Industry & Trade Summary

Structural Ceramic Products

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PREFACE

In 1991 the United States International Trade Commission initiated its current *Industry and Trade Summary* series of informational reports on the thousands of products imported into and exported from the United States. Each summary addresses a different commodity/industry area and contains information on product uses, U.S. and foreign producers, and customs treatment. Also included is an analysis of the basic factors affecting trends in consumption, production, and trade of the commodity, as well as those bearing on the competitiveness of U.S. industries in domestic and foreign markets.[1]

This report on refractory ceramics covers the period 1988 through 1992 and represents one of approximately 250 to 300 individual reports to be produced in this series during the first half of the 1990s. Listed below are the individual summary reports published to date on the minerals, metals, and miscellaneous manufactures sector.

USITC publication number	*Publication date*	*Title*
2426	November 1991	Toys and models
2475	July 1992	Fluorspar and certain other mineral substances
2476	January 1992	Lamps and lighting fittings
2504	November 1992	Ceramic floor and wall tiles
2523	June 1992	Prefabricated buildings
2587	January 1993	Heavy structural steel shapes
2623	April 1993	Copper
2653	June 1993	Glass containers
2692	November 1993	Refractory ceramic products
2694	November 1993	Flat glass and certain flat glass products
2738	February 1994	Structural ceramic products

NO TAG The information and analysis provided in this report are for the purpose of this report only. Nothing in this report should be construed to indicate how the Commission would find in an investigation conducted under statutory authority covering the same or similar subject matter.

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INTRODUCTION

Background

Structural ceramics[1] are used principally in the manufacture of wear parts[2] and cutting tool parts where their superior impact resistance makes them ideal for applications that require resistance to high wear, high temperatures, and chemical corrosion (See appendix A for a Glossary of Terms defining industry-specific terms used through the report). Among the markets served by the structural ceramics industry are the automotive and related machine tool and defense and aerospace industries (figure 1). In 1992, wear parts and cutting tool applications accounted for 56 percent of the structural ceramics market, with defense/aerospace and automotive applications each accounting for 19 percent (figure 2). Ceramics are also often superior to metal in bushing and bearing applications because of greater heat and corrosion resistance and minimal lubrication requirements. This report contains information on the domestic and foreign industries producing structural ceramic products and the U.S. industry's performance in domestic and foreign markets. The report covers the period 1988 through 1992.

Structural ceramics are, thus far, a small segment of the entire ceramics industry, representing only 3 percent ($2 billion) of 1992 world ceramic sales. However, they represent the fastest-growing ceramic industry segment because of the demand for "advanced"[3] structural ceramic (ASC) parts, which have even greater advantages over competing metal parts in applications subject to high heat and corrosion. In addition, the light weight of ASC parts makes them potentially useful in the aerospace and automotive industries, which are concerned with weight reduction and increased energy efficiency. For example, silicon carbide ceramics, which perform effectively at temperatures of 1,375-1,425°C, are being

[1] Establishments primarily engaged in the manufacture of these commodities are classified according to the end-uses for which these products are used. These items are likely to be found in SIC 3541, "Machine Tools, Metal Cutting Types," SIC 3519, "Internal Combustion Engines, Not Elsewhere Classified," SIC 3562, "Ball and Roller Bearings," and SIC 3724, "Aircraft Engines and Parts."

[2] Includes items such as seals, valves, nozzles and wear pads.

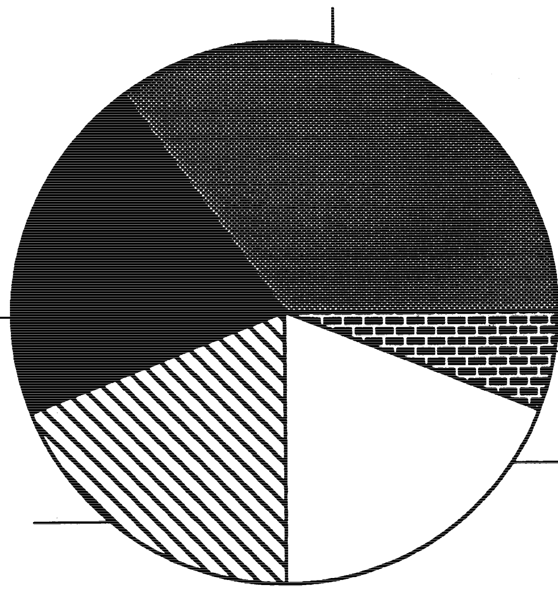
[3] Advanced ceramics use high-purity, synthetically produced raw materials, such as aluminum oxide, zirconium oxide, silicon carbide, and silicon nitride which are fired at higher temperatures than traditional ceramic materials. Advanced ceramics have greater hardness, higher melting temperatures, greater resistance to wear and corrosion, lower density, lower thermal conductivity and lower thermal expansion than traditional ceramic materials.

