The Future of Metals

The metals market will continue to thrive into the next century

BY T. W. EAGAR

Currently, there is intense worldwide interest in advanced materials and processing. The Office of Technology Assessment has selected advanced materials technology, biotechnology and information technology as the keys to future industries, with a growth in the materials market of $100-billion projected over the next decade. The development of these materials has been linked to our national competitiveness and our future standard of living (Ref. 1).

Many research findings extol the benefits of newly developed polymers, semiconductors, ceramics and composites, with predictions that these new materials will significantly change our lives in the years to come. Many companies have reduced their research efforts in metals and have diversified into these other classes of materials. Others, constrained by an increasingly competitive international trade climate, have greatly reduced or eliminated their research and development activities altogether. Some have predicted a continual erosion of the market for metals, in favor of alternate materials. The rationality of this prediction and the direction of future metals technology are examined in this article.

The Markets for Materials

A number of studies have projected the demand for advanced materials at the end of the next decade. Table 1 provides a summary of these predictions, as well as the projected annual growth rates. It can be seen that, while the market for steel has the lowest growth rate, it has by far the greatest volume. Even at a 2% annual growth rate, the increased market for steel over the next ten years will exceed the increased market for ceramics, composites and semiconductors combined. In addition, the metals industries will continue to be the largest employer among the materials-producing industries (Ref. 2).

Metals are primarily structural materials and, as such, are used in extremely large quantities in bridges, buildings, ships, transportation vehicles, and the like. Steel is the most common metal, comprising over 95% of all metals by volume—Fig. 1.

The primary advantage of metals as a structural material is the exceptional combination of strength and toughness. Figure 2 is a modified ratio-analysis diagram that illustrates this point vividly. Designers avoid the elastic plane strain region of this diagram in order to prevent brittle fractures. Most modern structures are designed in the elastic-plastic regime, while a few, very critical structures are designed to behave plastically (Ref. 3). Clearly, metals, and especially steel, have the most favorable combination of strength and toughness. Ce-

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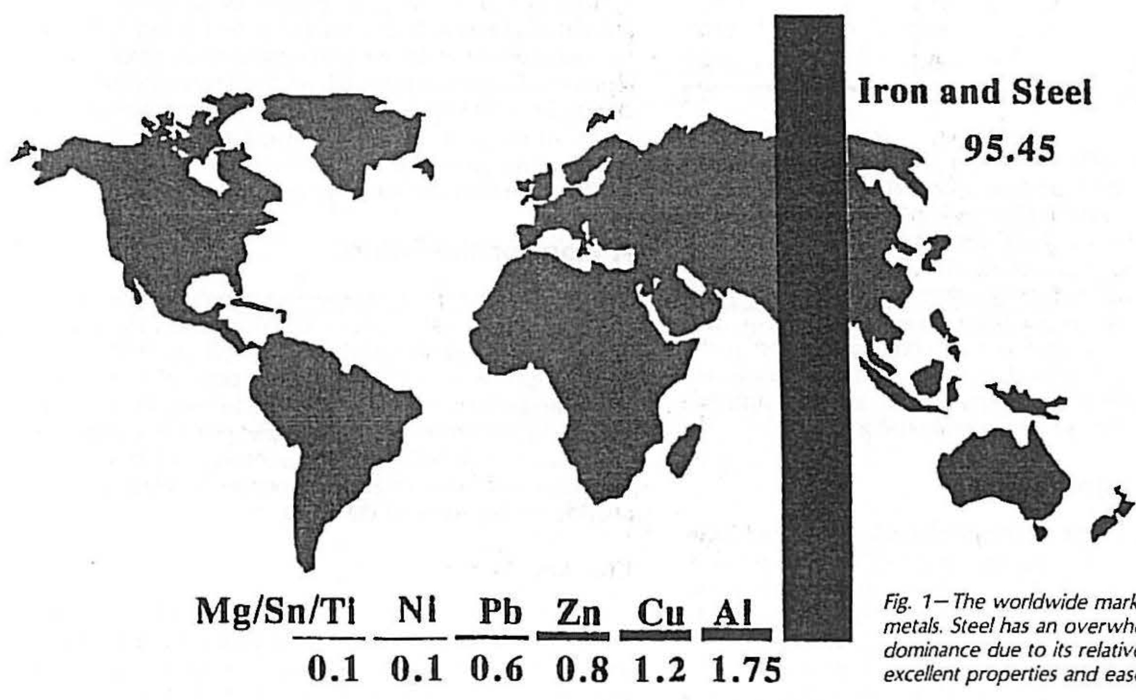

Fig. 1—The worldwide market distribution of metals. Steel has an overwhelming dominance due to its relatively low cost, excellent properties and ease of fabrication.

