted significant R&D resources to develop steel and aluminum products and process technologies that require less steel or aluminum to satisfy a particular market need.
- *Materials substitution:* When a new material can offer a cost or performance advantage over the current material in an established application, the new material will begin to displace the old in that application. For instance, aluminum showed rapid growth in the post World War II era as it replaced such traditional materials as wood in construction, copper in high voltage transmission lines, and steel in beverage cans.

Interrelationships of Factors Affecting Supply and Demand

Domestic raw steel overcapacity is significantly increased by several factors that are outside of the control of the steel industry and act to increase supply. For instance, the factor of foreign government ownership of steel mills encourages foreign overproduction by mills not acting in response to market forces.

The problem of domestic overcapacity is also affected by worldwide overcapacity (this provides an increased incentive for importers to import to the United States). Industry restructuring (i.e., growth of mini-mills, plant closings and bankruptcy filings, joint venture and acquisition activity in new materials) has occurred as a response to domestic and worldwide overcapacity.

Materials substitution and efficient use of materials are strongly interrelated factors. The threat of materials substitution has encouraged producers to apply new technologies aimed at reducing the amount of material (and hence lowering the cost) required to meet consumer needs. In the steel industry, this interrelationship is seen in the case of HSLA steel and coated steels that have been developed in response to the threat by lightweight materials such as unreinforced plastics, PMCs, and aluminum.

Materials substitution significantly affects the trend toward more efficient use of aluminum. For instance, the increasing use of PMCs in aircraft applications has motivated the aluminum industry to provide lighter weight aluminum alloys and MMCs. To develop these advanced materials, the aluminum industry has undergone some restructuring in the form of joint ventures and acquisitions.

THE RELATIVE IMPORTANCE OF THE END USES OF STEEL AND ALUMINUM

To understand the impacts of substitution on the steel and aluminum industries, it is necessary to know the major markets for these materials. Tables 6-2 and 6-3 present industries classified in the most recent (1 977) complete U.S. input-output tables, ranked in the order of highest use

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[4] E. D. Larson, M.H. Ross, and R.H. Williams, "Beyond the Era of Materials," Scientific *American, 254(6):37, June 1986.*

Table 6-2.—industries Using the Largest Amount of Steel, 1977[a] (in millions of dollars at producers' prices)

Industry classification	Use of steel	Percent	Potential for substituting alternative materials
1. Motor vehicles and equipment	9,471	15	High
2. Heating, plumbing, and fabricated structural metal products	5,700	9	Medium
3. Screw machine products and stampings	5,318	8	Low
4. New construction	4,567	7	Medium
5. Other fabricated metal products	3,791	6	Medium
6. Construction and mining machinery	2,880	5	Low
7. Metal containers	2,556	4	High
8. General industrial machinery and equipment	2,036	3	Low
9. Other transportation equipment	1,993	3	Low
10. Farm and garden machinery	1,432	2	Low
Total	39,744	62%[c]	

[a] Includes all categories listed under the Primary Iron and Steel Manufacturing Classification in the 1977 Input-Output Table: blast furnaces and steel mills, electrometallurgical products, steel wire and related products, **cold finishing** of steel shapes, steel pipes and tubes, **iron and steel foundries, iron and steel forgings, metal heat treating, and primary metal products, not elsewhere classified.**

[b] **Includes all categories listed under these Industry Classifications.**

[c] **There are 85 Industry** classifications in the Input-output tables. The remaining 38 percent of the total U.S. steel output is consumed by the 75 industries not listed here.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, The Detailed *Input-Output Structure of the U.S. Economy, 1977, Volume 1: The Use and Make of Commodities by Industries, 1977,* Washington, DC, 1984, pp. V-227.

Table 6-3.—Industries Using the Largest Amount of Aluminum, 1977[a] (in millions of dollars at producers' prices)

Industry classification	Use of aluminum	Percent	Potential for substituting alternative materials
1, Heating, plumbing, and fabricated structural metal products	1,950	11	Medium
2. Motor vehicles and equipment	1,276	7	Medium
3. Metal containers	1,166	7	High
4. Other fabricated metal products	675	4	Medium
5. Aircraft and parts	488	3	High
6. Screw machine parts and stampings	465	3	Low
7. Service industry machines	447	3	Low
8. Electric industrial equipment and apparatus	338	2	Low
9. Other transportation equipment	291	2	Medium
10. Engines and turbines	289	2	Medium
Total	7,385	44%[c]	

[a] Includes the **following** categories under the primary Nonferrous Metals Manufacturing Classification in the 1977 Input-output Table: primary aluminum, aluminum rolling and drawing, and aluminum castings.

[b] Includes all categories listed under these Industry Classifications.

[c] There are 85 industry classifications in the Input-Output tables. The remaining 56 percent of the total U.S. aluminum **output** is consumed by the 75 industries not listed here.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, The *Detailed Input-Output Structure of the U.S. Economy, 1977, Volume 1: The Use and Make of Commodities by Industries, 1977,* Washington, DC, 1984, pp. V-227.

of steel and aluminum to lowest. Each of these industries has been further evaluated as to the possibility for alternative materials substituting for steel or aluminum. The industries that were both major consumers of steel or aluminum and that held a high potential for substitution were evaluated.

Table 6-2 shows that of the top 10 industries that use steel, 5 are judged to have a high or medium potential for substituting alternative materials.[5] The two industries of high potential are motor vehicles and equipment, and metal containers, both of which are covered in this assessment.

Of the three largest steel-consuming industries with a medium potential of substitution, construction is the only one covered in this chapter. The other two, screw machine products, stampings, and other fabricated metal products, are not analyzed here because these sectors cover such a diversity of types of products, each of limited dollar value on its own, that it is difficult to conduct a reliable, in-depth analysis.

Table 6-3 shows that of the top 10 industries that use aluminum, seven have a high or medium

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[5] Izattt, op. cit., footnote 1, 1987.

potential for substituting alternative materials.[6] Three of these seven, which are treated in this chapter, are aircraft and parts, motor vehicles and equipment, and metal containers. In the four industries of medium possibility not analyzed here (heating, plumbing, and fabricated structural metal products; other fabricated metal products; other transportation equipment; and engines and turbines) the great diversity of products again precludes a reliable analysis.

Thus, the four end uses judged to be of greatest potential for substitution of new materials for traditional metals are: aircraft, motor vehicles, construction, and containers. In the category of motor vehicles, the analysis is entirely of the automobile industry. The analysis of the market for containers includes not only beverage containers but food packaging as well.

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[6] Ibid.