Figure 1
U.S. structural ceramics industry: Principal markets, applications, and physical properties

MARKETS	APPLICATIONS	PHYSICAL PROPERTIES
Military	Aircraft, protective armor	Light weight; strength.
Aerospace	Rocket engine exhaust and personal protective armor.	Wear resistance; heat resistance; electrical insulation.
Automotive	Engine components.	Light weight; high temperature/ corrosion/wear resistance.
Industrial	Machine components, bearings.	Wear and corrosion resistance; minimum lubrication
	Process pump seals and contol valves.	Abrasion, and corrosion resistance.
Electronics	IC substrates.	Surface smoothness; dielectric control.
	Wafer support in semiconductor processing.	High temperature strength; high purity; chemical resistance.

Source: The Norton Company.

Figure 2
U.S. consumption of structural ceramics, by end use, 1992



Source: Dr. Thomas Abraham, Business Communication Company.

used in experimental heat engines, heat exchangers, and cutting tools; competing metallic components are generally limited to temperatures below 1,100°C. Silicon nitride ceramics are increasingly being used in high-speed applications and applications where temperature varies over a wide range (see table 1 for a comparison of ceramic and metal properties).

Ceramic matrix composites are also ASC products that have been developed recently to improve the fracture strength and toughness of structural ceramic materials by reinforcing silicon nitride ceramics with silicon carbide whiskers and fibers. The introduction of whiskers and fibers reduces the potential of catastrophic failure of ceramic materials used in the machine tool, gas turbine, aerospace, and chemical industries. Ceramic matrix composites presently account for nearly 37 percent of total U.S. production of structural ceramic products.

Principal potential applications for ASC parts include automotive components such as turbocharger rotors, pistons, cylinder liners, valves, and water pump seals and defense and aerospace applications such as armor, radomes, rocket nozzles, aircraft journals, and bearings for missiles. Ceramic matrix composites have great potential application in the automotive industry as wear parts (valves and seals) and as engine components (piston rings, cylinder liners, and bearings).

Because structural ceramics are increasingly being used in a number of advanced, high-performance applications where traditional materials are inadequate, the success of the U.S. industry in producing these materials will have significant implications for U.S. international competitiveness. At present, the United States and Japan are the technological leaders in producing ASC products; the United States presently leads in the manufacture of ASC products for aerospace and defense applications while Japan leads in the manufacture of these products for the automotive industry. At present, the United States is considered to be the world leader in ceramic matrix composite production and technology.[4]

Manufacturing Process

The manufacture of structural ceramic products begins with the strip-mining or open-pit mining of raw material deposits - typically clays, fluxing minerals[5], silica, refractory oxides, and others (figure 3). The bulk raw materials are then crushed and ground to particles of 0.1 inch or less and screened to eliminate coarse oversized material or fine undersized material. Particle size and distribution are critical to producing uniform densities and aiding in sintering, or, "firing" the material.

[4] "The Status of the Global Ceramics Industry," *American Ceramic Society Bulletin*, July 1993, p. 109.

[5] Any mineral that appreciably lowers the combustion temperature of a ceramic by reacting with other materials present. Most fluxes for ceramics contain alkalies, alkaline earths, boric oxide, and lead oxides.

Table 1
Properties and end–uses of selected advanced ceramic materials compared to tool steel[1]

Material	Flexural strength	Hardness (Vickers)	Fracture toughness	Maximum use temperature	Young's modulus[4]	End–uses
	MPa[2]	*GPa*[3]	*MPa m^1/2*	*Degrees centigrade*	*GPa*	
Alumina	310	17	4	1,200	310	Wear parts, cutting tools
Silicon carbide	690	22.4	4	2,000	450	Wear parts, cutting tools, heat exchangers
Silicon nitride	925	15.9	5.5	1,400	315	Wear parts, automotive engine applications
Zirconia	1,440	12.8	8.5	800	220	Cutting tools, wear parts, experimental heat engines
Tool steel	5,500	10	98	700	210	Cutting tools, wear parts

[1] In comparing materials in this table it should be noted that while metals, such as tool steel, often exhibit higher strength characteristics than ceramics at normal operating temperatures, their strength characteristics fall considerably, compared to ceramics, at relatively high operating temperatures.
[2] Mega (1,000) pascals. A pascal is a metric measurement of force. One pound per square inch (psi) = 6.894 pascals.
[3] Giga (million) pascals.
[4] Young's Modulus defines the ratio between stress and strain and is an indicator of the elasticity of a material.

Source: Saint–Gobain/Norton Industrial Ceramics Corp.

The quality of modern structural ceramics is, to a large extent, based on the ability to correctly weigh and mix various raw materials of the proper purity and in the desired proportions. After proportioning and mixing, the material is tempered, which involves the addition of water or other liquids to dry ceramic powder, to produce a mixture suitable for forming into solid shapes which can later be sintered. The most common techniques used to form ceramic products include the following[6]:

- ***Dry pressing,*** whereby prepared powder is automatically fed into a tool cavity and compacted from two opposing directions to form pre-sintered shapes of complex geometry that yield tight tolerances. Dry pressing is often used for large volume production.
- ***Isostatic pressing,*** in which dry or semi-dry granulated ceramic powders are placed in a pliable rubber or polymer mold and are then pressed uniformly from all directions while immersed in a high-pressure oil or water cylinder. The resulting billet is then machined to near final shape before sintering.
- ***Slip casting,*** in which a slurry of fine ceramic materials, or "slip", is poured into a porous mold. The slip loses water to the mold and solidifies, conforming to the mold geometry.