Table 1—Estimated World Markets for Advanced Materials In the Year 2000

	Market Volume	Estimated Annual Growth
Fine Ceramics	$5-billion	20%
Composites	$15-billion	10%
Semiconductors	$100-billion	5%
Steel	$500-billion	2%

Table 2—Comparison of Expected U.S. Expenditures between 1991 and 2000

A new TV and VCR for every U.S. Household	$60-billion
*A new car for every U.S. household	$2000-billion
*Rebuild the infrastructure—highways, waterworks, etc.	$3000–10,000-billion
Savings and loan bailout	$500-billion
*Defense budget	$3000–5,000-billion
HHS budget	$5000–10,000-billion

*Metals intensive

Table 3—Ferrous Metals Content in the Average U.S. Automobile

Year	1984	1990
	Weight, lb	
Total	3232	3142
Cold-rolled steel	1526	1405
High strength steel	210	238
Stainless steel	28.5	34.0
Iron	481	454
Powder metal	18.5	24.0
Ferrous, percentage	70.0%	68.6%

ramics have exceptional strength, but their extreme brittleness precludes their use in true structural applications (Ref. 4). Polymers can operate in the elastic-plastic regime, but their low strength creates many premature structural failures. Although the chemical and environmental stability of polymers is exceptional, increasing concerns over waste disposal may make this as much of a detriment as it is a benefit of these materials. Finally, one notes that composites overlap the strength and toughness of aluminum, which explains why advanced composites are slowly making inroads in the structure of aircraft and other weight-critical products.

The Markets for Metals

It is useful to consider the major expenses the United States will face over the next decade, and to determine whether metals will be necessary in each category. For example, many people decry the loss of the consumer electronics industry to offshore suppliers. Purchase of one new VCR and one new television for each of the 100-million households in the United States over the next ten years will cost $60-billion. This is a large sum, but its significance pales beside a number of other "national" expenses. A new car for each household over this period would cost $2000-billion, while rebuilding our highways, waterworks, etc., would cost even more. Table 2 compares some of our major expenses and notes that three of the four largest expenses are metals intensive. Only the Health and Human Services costs will match or exceed the costs of providing transportation, infrastructure and defense. Clearly, there is a very large market for metals over the next decade.

Nonetheless, many people claim that the use of metals in these applications has decreased sharply in recent years and will continue to decrease in the future. In general, this is not true. Table 3 shows the weights of ferrous metal used in the average U.S. automobile in 1984 and in 1990. In spite of a 12% increase in the use of plastics and composites (to 229 lb), the net decrease in the use of steel was only 1.4% of the total weight. The use of all metals decreased by only 0.4% as a fraction of the vehicle weight over this same period. Thus, metals are not losing market share as rapidly as is often reported in the general press.

Metals as High-Technology Materials

Many observers suggest that the metals industry is based on old, outdated technology, and that the advanced ceramics, semiconductors, polymers and composites represent the high-technology wave of the future. For those whose professional interests have straddled the traditional metals industries, as well as the newer "high technology" industries, the claim of technological sophistication of advanced materials is striking. From the point of view of materials science and fabrication technology, our knowledge of traditional materials far exceeds our understanding of advanced materials. The traditional materials (such as metals) have been studied for many years and, as one of my colleagues says, "All the easy problems have been solved." The scrap rate in processing of traditional materials is low, especially when compared to advanced materials where rejection rates of 75 to 90% or more are not uncommon. Given the sophisticated technological applications of advanced materials, the processing that is employed in the production of these materials is remarkably crude.