POTENTIAL FOR SUBSTITUTION IN THE AIRCRAFT INDUSTRY

About 3 percent of the total aluminum output and one percent of the total steel output (by dollar value) of the United States is consumed by the aircraft industry. Even though the aircraft industry is a minor market for pounds of aluminum shipped (approximately 5 percent of the transportation segment), it is an important one in terms of the value of the aluminum shipped, as well as in terms of the U.S. balance of trade. The aircraft market is performance-sensitive and is therefore willing to pay a premium for materials that increase performance. This market acts as a development market for advanced materials that have a high initial cost.

Currently, aluminum accounts for 80 percent of the structural weight of commercial aircraft.[7] In military aircraft, the percentage has varied from 65 percent in the 1960s (F-4) to 50 percent in the 1970s (F-15) and to 55 percent in the 1980s (AV-8B).[8]

Although PMCs, and less developed materials such as A1-Li alloys, MMCs, and rapidly solidified aluminum alloys, are all possible future contenders for aircraft, it may be some time before they actually displace traditional aircraft materials. The planning cycles of aircraft have a significant effect on materials substitution. A new material must be fully developed and qualified in time to be considered for use in the next generation of aircraft. Missing this cyclic “window” means that the material cannot be considered for use until a new generation of aircraft is developed. Each of the materials that are candidate substitutes for aluminum is at a different point in development.

Table 6-4 describes the possible use of advanced structural materials in aircraft applications. PMCs and MMCs have been or could be used in many Navy, Army, Air Force, National Aeronautics and Space Administration (NASA) or civilian commercial helicopters, aircraft, and space structures. To date, the motivation for this substitution has mainly been the opportunity to achieve weight savings. As the properties of these materials improve, their level of performance, and hence substitution, should also increase. More important, as more experience is gained with these materials, their associated costs could decrease, providing the major motivation for their use, especially in commercial aircraft.

Reducing aircraft weight increases fuel efficiency, which results in lower life-cycle costs. Significant reductions in weight and increases in strength are desired to meet fuel efficiency needs. Industry experts have projected that substantial weight savings could be achieved along with property improvements; for instance, a 30-percent weight savings could be obtained with a 200-percent increase in fatigue strength by using PMCs, and a 20-percent weight savings could accrue with an 80-percent improvement in stiffness using MMCs (see figure 6-1).

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[7] Standard and Poor's Industry Surveys, Metals-Nonferrous, Basic Analysis, July 10, 1986, pp. M76-M77.

[8] B.A. Wilcox, “influence of Advanced Materials on the Domestic Minerals Industry, ” *Materials and Society, 10(2):209, 1986.*

Table 6-4.—Current and Proposed Use of Advanced Materials in Aerospace Structures

System	Structure	Material
Aircraft:		
Boeing 747	**30°/0** of exposed surface area, 10/0 of structural weight, secondary structures	fiberglass/epoxy
Boeing 767	rudders, elevators, spoilers, ailerons ducting, stowage bins, partitions, lavatories, escape system parts, leading- and tailing-edge panels, cowl components, landing gear doors, fairings	graphite/epoxy Kevlar/epoxy graphite-Kevlar/epoxy hybrid
F-15	secondary structure, empennage parts	graphite, boron/epoxy
F-18	I0% by weight of total structure; primary structure, wing applications, sandwich panel skins	graphite/epoxy
Beech Starship I	90% of aircraft; primary and secondary structures	graphite/epoxy
ATF	40% of total structure; fuselage substructure, inlet structure, integral tankage, bulkheads, fins	graphite/polyimide or graphite/bismaleimide or silicon carbide/aluminum
Avtek 400	all primary and secondary structures	Kevlar/epoxy
Helicopters:		
AH-64 Apache	secondary structures, primary structures, i.e., fuselage, rotor blades	Kevlar/epoxy
AV-8BV/STOL	26% of total weight; forward fuselage horizontal stabilizer, elevators, rudder, overwing fairings, wing box skins and substructure, ailerons, flaps	graphite/epoxy
Boeing Vertol 234	center section of aft rotor assembly	graphite-fiberglass/epoxy hybrid
LHX, JVX	airframes (results in acquisition and operational cost savings, weight savings, increased damage tolerance, etc.)	graphite/epoxy, Kevlar/epoxy, fiberglass/epoxy, fiberglass/polyimide
Space shuttle	fuselage, frame support struts, payload bay doors, purging ducts system, filament wound pressure vessels, nose cap, wing leading edges, structural parts (increasing allowable temperature)	graphite-fiberglass/epoxy hybrid, graphite/epoxy, Kevlar/epoxy, carbon/carbon, graphite/polyimide

SOURCE: Steven R. Izatt. "Impacts of New Structural Materials on Basic Metals Industries," a contractor report prepared for the Office of Technology Assessment, April 1987.

A note of caution is appropriate here on the strong influence of fuel prices: If fuel prices do not increase during the next 10 years, PMCs could look less attractive compared to aluminum. Aircraft designers currently estimate that a pound of weight saved is worth $100 over the life of the aircraft. Fuel prices as of August 1986 were about 55 cents per gallon. It has been estimated that it would take at least a factor of 2 increase in these fuel prices to make PMCs look attractive to aircraft buyers.[9]

The important cost factors in considering advanced composites substitution for aluminum are life-cycle costs, as noted above, and production costs. The major improvement in future costs should come from improved fabrication methods. The contribution of the base material costs to overall structure costs is relatively small. For instance, lower stiffness (30 Msi) PAN-based graphite fibers generally sell for approximately $20 per pound. Prepreg tape made from these fibers and infiltrated with a resin system typically sells for approximately $40 per pound. The final cost of the finished aircraft structure can be in the range of $100 to $400 per pound.[10]

Another important cost consideration in comparing PMCs with metals is the significantly reduced number of parts made possible by using PMCs. For instance, in the Bell Helicopter Textron, Inc./Boeing Vertol prototype PMC helicopter body, the V-22 Osprey, there is a reduction in the number of airframe parts from 11,000 (aluminum) to 1,530 (PMC). The number of fasteners is reduced from 86,000 to 7,000. The weight reduction is from 4,687 lbs to 3,281 lbs.[11]

Figure 6-2 shows the potential savings in aircraft structural weight forecast for the next quarter-century. PMCs have the potential to give the largest weight reduction (30 to 40 percent) using advanced fibers with modified epoxies and ther-