[6] Newer, non-traditional manufacturing methods, including hot-isostatic pressing (HIP), sol-gel processing, and chemical and physical vapor deposition are being used to produced advanced ceramic materials because they are able to achieve greater and more uniform material densification and greater purity than traditional methods.

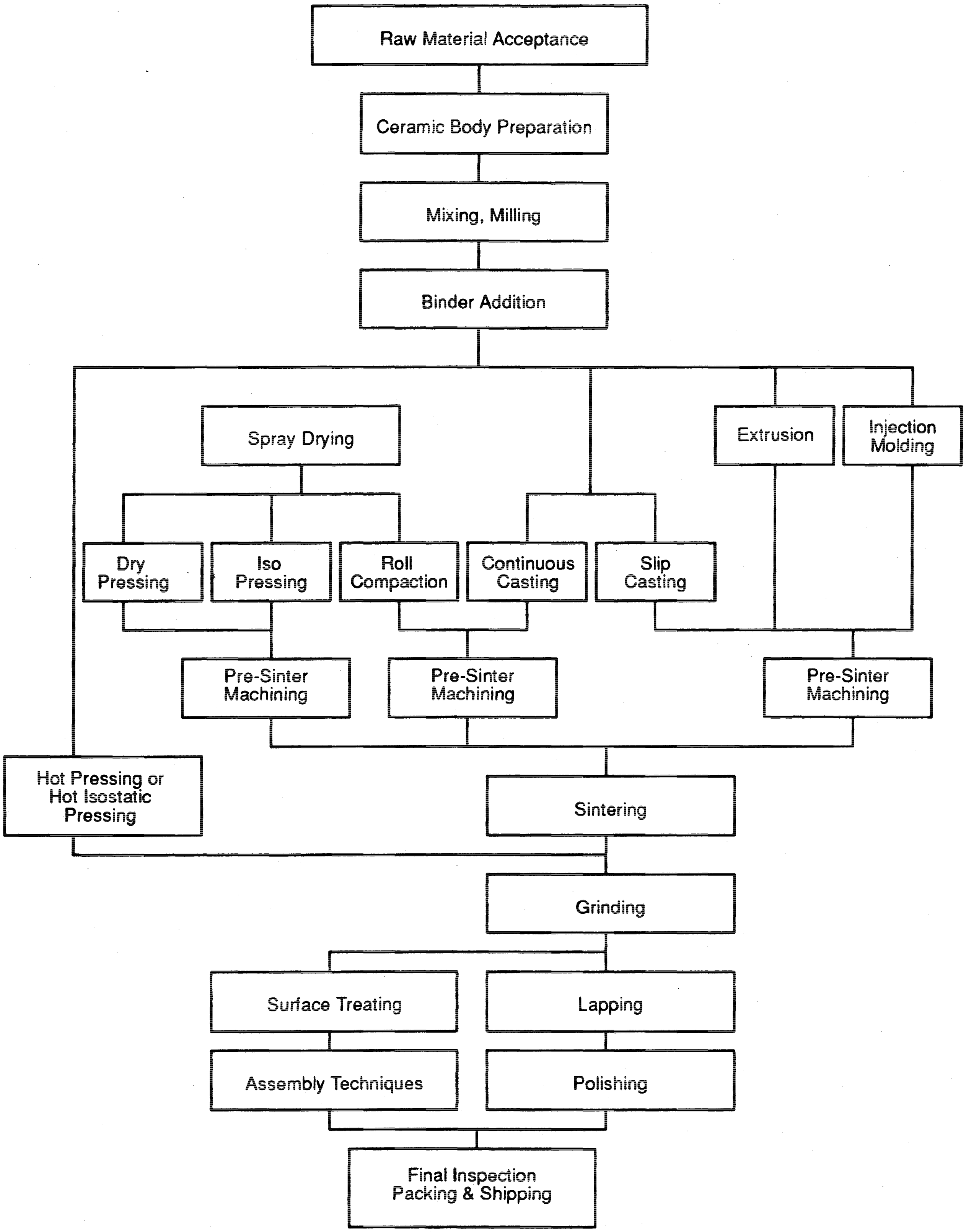
The type of forming process used will depend on the complexity of the shape to be formed, the nature of the raw materials to be used, and on the desired strength and thermal properties of the part to be produced. After forming, the soft ceramic shape may be dried to vaporize water and other additives such as plasticizers and binders and machined prior to sintering. Sintering involves converting the dried material into a hard, solid finished ceramic component by subjecting the formed shape to temperatures as high as 1,800°C in a kiln. This results in the reduction or near elimination of pores in the material, accompanied by shrinkage and increased density. Many ceramic products can be taken directly from the kiln, inspected, and shipped to the customer. Other structural ceramic products may undergo finishing operations which include grinding and either surface treating or lapping and polishing.