In addition, extensive development has raised the physical properties of metals to exceptional levels. For example, a 10 ksi improvement in the fracture toughness of a steel would represent an approximate 10% relative improvement, while an equal increase for a ceramic would represent a relative increase of 400% or more. Thus, major relative gains in the structural properties of metals are much more difficult to achieve than they are for other materials classes.

A Plan for the Future

Even if major relative improvements in the structural performance of metals is likely to be evolutionary rather than revolutionary, their market dominance will ensure their continued importance from an economic point of view. However, the question remains as to where to invest in the metals industry in the future. Several examples provide a simple answer: lower-cost, higher-quality processing will provide future payoffs in metals production and use. Two U.S. factories provide the evidence of this trend.

Chaparral Steel

Chaparral Steel, located near Dallas, Tex., began operating in the mid-1970s. The company uses steel scrap as a raw material, electric furnaces for melting, and continuous casting and rolling to produce bar stock and structural beams. The corporate strategy is to be the world's low-cost producer of quality steel products. Given that world labor rates are much

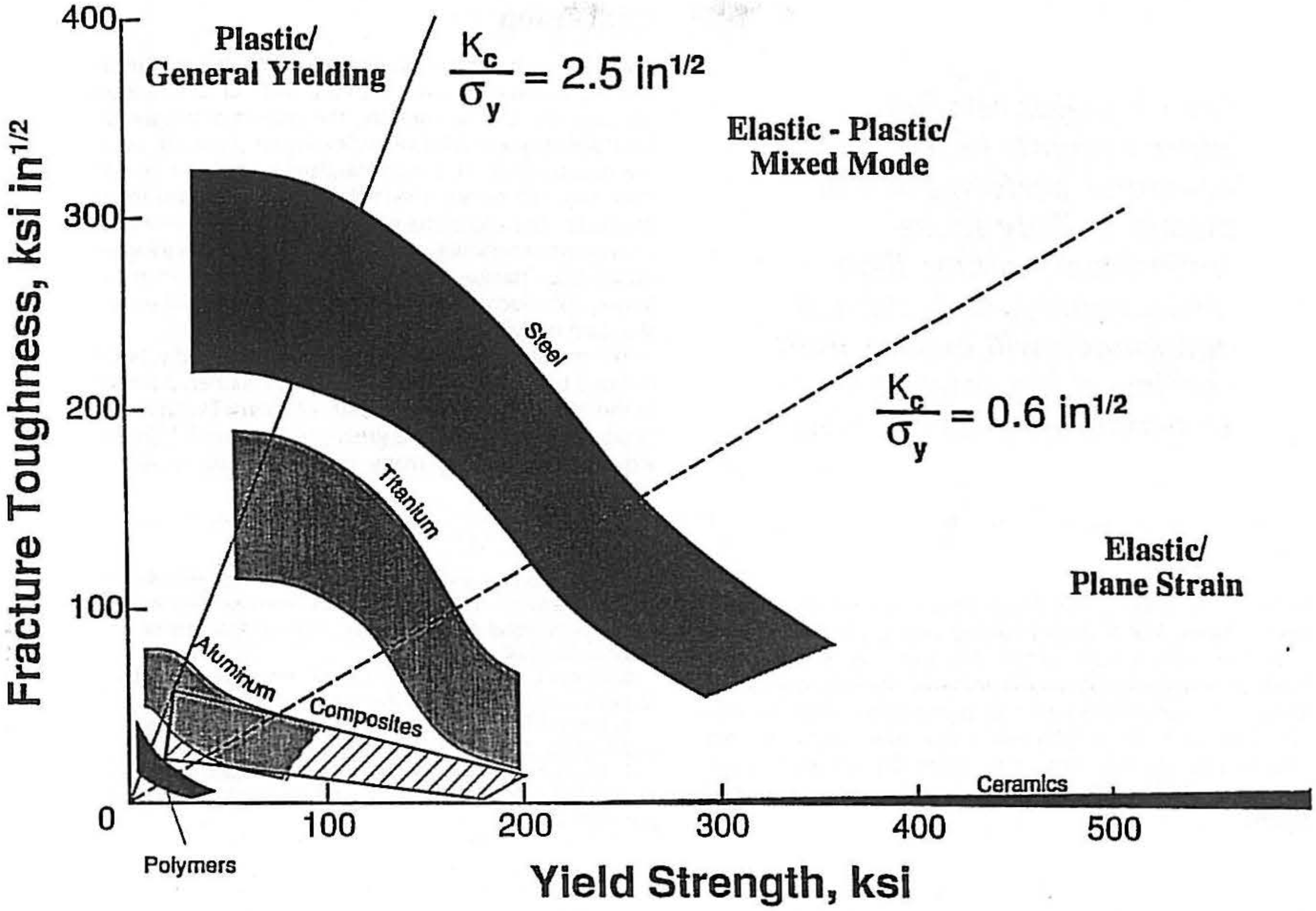

Fig. 2 — The relationship between fracture toughness and strength for various materials. The three regions defining elastic and plastic behavior are described for materials of approximately 1 in. in thickness. For materials much thinner or much thicker than 1 in., these transitions will shift.

lower than U.S. wages, the company's philosophy was to reduce the labor content of a ton of steel to less than the shipping cost of a ton of imported steel. Thus, as Chaparrel President Gordon Forward, said, "Even if other countries pay their workers nothing, they would not be able to sell steel in the United States at a lower cost than Chaparral." The strategy has worked. With less than 1000 employees, Chaparral produces 1.5-million tons of product per year. This is equivalent to 1.2 man-hours per ton of steel, whereas the best integrated steel producers, both in the U.S. and abroad, require 6 man-hours per ton.

By use of unconventional management, near-net-shape continuous casting, and rolling schedules that others said would be impossible, Chaparral has reduced the cost of structural steel beams by approximately 30%. It completes the rolling process in seven to 11 passes, as compared with 25 to 30 passes for conventional processing.

This is hardly a high-technology product, and it is certainly a product for which most people thought the processing practice was mature. There appears to be little opportunity to gain significant competitive advantage in such an industry, but Chaparral has shown that a motivated work force can make major strides in the processing of an established material. Its progress has been so great and so rapid that the portland cement industry has begun a new research program to develop methods of competing with this new low-cost structural material — steel beams.