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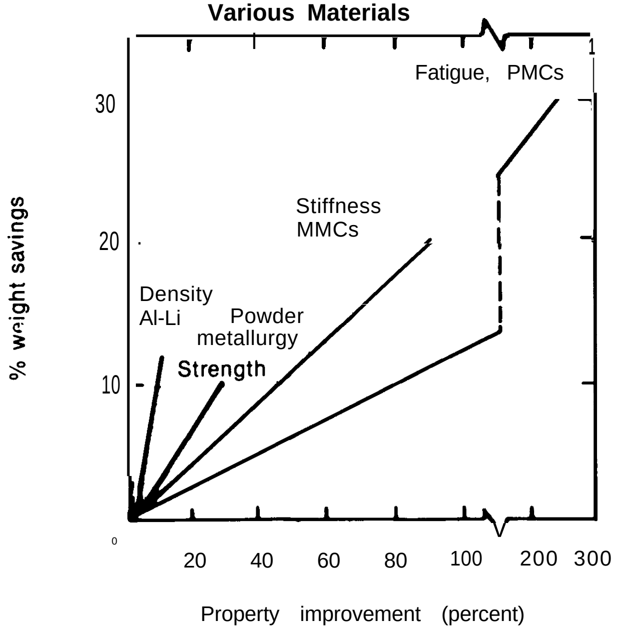
[9] Bob Hammer, Boeing Aircraft Co., personal communication, September 1987.

[10] D. R. Tenney and H.B. Dexter, "Advances in Composites Technology," *Materials and Society, 9(2):188, 1985.*

[11] P. N. Lagasse, "The Role of Reinforcing Fibers in Composites, " *Rubber World,* May 1985, pp. 27-28.

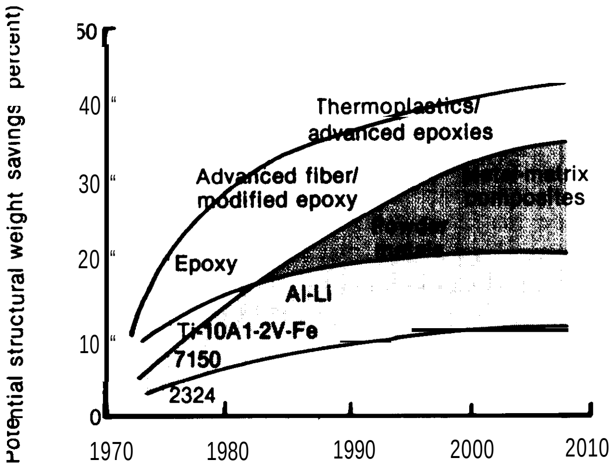
Figure 6-1 .—Relationship Between Property Improvement and Weight Savings for Various Materials



Compared with conventional materials, using advanced materials offers improvements in mechanical properties as well as weight savings.

SOURCE: P.R. Bridenbaugh, W.S. Cebulak, F.R. Billman, and G.H. Hildeman, "Particulate Metallurgy in Rapid Solidification," Light Metal *Age,* October 1985, p. 18.

Figure 6.2.—Projected Savings in Aircraft Structural Weight Based on Selected Advanced Materials



7150—Wrought aluminum alloy with zinc.
2324—Wrought aluminum alloy with copper.

Advanced PMCs offer the greatest weight savings

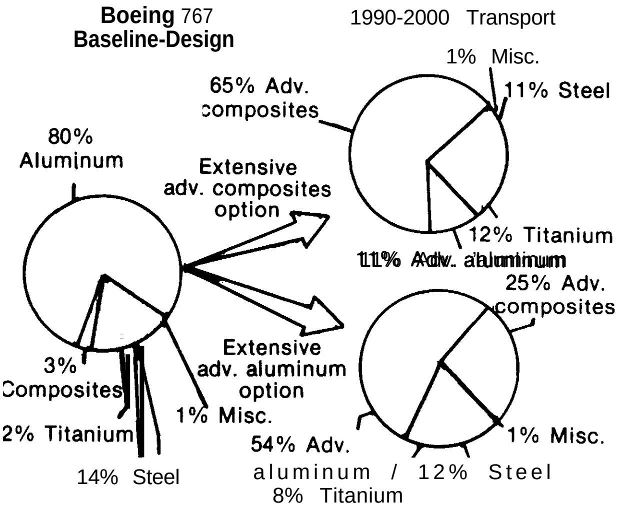
SOURCE: D.R. Tenney and H.B. Dexter, "Advances in Composites Technology," Materials *and* Society 9(2):186, 1985.

moplastic matrices. A1-Li and powder metallurgy (P/M) alloys are expected to be introduced over the next 5 to 10 years and offer a 10- to 15-percent weight savings.

The open question is whether aluminum (and its new alloys and composites) or PMCs, will be the material of choice in the next generation of commercial transport aircraft. Figure 6-3 shows two possible options (extensive use of new aluminum technologies or extensive use of PMCs) for a hypothetical commercial transport built in the 1990s. Due to recent improvements in resins, fibers, and processing technology for PMCs, and to higher-than-projected costs for aluminum alloys, the extensive PMC scenario currently looks very promising. However, the actual outcome is likely to lie in between these two scenarios.

The use of A1-Li alloys or rapidly solidified technologies would cause the total amount of aluminure used in aircraft applications to decline, since they are stronger per unit weight and/or less dense than traditional aluminum alloys. Whichever scenario (i. e., extensive use of PMCs or extensive use of new aluminum technologies as described in figure 6-3) occurs, the use of traditional alum i-

Figure 6-3.— Breakdown of Structural Materials Use in Two Alternative Designs of Commercial Transport Aircraft



In the option featuring extensive use of advanced aluminum, the proportion of aluminum drops by 26 percent due to improved structural efficiency. In the option featuring extensive use of advanced composites, the proportion of aluminum drops by 69 percent. Steel use remains virtually unchanged.

SOURCE: D.R Tenney and H.B. Dexter, "Advances in Composites Technology," *Materials and Society 9(2):194,* 1985.

num could decrease by between 26 and 69 percent. Since aircraft and aircraft parts account for slightly less than 3 percent of total aluminum output in the United States (table 6-3), this decrease in aircraft use of aluminum could mean a 1 to 2 percent decrease in the dollar value of total U.S. aluminum use by the year 2000. Note that steel use remains roughly constant in either scenario.

POTENTIAL FOR SUBSTITUTION IN THE AUTOMOBILE INDUSTRY

In evaluating substitution in the automobile industry, it is very important to understand that the automotive market is a commodity market that is extremely cost-sensitive, compared to the high performance-oriented aircraft market. Thus, it is more difficult for new, high-performance (high-cost) materials to penetrate the automotive market, unless a significant cost savings can be realized.