U.S. INDUSTRY PROFILE

Industry Structure

U.S. producers enjoy certain technological advantages in the production of many structural ceramics due largely to their lead in supplying components for end-use industries (machine tool, automobile, aerospace and defense-related industries). A number of new firms entered the industry during the past decade as the number of applications for advanced structural ceramics has grown. There are nearly 400 U.S. firms, ranging from small job shops to large multinational corporations, producing a wide variety of products; there are at least 20 major integrated producers of these products. Although the degree of

Figure 3
Ceramic processing flowchart



Source: American Ceramic Society.

vertical integration in the industry varies, most firms purchase raw materials from independent sources rather than supply their own raw material. Leading U.S. producers of structural ceramics[7] are included in the tabulation at the bottom of the page.

The Norton Co., Carborundum Co., and Vesuvius McDaniel are all foreign-owned. The Norton Co. is owned by the French multinational firm, Saint-Gobain; Carborundum is owned by British Petroleum; while Vesuvius McDaniel is owned by the Belgian firm, the Vesuvius Group. These firms, unlike much of the remaining U.S. industry, are vertically integrated producers that supply their own raw materials.

Because of the rapid growth experienced in the ceramics industry over the past decade, as many as 150 firms entered the industry during the 1980s.[8] During the same period there were more than 50 acquisitions by foreign firms and joint ventures in the U.S. ceramics industry, as Japanese and European companies entered the U.S. market in greater numbers.[9] There were three primary reasons for this foreign entry:[10]

- to buy U.S. assets which were perceived to be undervalued;
- to gain direct access to the rapidly growing U.S. market for advanced structural ceramics; and
- to gain competitive advantages from pooling technology, personnel, and company facilities in an effort to accelerate the pace of new product development while reducing production costs.

The competitiveness of structural ceramics depends, in large part, on the ability of producers to provide reliable components which are capable of performing at high temperatures for extended periods of time, at prices competitive with metallic counterparts. To meet these objectives, the structural ceramics industry has devoted much of its research and development efforts to developing improved process technologies. Examples of such technologies include near-net-shape processing, enabling manufacturers to produce in large volumes with lower unit costs; vapor deposition processes, which allow high-temperature ceramic coatings to be deposited on non-ceramic substrates; and hot-isostatic pressing (HIP) and high-temperature sintering to enable production of higher-quality products. Finally, because the quality of ceramic powders is probably the greatest factor influencing the structure and performance of structural ceramic parts, the industry is developing technologies, including sol-gel processing, to create high-purity powders.

According to industry analysts, production cost allocations for this industry vary depending on the type of component being produced and the manufacturing process used. In general, nearly 40 percent of production costs is accounted for by raw materials, while labor costs account for about 30 percent. Remaining costs are allocated among energy, product testing, environmental, and other miscellaneous categories. Plants generally are located within a 24-hour trucking or rail distance from where the product is to be consumed in order to minimize shipping costs and delivery time. Structural ceramic producers tend to be located in regions that can easily service important end-use markets such as the machine tool industry, which is concentrated in the industrial midwest, and defense- and aerospace-related industries.

Because structural ceramic products typically are chemically stable materials, they generally do not pose a health hazard. However, the Federal Occupational Safety and Health Administration does regulate the allowable levels of exposure to ingestible and airborne particulate matter in ceramic plants. The most serious environmental and health hazard involved in ceramic plants occurs from the use of ceramic fibers and whiskers in ceramic matrix composites.[11] According to the National Cancer Institute, virtually all mineral fibers having a diameter of less than 1 micrometer may be carcinogenic when introduced into the lungs of laboratory rats. No data on the effects of ceramic fibers or whiskers on humans are yet available and no industry standards for allowable fiber concentration in the workplace have yet been established.[12]

[7] Separate structural ceramics shipments figures for these firms are not available as many of these firms produce a wide variety of ceramics products which they do not separately report.

[8] Dr. Thomas F. Abraham, "Advanced Materials Industry Analysis," Business Communications Co., 1992, p. 3.

[9] Figures are not separately reported for the structural ceramics industry.

[10] Dr. Thomas F. Abraham, "Structural Markets On Rise," *Ceramic Industry,* Dec. 1988, p. 28.

[11] William J. McDonough, U.S. Bureau of Mines, and Greg Geiger, American Ceramics Society; telephone interviews by USITC staff, Washington, DC, Nov. 1993.

[12] *The New Materials Society: Challenges and Opportunities* (Washington, DC: U.S. Department of the Interior, 1990), Vol. 2, p. 7.67.

Company	Location	Principal ceramic products
Coors Ceramic Co Golden, CO		Alumina, silicon carbide, silicon nitride, zirconia
GTE Corp Stamford, CT		Alumina, silicon nitride
The Norton Co	Worcester, MA	Alumina, silicon carbide, silicon nitride
The Carborundum Co	Niagara Falls, NY	Aluminum nitride, silicon carbide
Vesuvius McDaniel	Beaver Falls, PA	Alumina, silicon carbide

Consumer Characteristics and Factors Affecting Demand

Demand for structural ceramics is strongly tied to demand in such end-use markets as the machine tool, automotive, and aerospace- and defense-related industries where they are used in wear parts, cutting tools, and bearings. Thus far, ceramics account for only 5 percent of the entire market in wear parts and cutting tool components; metal components account for the remainder. However, substantial growth in market share is anticipated given the product improvements that have characterized this industry in the past.[13] There are three principal factors limiting competitiveness with metal components and increased market penetration.