When Chaparral began producing steel beams, imported beams had 41% of the U.S. market. Today, there are virtually no structural beams of this size class imported, and Chaparral is exporting to both Europe and Japan.

Alcoa Tennessee

The aluminum plant in northeast Tennessee is one of the oldest in the Alcoa system. As recently as ten years ago, the labor-management relationships were among the worst anywhere. After a bitter strike in the late 1970s, Alcoa's senior management was considering closing the entire facility. With this fate in mind, the Tennessee employees developed a strategy to streamline to one product — aluminum beverage can body sheet — with the goal of becoming the lowest-cost, highest-quality producer in the world. After four years of cooperation and increased productivity, they convinced Alcoa's senior management to not only keep the plant open, but to invest $400-million in new facilities. Today, the plant is considered the most modern aluminum sheet rolling facility in the industry and the product is exported around the world. Jobs are secure, but in addition, they have shown that intelligent investments in people and in facilities can produce major profits and performance in a commodity product.

Both Chaparral and Alcoa Tennessee have a sales-to-employee ratio of approximately $400,000 per year. This is three to four times as large as the ratio in many of the advanced

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materials companies. This clearly shows that metals not only have a future, but that they can be very profitable, as well.

The key to the success of both Chaparral and Alcoa has not been development of a new material. Rather, it was the thoughtful application of improved processing and considerate treatment of employees, such that everyone has "ownership" in the success of the plant. These successes are worthy of emulation by many other companies in the United States.

Conclusion

In spite of the many predictions about the growth of advanced materials, it is not the case that our need for metals will diminish. On the contrary, the growth of the world's infrastructure, especially in less-developed countries, as well as the maintenance of a high standard of living in developed countries, will create a steadily growing demand for metal products. The successful producers will be those who have the vision to continually improve on existing technologies and processes. Changes will be evolutionary rather than revolutionary, but such changes *are* occurring and, as they do, the standard of living for each of us improves.

The metals industry may not be growing rapidly, but this is not due to atrophy or lack of progress. Rather, it is because of the gigantic size of this industry. As Mark Twain once said, "Rumors of my death are greatly exaggerated." The metals industry is alive, and many parts of it are in very good health. ◆

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