During the past 20 years, three trends have had major effects on the materials content of automobiles in the United States. From 1967 to 1976, government standards encouraged automakers to add structural weight to make autos safer. In 1975 the passage of the Energy Policy and Conservation Act (Public Law 94-1 63) required yearly increases in the average fuel efficiency of each manufacturer's fleet of vehicles. This trend toward fuel-efficient cars resulted in a substantial decrease in the average weight of an automobile. The majority of this decrease can be attributed to downsizing and most of the remainder to use of high-strength steels, and to a lesser extent, unreinforced plastics and aluminum as substitutes for mild steel and iron.[12]

The most recent trend affecting the U.S. automobile industry has been the increase in international and domestic competition that has developed since about 1983. The industry has become increasingly cost- and quality-conscious as U.S. consumers have turned increasingly to imported vehicles. To compete in the low-growth automotive market, one of the strategies that automakers have used to keep market share is to appeal to a broad range of consumers in different market niches. For this reason, the number of major automotive nameplates is projected to increase from 68 in 1984 to 77 in 1989.[13] This market segmentation could mean that an increasing number of models will be made in smaller production volumes and model design could change more frequently.

The current trend toward market segmentation (more automotive models) could increase the likelihood of substitution, since sheet molding compound (SMC) fabrication is competitive with that of steel in low production volumes. The SMC composite-skinned Fiero, for instance, is assembled at the rate of only 100,000 cars per year while the annual production rate for the steel-bodied J-body cars (Cavalier, 2000 Sunbird, Firenza, Skyhawk, Cimarron) is 600,000. Most automobiles, because of the cost/benefit advantages for large production runs, still have steel body panels.

Major materials used in automobiles are mild steel, cast iron, HSLA steel, aluminum, unreinforced plastics, and so-called lower technology PMCs. These latter two are now just beginning to have a presence in the automotive market. The ability to mold unreinforced plastics, and reinforced plastics such as sheet molding compound, into aerodynamic shapes more easily than steel makes them strong contenders for increased substitution. Stimulated by this threat, new types of steel products—HSLA and coated steels—have become available, providing the potential for continued dominance of steel in automotive applications. The trend toward the increased use of precoated steels has also reduced the potential substitution of current unreinforced plastics for steel sheets.

Table 6-5 lists examples of where lighter weight materials such as unreinforced plastics, fiberglass and graphite-reinforced composites, aluminum, and HSLA steel are substituting for iron and steel in automobiles. These programs are a mixture of approved projects and projects that have been proposed. Most are secondary-structural or nonstructural applications such as fenders, door parts,

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[12] Izatt, op. cit., footnote 1, 1987.

[13] L. Leonard, "Automotive Materials War Heats Up," *Materials Engineering*, October 1985, p. 29.

Table 6-5.—Current and Proposed Use of Advanced Materials in Automobiles

Material/current use

Plastics:

- *Ford Merkur XR4Ti:* rear double spoiler (injection molded polycarbonate/acrylonitrile-butadiene-styren(PC/ABS)), instrument panel and glove compartment, door handles, radiator grille, light frames, rear package tray and center console[a]
- *Chrysler T-Vans (commercial version):* plastic back butterfly doors[b]
- *Ford Aerostar van (commercial version):* plastic back butterfly doors[b]
- *GM Fiero:* roof, decklid (SMC); fascias, fenders and doors (reaction-injection-molded urethane)[d]
- *Ford Aerostar van:* fuel tank, lamps, front and rear bumpers’

Composites:

—Fiberglass

- *Chevrolet Corvette:* body and transverse rear spring[c]
- *GM Eank cars:* leaf springs[e]
- *Ford Aerostar* hood, rear liftgate[i]
- *Chrysler Dakota pickup:* leaf springs[b]

— Fiberglass/graphite

- *Ford Econoline van:* **rear wheel drive shaft**[c]

Aluminum:

- *Chevrolet Corvette:* driveshaft[h]
- *Ford Aerostar van:* driveshaft, one-piece wheels, rear axle carrier, oil pan, and enginemount brackets[i]
- . *Ford Ranger pickup.* **one-piece aluminum wheel**[i]
- *Chrysler* 2.5 L *balance-shaft engines:* carriers for the balance shafts[k]
- *Chevrolet Corvette.* cylinder heads on 5.7 L V-8[i]
- . *Dodge Dakota pickup.* intake manifold on 3.9 L V-6 engine
- *Lincoln Town Car:* inner and outer hood panels and hinge reinforcements”

Stainless steel:

- *0ldsmobile Toronado:* exhaust system from manifold to tailpipe[i]
- *Cadillac:* exhaust manifolds
- *Ford Taurus/Sable:* exhaust pipes and supports[i]

High-strength steel:

- *Current or potential use: 35-45* ksi—outer and inner body components such as door, hood, fender, deck, quarter, floor, pan, and dash panel; 50-60 ksi—rocker panel (side sill), front and rear rails, wheel, frame, control arm, bracket, bumper and reinforcement, seat track, and cross member; 70-80 ksi—door beam, bumper reinforcement, and bracket[j]

Material/proposed use

Plastics:

- *Buick LaSabre (1987):* front fenders[b]
- *Chrysler’s P-body cars (1987):* bumper fasciasb
- *Buick Reatta (1987):* front fenders[b]
- *Chrysler’s imported Q-coupes (1987):* bumper fascias[b]
- . *Ford Ranger pickup (1988):* plastic leaf springs[b]
- *Ford Tempo and Topaz (1988):* all plastic bumpers[b]

Plastics and composites:

- *GM composite bodied cars (GM80 Program):* Camaro and Firebird replacement cars (1991 was target date, but has been cancelled)[b]
- ***Pontiac Fiero:*** space frame[e]
- *Chrysler Genesis Program (1990s):* composite chassis[g]
- *Ford Alpha Program (1990s):* **composite chassis**[g]
- *GM-100 Program (1990s):* composite chassis[g]

Aluminum:

- *Ford F-trucks and Econoline van (1987):* aluminum drive shafts[h]
- *GM 3200 series V-6 engine (1989 Camaro and Firebird):* cylinder block, head, two inlet manifolds, oil pan, water pump, and pistons[i]
- *Audi (date unspecific@* entire body—formed jointly with Alcoa[l]
- *Chrysler Voyager, Caravan, and Daytona (1987):* case for manual transaxies[m]
- *Chrysler LeBaron (1987):* bumper reinforcements
- *GM Genll 2.8 L V-6 (1987):* front cover, rocker cover, generator mounting bracket and belt tensioner, cylinder heads, and intake manifold[k]
- *GM Genll 2.0 L 4 cylinder(1987):* front cover, rocker cover, elbow on remote air cleaner assembly, air cleaner housing, and cylinder heads[k]
- *AMC 4.0 L. 6-cylinderJeep engine (1987):* engine covers, rocker covers[k]
- *Ford 4.9 L inline 6 cylinder for light trucks (1987):* intake plenum and branch manifold individual runners[k]
- *Chrysler Turbo II 4 cylinder for Dodge Daytona Shelby (1987):* intercooler and dual toned intake manifold[k]
- *Chrysler 3.O L V-6 (import, 1987):* cylinder heads, rocker arms, and three-piece intake manifolds
- *Oldsmobile Buick LaSabre and Trofero (T-Type), Pontiac Bonneville, Chevrolet Celebrity and Cavalier Z24 (1987):* wheels[k]
- *Ford Econoline van (1987):* driveshaft[k]
- ***Cadillac Allante (1987):*** stamped body panels—six inner and outer hood, deck lid and removable roof panels[k]
- *Ford 4-wheel-drive Tempo and Topaz (1987):* transfer case[k]

Stainless steel:

- *Chrysler front-wheel-drive car/van lines:* exhaust systems[m]

SOURCES:

[a] Design News, Dec. 2, 1985, p. 30.

[b] American *Metal Market,* Aug. 21, 1986, p. 8.

[c] *Popular Science,* July 1985, pp. 50-53.

[d] Chemical *Business,* June 1988, pp. 10-13.

[e] Iron Age, Dec. 20, 1985.

[f] American Metal Market/Metal *Working News,* May 19, 1986, p. 1.

[g] Automotive News, 1985, p, 1.

[h] American *Metal Market,* Jan. 26, 1986, p. 5.

[i] Materials *Engineering,* October 1985, pp. 28-35.

[j] Chemtech, September 1985, p. 556.

[k] American *Metal Market,* Aug. 14, 1986, p. 1.

[l] Light Metal Age, December 1985, pp. 16-17.

[m] Amerjcan Metal *Market/Metal Working News,* July 21, 1986

[n] Metal *Progress,* May 1986, p. 44.

grilles, and interior panels. Structural applications, using glass and graphite fiber-reinforced matrices, include leaf springs and drive shafts.

For the automakers, using unreinforced plastics and fiberglass composites trims tooling costs (tooling for a steel hood requires 52 weeks; for a fiberglass composite hood, 39 weeks[14]) and allows them to respond quickly to market and competitive changes because of the cost advantages of unreinforced plastics and fiberglass composites at low production volumes. Using these materials also provides increased part durability and decreases the number of necessary parts (e.g., the space frame used in the Fiero has 300 structural steel parts; by using PMCs, this total could be reduced to ***30,*** and ***4,000*** welds could be eliminated).[15]

New coating technologies, mostly of zincrometal, have improved the corrosion resistance of steel and helped to keep it competitive with noncorroding reinforced plastics. One company has developed an alumina-ceramic coating derived from aerospace products (blades, vanes, and other gas turbine engine hardware) that can be used to protect automobile fasteners from corrosion.[16] HSLA steels offer weight savings over traditional carbon steels due to their higher strength. The use of HSLA steels in automobiles has increased from 5 percent in 1975 to 14 percent in 1985 and is expected to rise above 20 percent by early in the 1990s.[17] Aluminum is generally not considered cost-competitive with either HSLA or mild steel, but it is almost cost-competitive with cast iron. A recent joint venture by an aluminum company and an auto manufacturer produced a prototype aluminum car body that weighed 46.8 percent less than a comparable steel prototype and performed as well as a comparable steel body.[18]

Substitution of lightweight materials in automobiles is at a plateau; most of the easier substitutions have been made, and only those requiring substantial improvements in the technology of alternative materials remain.[19] When the newer unreinforced plastics and PMCs are improved to the point where they can be used in more demanding applications and can be produced economically, materials substitution can occur at a faster rate.

Early estimates by automakers suggested that the usage of lightweight materials would increase significantly by 1991.[20,21] Such a change in usage would depend heavily on: 1) the concurrent development of lightweight materials technologies and competitive costs, 2) maintenance of the current automotive industry trend toward increased competitiveness, and 3) the acceptance of new materials by car buyers, automakers, and suppliers to the automotive industry.

However, automakers now feel that these early estimates may have been too optimistic by about five years. A plausible scenario might be that composites could displace 3 percent of automotive steel use by the late 1990s.[22] this would mean a decrease in total steel use in the United States of only 0.4 percent by dollar value.

Because aluminum is a lightweight material, there is not as much driving force for substitution by PMCs. However, if PMCs offer other advantages over aluminum, such as lower cost or greater ease of manufacturing, PMCs may begin to substitute for aluminum in automobiles.

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[14] "Fiber-Glass Composites Aim at Autos' Structural Parts, " *Iron Age,* Dec. 20, 1985, p. 16.

[15] Ibid.

[16] D. F. Baxter, "Developments in Coated Steels," *Metal Progress,* May 1986, pp. 31-34.

[17] Larson et al., op. cit., footnote 4, p. 38.

[18] "Aluminum Car Bodies in the Future, " *Light Metal Age,* December 1985, pp. 16-17.

[19] Izatt, op. cit., footnote 1, 1987.

[20] H.E. Chandler, "Material Trends at Mazda Motor Corp., " *Metal Progress,* May 1986, pp. 52-58.

[21] A. Wrigley, "Alloys and New Materials – Auto Industry in Materials Flux: Alloys Outlook Still Optimistic, " *American Metal Market,* Feb. 24, 1986, pp. 7, 10.

[22] Ch. 7 presents a scenario of 500,000 PMC automobiles per year in production by the late 1990s. This would cause a drop in automotive steel use of 250,000 tons or about 3 percent.

POTENTIAL FOR SUBSTITUTION IN THE CONSTRUCTION INDUSTRY

New construction represents the fourth largest U.S. market for steel (about 7 percent of total steel output as shown in table 6-2). New construction consumes less than 1 percent of the total U.S. aluminum output.

High= Strength Concrete as a Substitute for Steel

The development and increasing use of high-strength concrete represents a market challenge to both steel structural shapes and steel reinforcing bars. Because of the high compressive strengths of high-strength concrete (defined to be in the range of 84 to 110 megapascals (MPa)) this material can be used in structural applications that would otherwise use structural steel members. High-strength concrete has comparatively low tensile strength, low stiffness, and low toughness, although its toughness is higher than that of lower strength concrete. In addition, it requires less reinforcement than ordinary concrete, thus reducing the need for reinforcing bars.

High-strength concrete, which has been under development for several years, has now entered a high-growth phase. Use of high-strength concrete could increase at a much more rapid rate over the next 5 to 10 years as those various high-strength concretes under laboratory testing are used in actual construction.