- ***Technical.*** The brittle nature of ceramic components makes them sensitive to small cracks and voids. Flaws as small as 10 to 20 micrometers can reduce the strength of a ceramic structure to a few percent of its theoretical strength, resulting in failures under excessive loads.

- ***Economic.*** Structural ceramic components are more expensive than metal components. In specialized applications where the unique properties of structural ceramic materials are desired, these materials may successfully sell at somewhat of a price premium when compared to prices of metal parts. However, at present, ceramic parts often cost 2 to 4 times more than the comparable metallic part which often makes their use prohibitively expensive.

- ***Resistance to change.*** End-users are somewhat reluctant to shift away from proven metal components which have had a long and successful service history toward newer materials which have had little long-term experience in highly critical applications.

The industry hopes to overcome technical obstacles to further ceramic use through microstructure design processes which reduce the probability of catastrophic failure in structural applications by increasing the toughness of ceramics. In addition, improvements in the quality of ceramic powders are being pursued through the development of ultrapure and uniform ceramic powders which are essential for the production of high-quality structural ceramics. Structural ceramics can be made more economically competitive through the use of near-net-shape techniques which reduce the need for highly expensive finishing operations.[14] Producers of structural ceramics hope to overcome resistance to change by end-users through constant attention to end-user needs, joint-venture arrangements with end-users to allow manufacturers to confer with design engineers of end-user companies, and demonstration of acceptable performance characteristics over time in those applications where sudden failure would not cause catastrophic consequences.

FOREIGN INDUSTRY PROFILE

Most industry analysts anticipate that the United States and Japan will continue to dominate the world market for structural ceramics during the next decade, in terms of both technical developments and market share.[15] At present, the United States tends to lead in the production of structural ceramic parts designed for aerospace and defense-related applications due to U.S. leadership in these industries. However, Japanese automobile producers generally have been more aggressive than U.S. manufacturers in using advanced ceramic parts in their automobile production lines.[16] Japan tends to lead the U.S. in the manufacture of structural ceramic components for the automotive industry because of its long experience in designing turbocharger parts for the Japanese automotive industry. In addition to turbocharger rotors, Japanese manufacturers are also further along than U.S. manufacturers in developing advanced ceramic engine parts such as diesel glow plugs and rocker arms and valves. European involvement in the structural ceramics market tends to be concentrated in the production of wear parts and cutting tool parts while efforts to produce components for automobile and aerospace markets are limited.

Japanese research and development policy is characterized by close cooperation among government, academia and industry. Government funding of research and development in advanced structural ceramics (known in Japan as "fine" ceramics) is provided through Japan's Ministry of International Trade and Industry (MITI) and has increased dramatically since 1980 as a surge of new companies entered the industry.[17] MITI's annual budget for advanced ceramics research amounted to $150 million in 1991 and is concentrated in advanced ceramics applications in gas turbine components, high-performance materials for severe atmospheric environments, and surface processing and machining.[18] In 1991, Japanese producers and MITI undertook a joint 10-year project to develop chemical process techniques to improve the purity, structure, and other properties of ceramic materials. The goal of this project is to advance the point in time at which advanced ceramic components substitute for metal components.[19] The Japanese market for advanced

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[13] S.B. Bhaduri and F.H. Froes, "The Science and Technology of Advanced Structural Ceramics," *Journal of Materials Science*, May 1991, p. 20.

[14] John Mack, "Advanced Ceramics Processing: Cracking the Problem," *Materials Edge*, 1990, p. 25.

[15] Dr. Thomas F. Abraham, Business Communications Co., telephone interview by USITC staff, Washington, DC, Nov. 1992.

[16] Ibid.

[17] Akio Kato and Hisayoshi Yoshida, "Advanced Ceramics Production and Markets in Japan," *Ceramics Today*, 1991, p. 3133.

[18] *Advanced Ceramics: Foreign Industry Analysis*, by Maurice M. Cook (Washington, DC: U.S. Department of Commerce, 1993), Section 5.1, p. 16.

[19] "Japan Fine Ceramic Trends," *Ceramic Industries International*, April/May 1993, pp. 8-9.

structural ceramics, which totaled nearly $700 million in 1991, is presently growing at an average annual rate of 8-10 percent and will likely be considered a major Japanese industrial sector by the next century.[20] Structural ceramics are used in Japan for the production of wear-resistant parts; cutting tools for the steel and automotive industries; engine components such as turbochargers, rocker arms, and precombustion chambers; and a limited number of consumer products.

Major Japanese producers of structural ceramics include Kyocera, which specializes in sintered ceramics, alumina, silicon carbide, and silicon nitride for use in cutting tool parts, bearings and other wear parts, and rotors for automotive turbochargers. Kyocera supplied nearly $2.6 billion of ceramics (including structural components) worldwide in 1992. Kyocera is currently working with both the U.S. and Japanese governments to develop all-ceramic turbine components.[21] Sumitomo Electric Industries Ltd., with total ceramics sales of nearly $650 million in 1992 and NGK Insulators Ltd, a major producer of turbocharger rotors, with total ceramics sales approaching $600 million in 1992, each produce a wide range of structural ceramic products. Japanese firms have also established strong supply relationships with U.S. manufacturers. For example, Kyocera, which produces structural ceramics in the United States, supplies material to the U.S. electronic, automotive and machine tool industries both through direct export sales and through ownership of its U.S.-based subsidiary, AVX Corp. Kyocera also currently has licensing arrangements with Ford Motor Co.