The major driving force for using high-strength concrete is its relatively greater ratio of strength to unit cost which makes it the most economical means of carrying compressive forces. Because compressive strength is also higher per unit weight and volume, less massive structural members can be used compared to lower strength concrete. Cost studies have been conducted that show the advantage of using high-strength concrete with a minimum of steel reinforcement.[23]

An example presented in table 6-6 shows that total cost of 33 steel-reinforced concrete columns for a 79-story building would be about $3.8 million for high-strength concrete, compared to approximately $7.7 million for normal-strength concrete.

The major uses for high-strength concrete have been for columns of high rise structures and precast, prestressed bridge girders, although there have also been some special applications in dams, grandstand roofs, piles for marine foundations, decks of dock structures, industrial manufacturing applications, and bank vaults.[24]

Significant improvements in the properties of high-strength concrete can occur over the next 20 years. Research is underway on fibers for a new generation of fiber-reinforced high-strength

Table 6-6.—Cost Comparison of Using Normal and High-Strength Concrete for a 79-Story Building

	Compressive strength	
Materials	High[a] (up to 12,000 psi) (84 MPa)	Normal[b] (4,000 psi) (28 MPa)
Cost per 25 x 25 ft. panel		
Concrete	$45,035	$88,836
Forms	35,729	54,606
Longitudinal steel	34,449	87,161
Spirals	1,441	1,930
Total	$116,654	$232,533
Total cost for 33 columns	$3,849,582	$7,673,589

[a] With the high.strength concrete, column dimensions were kept constant and were calculated so that the lowest story columns can be made with a 12,000 psi (84 MPa) concrete and 1 percent longitudinal steel. The dimensions of the column and the percentage of the longitudinal steel was maintained constant for all 79 stories. The top 29 floors were designed with 4,000 psi (28 MPa), the next 31 floors with 9,000 psi (63 MPa), while the bottom 19 floors were designed with 12,000 psi (84 MPa).

[b] For normal strength concrete, all floors had concrete with a Compressive strength of 4,000 psi (28 MPa). However, to maintain a 1 percent ratio of the longitudinal steel, the dimensions of the designed circular columns were increased from 1,400 mm at the top to 2,950 mm for the bottom story,

SOURCE: S.P. Shah, P. Zia, and D. Johnston, “Economic Consideration for Using High Strength Concrete in High Rise Buildings, ” a study prepared for Elborg Technology Co., December 1983 As presented in: S.P. Shah and S.H. Ahmad, “Structural Properties of High Strength Concrete and Its Implications for Precast Prestressed Concrete,” *Prestressed Concrete Institute Journal 30(6):109-110,* November-December 1985.

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[23] ACI Committee 363, “State of the Art Report on High Strength Concrete,” ACI 363 R-84, *ACI Journal,* July-August 1984, pp. 366-367.

[24] Ibid,, pp. 403-404.

concretes. As this technical improvement occurs, construction markets originally dominated by steel could become potential markets for the new concrete. Assuming from the example in table 6-6 that 60 percent less steel (by dollar value) is needed to reinforce high-strength concrete building columns, and that this figure could be used as an estimate for the decrease due to substitution in total construction use of steel (7 percent by dollar value), this would mean a decline in total steel use by a dollar value of about 4 percent

PMCs and Unreinforced Plastics as Substitutes for Steel and Aluminum

PMCs are highly unlikely to substitute for steel or aluminum in the construction industry to a significant degree in the foreseeable future. The cost of PMCs is prohibitive compared to other construction materials. Steel, cement, and concrete sell for dollars per ton, whereas PMCs that have matured in their processing technology (e.g., fiberglass/epoxy) sell for dollars per pound. As with high-strength concrete, the general lack of familiarity with the properties of PMCs as well as the highly fragmented nature of the construction industry tends to retard their widespread adoption. However, in the longterm, PMCs may find limited use in specialized applications such as nonmetallic, nonmagnetic structures, bridges, and manufactured housing (see ch. 3).

Unlike PMCs, unreinforced plastics have the potential to displace significant amounts of metal (mainly aluminum) in the construction industry. Sales of unreinforced plastics to the construction market rose from 2,354 million metric tons in 1974 to 4,212 metric tons in 1984, an increase of nearly 80 percent. Sales are expected to grow an additional 25 percent by 1990, to 5,265 million metric tons.[25] These figures highlight the overall trend in the construction market toward using unreinforced plastics. Unreinforced plastics compete directly with aluminum in those applications that require little load bearing capability such as window frames, doors, and screens.

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[25] J.A. Schlegel, *Barrier Plastics: The Impact of Emerging Technology,* AMA Management Briefing, American Management Association, 1985, p. 43.

POTENTIAL FOR SUBSTITUTION IN THE CONTAINER INDUSTRY

Containers and packaging constitute the third largest market segment for aluminum (see table 6-3) and the seventh largest market segment for steel (see table 6-2). The large majority of rigid containers are used for the primary packaging of beer, food, and soft drinks. Total rigid container shipments increased at an average annual rate of 1.4 percent during the 1974-84 period; this represents 19.6 billion containers.[26] However, because the food and beverage segments of the container market have reached maturity, the growth for any one material must come at the expense of another.

The container market represents a competition among several materials: aluminum, steel, unreinforced plastics, and glass. With respect to beverage containers, both aluminum and steel are in the mature phase of their technology development. In contrast, unreinforced plastics for the soft drink market are still relatively new technologies. To compete in the soft drink market, plastic containers are required to have barrier properties to protect the container contents against permeation of gases (e.g., oxygen, carbon dioxide, and water vapor), degradation due to light (especially ultraviolet light), aroma/odor changes, and effects of organic chemicals and hydrocarbons. Aluminum, steel, and glass provide an “ultimate barrier” against these possibilities.

There are a number of driving forces for the adoption of unreinforced plastics in those markets currently served by metal containers. These include potential for processing savings; shipment and storage savings (aseptic products made of plastic can be shipped and stored without refrigeration); consumer preference for convenience packaging that allows a container to be used eas-

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[26] U.S. Department of Commerce, *1985 U. S. Industrial Outlook,* January, 1985, Washington, DC, p. 6-1.

ily, e.g., taken from freezer to microwave (or conventional oven) and thence to the table. The fact that some barrier plastics can be recycled may also be a driving force for adopting unreinforced plastics for containers and packaging. It is estimated that 100 million pounds, or about 19 percent of the total annual polyethyleneterephthalate (PET) production of 535 million pounds was recycled in 1984.[27]

Over the short term (2 to 5 years), aluminum could face a continually increasing competitive threat from unreinforced plastics in the single-serve soft drink market. Unreinforced plastics would not substitute directly for aluminum in the short term, but they could continue to displace glass in half-liter sizes and hence offer consumers a choice of the plastic container as an alternative to the 12-ounce can. These competitive forces do not constitute substitution of unreinforced plastics for aluminum; rather, this situation would hold the demand for cans under what it normally would have been, thereby decreasing the overall growth of the market for aluminum.