Germany, France, and the United Kingdom are the leading European producers of structural ceramic products. European producers have traditionally concentrated on the production and sale of its products within Europe. However, this emphasis is now beginning to change as European firms have moved aggressively to acquire ceramics-related firms and to establish joint subsidiaries in the United States, China and Australia.[22] Major European producers of structural ceramics include Compagnie de Saint Gobain and the Pechiney Group (France), Morgan Crucible Co. (United Kingdom), and the Hoechst Group, Siemens AG, and Feldmuhle (Germany). These firms are diversified multinational producers of a wide range of ceramic products including structural ceramic products such as wear parts (seals and bearings), cutting tools, engine parts, heat exchange tubes, and high-temperature fibers. European production of structural ceramics accounts for about 15 percent of total world production of structural ceramic products.[23] European participation in the U.S. market largely consists of ownership of large U.S. firms (Norton Inc., Carborundum Co., and Vesuvius McDaniel). European firms serve the U.S. market primarily from facilities located in the United States. U.S. subsidiaries of European firms are also important means for transferring advanced ceramics technology between the United States and Europe.

[20] *Advanced Ceramics: Foreign Industry Analysis*, by Maurice M. Cook (Washington, DC: U.S. Department of Commerce, 1993), Section 5.1, p. 16.
[21] Ibid., p. 18.
[22] Ibid., p. 25.
[23] "Giants in Advanced Ceramics," *Ceramic Industry*, Aug. 1992, pp. 27-30.

U.S. TRADE MEASURES

Tariff Measures

Column-1 duty rates in 1993 ranged from 3.9 percent for ferrite core memories to 9 percent for porcelain or china wares for laboratory, chemical or other technical uses, not elsewhere specified; these rates are not considered a limiting factor in the entry of foreign goods into the U.S. market. All column 1 dutiable items are eligible for duty-free treatment under special trade provisions. Current U.S. tariff rates, including special rates of duty, are provided in table 2.

The recently completed (December 1993) GATT Round of trade negotiations may result in further reductions in U.S. and foreign duties on the articles covered by this summary. The Uruguay Round schedule of U.S. concessions was not available when this summary was prepared.

Nontariff Measures

The Commission is unaware of any statutory investigation that has been instituted in the United States during the past 5 years involving imports of structural ceramic products.

FOREIGN TRADE MEASURES

Foreign ad valorem tariff rates for U.S. exports of structural ceramics in 1992 ranged from 5.1 percent to 7.7 percent on goods exported to the EU and from 2 percent to 6.7 per cent on goods exported to Canada. Tariff duty rates ranged from 10 to 20 percent ad valorem on structural ceramic items entering Mexico from the United States.[24] Japanese imports of structural ceramics are assessed ad valorem duty rates ranging from duty-free to 5.2 percent in addition to a 3 percent consumption tax assessed on the import value. There are no known nontariff measures affecting trade of structural ceramics with the EU, Canada, Mexico and other foreign markets.

The North American Free Trade Agreement (NAFTA), as implemented by the North American Free Trade Agreement Implementation Act (Public Law 103-182, approved Dec. 8, 1993), provides for the elimination of U.S. duties on structural ceramic products, effective January 1, 1994. Under the NAFTA, Mexico also eliminated its duties on imports of such goods from the United States, effective January 1, 1994. The NAFTA became effective for both the United States and Mexico on January 1, 1994.

[24] Under the United States-Canada Free-Trade Agreement (CFTA), tariff duties on 100 percent of U.S. structural ceramic products exported to Canada in 1992 are eliminated, effective January 1, 1994 (See app. B for explanation of CFTA).

Table 2
Structural ceramic articles: Harmonized Tariff Schedule subheading; description; U.S. col. 1 rate of duty as of Jan. 1, 1993; U.S. exports, 1992; and U.S. imports, 1992

HTS subheading	Description	Col. 1 rate of duty as of Jan. 1, 1993		U.S. exports, 1992	U.S. imports, 1992
		General	Special[1]		
				— 1,000 dollars —	
6909.11.20	Machinery parts of porcelain or china	4.7%	Free (A,E,IL,J) 2.3% (CA)	7,227	30,065
6909.11.40	Porcelain or china wares for laboratory chemical or other technical uses, nes	9%	Free (A,E,IL,J) 4.5% (CA)	73	428
6909.19.10	Ferrite core memories	3.9%	Free (A,E,IL,J) 1.9% (CA)	6,558	377
6909.19.50	Ceramic wares for laboratory, chemical or other technical uses, other technical uses, other than of porcelain or china, nes	8%	Free (A,E,IL,J) 4% (CA)	52,094	9,478
6909.90.00	Ceramic receptacles for agriculture and for conveyance of package goods	8%	Free (A,E,IL,J) 4% (CA)	44,631	1,694
8113.00.00	Cermets and articles thereof, including waste and scrap	5.5%	Free (A,CA,E,IL, J)	3,052	1,394

[1] Programs under which special tariff treatment may be provided, and the corresponding symbols for such programs as they are indicated in the "Special" subcolumn, are as follows: Generalized System of Preferences (A); Automotive Products Trade Act (B); Agreement on Trade in Civil Aircraft (C); United States-Canada Free-Trade Agreement (CA); Caribbean Basin Economic Recovery Act (E); and United States-Israel Free Trade Area (IL), and Andean Trade Preference Act (J).

Source: U.S. exports and imports compiled from official statistics of the U.S. Department of Commerce.

U.S. MARKET

Consumption

U.S. demand for structural ceramics experienced rapid growth during 1988-92 because of expanded end-use applications for advanced structural ceramics and improvements in product quality and consistency. U.S. apparent consumption of structural ceramics increased steadily during the period from $288 million in 1988 to an estimated $328 million in 1992 (table 3). Demand for structural ceramics is expected to experience average annual growth of nearly 10 percent during the 1990s, as advanced structural ceramics continue to gain market share in end-use industries that have traditionally used metal components. Industry analysts anticipate sustained high growth in demand for structural ceramics and, in particular, for advanced structural ceramics, as the industry continues to make progress in improving the quality, consistency, and price competitiveness of its products. Demand for advanced structural ceramic components for such high-volume outlets as the automotive and aerospace markets have the largest potential for growth during the next decade due to industry need for light-weight, energy-saving components. Advanced ceramics are also expected to gain market share relative to metallic components in these markets because they can operate at the higher temperatures demanded by today's hotter-running automotive and aerospace engines. The ratio of U.S. imports to consumption declined from a peak of 19 percent in 1988 to a low of 11 percent in 1991 before rising to 13 percent in 1992, with U.S. shipments increasing strongly as imports generally declined during this period.

Shipments

U.S. shipments of structural ceramics increased steadily during 1988-92, from $295 million to an estimated $400 million in response to growth in demand by end-users for advanced structural ceramics (table 3). Wear parts and cutting tool parts for use by the machine tool industry were the largest single product categories shipped by the industry, accounting for nearly 60 percent of all products shipped. Because of rapid growth in demand for advanced structural ceramic products, U.S. firms are adjusting their product mix to produce a higher proportion of silicon carbide, silicon nitride, and zirconia materials that meet the thermal, corrosion, and strength requirements of end-users.

Imports

U.S. demand for structural ceramics is satisfied largely by domestic production. However, foreign producers occupy important market segments, such as ceramic cutting tools and wear parts, which account for the bulk of U.S. imports. U.S. imports of structural ceramics decreased from $54 million in 1988 to $36 million in 1991 before rising to $43 million in 1992. The decline during 1988-92 reflected declining imports of ferrite core memories from Hong Kong and Japan (table 4). Japan supplied 65 percent of total U.S. imports in 1992, principally imports of cutting tool parts. If structural ceramics achieve anticipated inroads in automotive and engine-related components, Japan will likely supply a significant percentage of this market given the Japanese lead in developing such components for its domestic market.

Imports of structural ceramic products entering duty-free accounted for 2 percent of total imports in 1992. Imports under the CFTA accounted for 2 percent of import value in 1992 while imports under the Generalized System of Preferences, the U.S.-Israel Free-Trade Agreement, and the Caribbean Basin Economic Recovery Act each accounted for less than 1 percent of total imports in 1992.

FOREIGN MARKETS

Foreign Market Profile

The structural ceramics market is one of the fastest-growing segments of the global ceramics industry with total worldwide sales approaching

Table 3
Structural ceramic articles: U.S. shipments, exports of domestic merchandise, imports for consumption, and apparent consumption, 1988–92

Year	U.S. shipments[1]	U.S. Exports	U.S. Imports	Apparent U.S. consumption	Ratio of imports to consumption
	Million dollars				*Percent*
1988	295	61	54	288	19
1989	320	87	51	284	18
1990	350	90	37	297	12
1991	380	98	36	318	11
1992	[1]400	115	43	[1]328	[1]13

[1] Estimated by staff of the U.S. International Trade Commission.

Source: U.S. trade data are compiled from official statistics of the U.S. Department of Commerce. Shipments are from data provided by the Business Communications Company, except as noted.

Table 4
Structural ceramics: U.S. imports for consumption, by principal sources, 1988–92

(1,000 dollars)

Source	1988	1989	1990	1991	1992
Japan	14,450	17,081	18,715	24,183	28,150
Germany	5,558	9,804	5,861	3,851	6,150
France	3,514	2,975	2,768	3,220	4,474
Canada	12,367	7,664	3,709	378	845
Australia	272	261	660	860	796
United Kingdom	1,300	1,256	1,120	891	627
Taiwan	3,829	517	411	391	442
Mexico	394	553	723	526	298
Italy	288	347	229	476	253
All other	12,325	10,842	3,249	1,548	1,400
Total	54,279	51,300	37,445	36,324	43,435

Source: Compiled from official statistics of the U.S. Department of Commerce.