In the longer term (5 to 10 years), the recyclability of unreinforced plastics versus aluminum will be an important consideration, as will the relative weight of the two materials since weight affects processing, shipping, and storage costs. Although the current plastic material, PET, is recyclable (the recycled product goes into converting textile fiber-fill, strapping, plastic lumber, and polyols for other polymer manufacture), this is not the material that would substitute directly for the aluminum beverage can. The plastic or plastic composite can (i.e., a can made of combined layers of plastic with special barrier properties) could be made of more than one type of plastic and hence could make recycling much more difficult.

Since the technology for aluminum food cans is still in a beginning stage, there could be significant advances over the next 10 to 20 years that could increase the aluminum can's competitive position. Aluminum's share of the food can market could increase to about 10 to 15 percent over the next 15 years.[28]

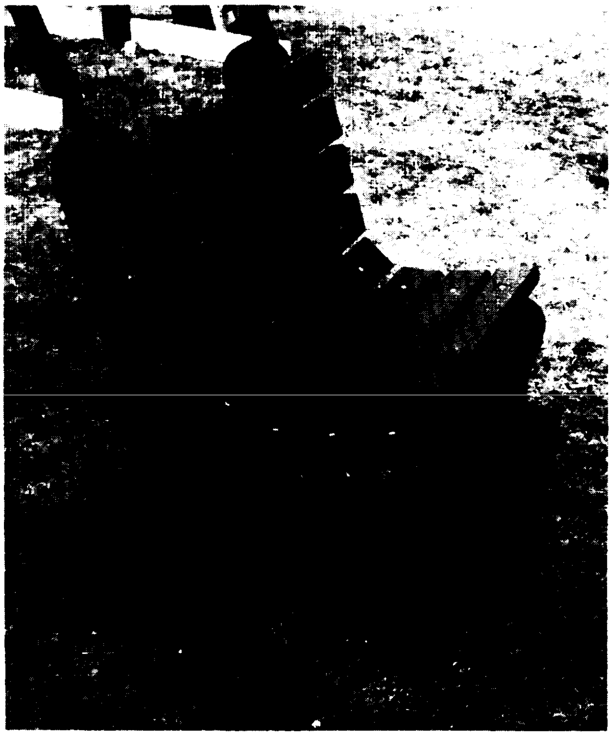

Photo courtesy of Processed Plastics Co.

Plastalloy bench made of 100°/0 recycled plastic.

The current trend toward alternative containers could continue to become very significant in the 3-to lo-year time frame, and unreinforced plastics could be the dominant materials for food cans. The substitution of unreinforced plastics for aluminum in beverage containers could begin in a significant way in the 3- to 10-year time frame and become a potentially serious competitor to aluminum in the 5- to 15-year time frame.

Assuming that in 15 years unreinforced plastics will capture half of all container markets for aluminum (currently 7 percent by dollar value of all aluminum use), total U.S. aluminum use could decrease by 3 to 4 percent by dollar value. Total container use of steel is currently 4 percent of the total steel output by dollar value, and *use* of steel is likely to decrease significantly as both aluminum and unreinforced plastics substitute for steel in containers.

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[17] *1986 Beverage Industry Annual Manual,* **produced by** Magazines for Industry, Harcourt, Brace, Jovanovich Publications, September 1986, p. 62.

[28] Alcoa 1985 Annual report.

DEVELOPMENT OF NEW INDUSTRIES AND CHANGES IN EXISTING INDUSTRIES

Substitution has the potential to become a significant force over the next 20 years as new materials technologies are commercialized. This assessment, however, is contingent on the ability of these materials to overcome key technical and economic barriers that are identified in this report.

To the present time, there have been two effects of materials substitution on the steel and aluminum industries: an increase in R&D aimed specifically at efforts to develop new materials; and inter- and intra-industry joint ventures aimed at new product development in traditional as well as advanced materials.

Intra-industry cooperative efforts in the steel industry have centered on developing a new direct sheet casting process and on electrogalvanizing (EG) lines. These efforts are being undertaken jointly (primarily due to a lack of individual company resources) as responses to a recognized materials substitution threat. The installation of EG lines is in direct response to more stringent automaker requirements concerning corrosion and surface quality, and represent the steelmaker' strategy to ward off competition from other metals and unreinforced plastics.[29] The commitment to this strategy can be seen by the fact that five new lines came on stream in 1986 representing a $500 million investment, and that there are 13 coatings for automotive sheet steel now being produced.[30]

There have been several joint ventures between aluminum user and supplier industries including one to develop and make high-performance plastic containers for the U.S. food industry, and one with a foreign automaker for the development of a prototype aluminum auto body and frame. These efforts are direct responses by the aluminum industry to the materials substitution threat and the potential for aluminum to substitute for steel in automobiles.

In addition to diversifying into nonmetals businesses, the aluminum industry is pursuing opportunities in Al-Li alloys, MMCs, and rapidly solidified technology. Currently, for instance, four aluminum firms either have or are anticipating having plants to produce Al-Li alloys. Because Al-Li alloys are sold to the same markets as traditional aluminum, aluminum firms have a strong marketing advantage over new firms. The widespread use of Al-Li alloys could also cause significant modifications to the end users of these new alloys.

Because lithium is poisonous even at very low concentrations, special precautions must be taken to segregate Al-Li scrap from other aluminum scrap that would be recycled by usual methods. Because of the special precautions that must be taken, specialized machine shops and recycling centers could be required.

Alcoa is developing its aramid-reinforced aluminum MMC (ARALL) to be used on commercial aircraft and Dural Aluminum Composites Corp. (a wholly owned subsidiary of Alcan Aluminum) brought 2 to 3 million pounds of capacity for silicon carbide-reinforced aluminum MMC on line in February 1988.[31]

Significant substitution of advanced materials for aluminum and steel in the various markets mentioned above could occur in roughly 10 to 30 years after substitution has begun, based on past experience in these or similar industries. As these materials begin to substitute for aluminum and steel, new industries will be formed.

PMCs and Unreinforced Plastics Industries

The PMC and unreinforced plastics industries have already established definite market segments. Significant growth in sales of PMCs is expected. Charles H. Kline& Co. estimates that the

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[29] Wrigley, op. cit., footnote 21, 1986.

[30] T. Cirisafulli, "Industry Striving for Better Steels to Battle Competition in Auto Market, " *American Metal Market,* Mar. 11, 1986, p. 3.

[31] "Alcan's Dural Unit to Expand Aluminum Composite Capacity, " *Performance Materials* (Washington, DC: McGraw-Hill, Jan. 11, 1988), p. 2.

demand for PMCs in automobiles could rise from approximately 700,000 pounds in 1984 to 1.4 million pounds in 1995, and the demand for PMCs in aircraft/aerospace applications could increase from approximately 8.6 million pounds in 1984 to nearly 75 million pounds in 1995.[32] This study projects that sales of PMCs will reach approximately $5.5 billion by the year ***2000.***[33] Overall, about 3 percent of total U.S. resin production is used in some type of composite.[34]

Adhesives and Coating Industries

increased growth in PMC materials could also increase the demand for specialty adhesives and coatings, C. H. Kline & Co. forecasts that demand for specialty adhesives and coatings for PMCs could grow from $35 million in 1985 to $110 million in 1995, an average rate of growth of 12.1 percent per year.[35] Liquid, paste, and film adhesives together accounted for 85 percent of the total dollar value of adhesives markets in 1985.

The current adhesives and coatings industry structure is fairly concentrated, with American Cyanamid, Ashland, 3M, and Morton-Thiokol together controlling about 60 percent of the market. However, the industry may become less concentrated over the long term as other suppliers strive to increase their presence.

Weaving Industry

PMCs using three-dimensional braided fibers or woven fabrics offer a significant advantage over unidirectional tape or two-dimensional prepreg, in that there is less tendency for the PMC structure to delaminate under loading. Although the number of companies now producing these braided structures is small, their numbers could grow as the demand for braided PMCs increases. This industry could grow quickly over the next 10 to 20 years because of expected increases in the use of braided preforms for PMCs and MMCs, especially in the aircraft industry.

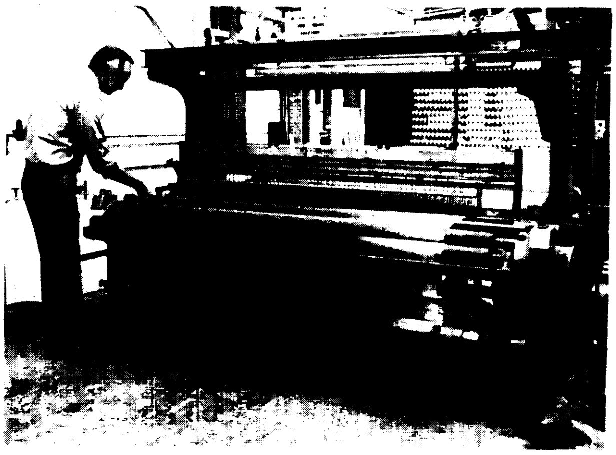

Photo courtesy of AVCO Specialty Materials

Flexible interweaving of, SiC-reinforced Al to be used **in investment casting** process.

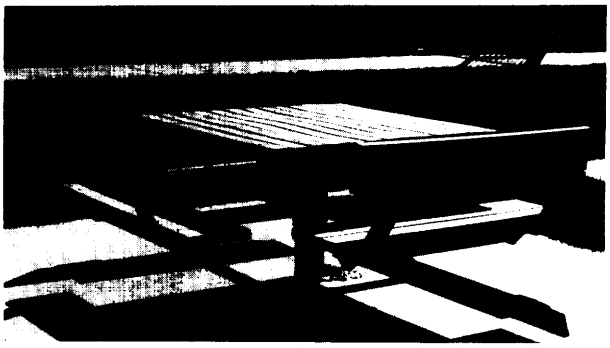

Photo courtesy of Polymer Products, Inc

Integrated benches and table made from 100% recycled plastics.

Recycling Industry

Disposal of unreinforced plastics and PMCs currently pose large problems; several States now have legislation pending to ban nondegradable plastic products such as six-pack rings, fast food packaging, and egg cartons.[36] However, no viable technologies currently exist for degradable plastics food packaging.[37] More and more, com-

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[32] S. Brown, C. H. Eckert, **and C. H. Kline, "Advanced Polymer Composites: Five Keys to Success, " presented to the Suppliers of Advanced Composite Materials Association (SACMA), in Anaheim, CA, Mar. 21, 1985,**

[33] Ibid

[34] Norman Fishman, **SRI** International, personal Communication, May 1988,

[35] "Adhesives, Coatings Makers Banking on Composites Growth, " *Chemical Marketing Reporter,* July 21, 1986, pp. 7, 26,

[36] **Robert Leaversuch, "Industry Weighs Need to Make Polymers Degradable, "** *Modern Plastics,* August 1987, p. 53.

[37] Ibid.

panics are beginning to look toward recyclable plastics. The fact that thermoses such as epoxies are not recyclable may make them obsolete, according to some industry experts .38 Reinforced or layered plastics may prove to be a major problem to recycling efforts, sufficient to inhibit their use, according to some recycling industry representatives.[39]

Three changes could occur in the recycling industry. First, since recycling of aluminum cans has become a significant activity over the past 15 years, the aluminum recycling industry could be seriously affected as the use of aluminum in beverage cans decreases. It is possible, however, that the recyclability of aluminum could give the metal a significant advantage over competing materials that cannot be easily recycled, e.g., unreinforced plastics and PMCs.

The second change could occur in the steel recycling industry. The increasing use of nonrecyclable materials in uses traditionally served by steel could have adverse effects on the recycling industry, especially in the case of automobiles, in that scrap steel is reused in electric furnaces.

The third change could be the emergence of specialty recycling facilities that can handle poisonous materials (e.g., aluminum alloys containing lithium) or difficult-to-recycle materials (e.g., unreinforced plastics, MMCs, or PMCs). There currently exists no satisfactory commercial process to recycle these materials. However, recycling processes are now under development, and it is possible that commercially viable processes could be put into use as the growth of these materials industries proceeds.

In summary, the substitution **of** new materials for aluminum and steel in major market segments could create significant new industries and modifications to existing industries over the next two decades. Secondary industries such as the adhesives, coatings, weaving, and recycling industries could also be affected as new materials are increasingly adopted. The recyclability of the new materials could become a major factor affecting their use.

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[38] Robert Leaversuch, "Practicality is the Key in New Strategies for Recycling," *Modern Plastics,* August 1987, p. 67.

[39] Ibid.