$2 billion per year and projected average annual growth of nearly 10 percent in major markets such as the United States and Japan. U.S. producers accounted for nearly 20 percent of world production of structural ceramic products in 1992. As a result of its technological strength in the development and production of structural ceramic products, the United States was a net exporter of these ceramic products during 1988-92. On the other hand, Japanese producers offer stiff competition to U.S. producers in such important markets as automotive applications and have taken a leadership role in the application and commercialization of certain structural ceramics products for this market. Global sales of advanced structural ceramics are expected to grow at near double-digit annual rates over the next decade because of the increasing need for these materials in high-temperature, high-corrosive environments and the need to find light-weight materials to promote energy efficiency.

The United States exports structural ceramic products principally to Western European markets whose machine tool, automotive, and defense and aerospace industries are consumers of these products. With strong growth anticipated in demand for advanced structural ceramics in coming decades, those nations with a strong presence in these end-use industries are expected to be primary consumers of U.S. products.

U.S. Exports

Because the United States is a leading worldwide producer of advanced structural ceramic products, it can be anticipated that U.S. exports will continue to have a strong presence in international markets. Efforts by other nations to create lighter-weight, more energy-efficient materials and processes should encourage greater use of these more advanced materials. Reflecting its strong relative position in the world structural ceramics market, the United States maintained its position as a net exporter during 1988-92. U.S. exports of structural ceramics increased steadily from $61 million in 1988 to $115 million in 1992 largely because of increased exports of ceramic machinery parts and bearings to Germany and the United Kingdom (table 5). The United Kingdom was

Table 5
Structural ceramics: U.S. exports of domestic merchandise, by principal markets, 1988–92

(1,000 dollars)

Market	1988	1989	1990	1991	1992
United Kingdom	4,033	5,606	5,192	6,059	13,913
Germany	5,407	7,382	8,773	8,288	13,271
S. Korea	3,431	8,451	9,278	10,662	12,333
France	1,807	3,958	4,032	5,420	10,884
Mexico	5,298	14,709	16,159	12,250	9,192
Canada	9,637	10,282	11,929	9,633	8,725
Taiwan	1,320	5,903	5,608	8,310	6,454
Japan	8,079	9,592	4,718	3,883	6,009
Italy	835	1,991	1,698	7,106	1,533
All other	21,466	19,204	22,936	26,329	32,980
Total	61,313	87,078	90,283	97,940	115,294

Source: Compiled from official statistics of the U.S. Department of Commerce.

the leading destination for U.S. exports in 1992, accounting for 12 percent of total exports, followed by Germany and South Korea, with each country accounting for 11 percent of total exports. U.S. exports of structural ceramics rose from 20 percent of U.S. shipments in 1988 to an estimated 28 percent of shipments in 1992 as certain export market sales expanded faster than domestic sales.

U.S. TRADE BALANCE

The U.S. trade surplus in structural ceramics increased from $7 million in 1988 to $72 million in 1992, as U.S. exports to major consuming markets increased steadily and U.S. imports declined overall during those years (table 6). Because U.S. producers are expected to face increasingly strong foreign competition, particularly from Japan, prospects for a sustained and growing U.S. trade surplus will depend on the ability of U.S. companies to compete effectively in the market for advanced structural ceramics by increasing the reliability of these products and reducing their cost relative to metal components.

Table 6
Structural ceramics: U.S. exports of domestic merchandise, imports for consumption, and merchandise trade balance, by selected countries and country groups, 1988-92[1]

(Million dollars)

Item	1988	1989	1990	1991	1992
U.S. exports of domestic merchandise:					
Canada	10	10	12	10	9
Mexico	5	15	16	12	9
United Kingdom	4	6	5	6	14
Germany	5	7	9	8	13
France	2	4	4	5	11
Japan	8	10	5	4	6
Italy	1	2	2	7	2
Taiwan	1	6	6	8	6
S. Korea	3	8	9	11	12
All other	22	19	22	27	33
Total	61	87	90	98	115
EU-12	14	22	22	30	46
OPEC	1	1	1	1	1
ASEAN	10	4	3	3	8
CBERA	1	1	1	([2])	1
Eastern Europe	([2])	([2])	([2])	([2])	([2])
U.S. imports for consumption:					
Canada	13	8	4	([2])	1
Mexico	([2])	1	1	1	([2])
United Kingdom	1	1	1	1	1
Germany	6	10	6	4	6
France	4	3	3	3	4
Japan	14	17	19	24	28
Italy	([2])	([2])	([2])	([2])	([2])
Taiwan	4	1	([2])	([2])	([2])
S. Korea	1	([2])	([2])	([2])	([2])
All other	11	9	2	1	1
Total	54	51	37	36	43
EU-12	11	15	10	9	12
OPEC	([2])	([2])	0	0	0
ASEAN	([2])	([2])	([2])	([2])	([2])
CBERA	([2])	([2])	([2])	([2])	([2])
Eastern Europe	0	0	0	0	([2])
U.S. merchandise trade balance:					
Canada	-3	3	8	9	8
Mexico	5	14	15	12	9
United Kingdom	3	4	4	5	13
Germany	-1	-2	3	4	7
France	-2	1	1	2	6
Japan	-6	-7	-14	-20	-22
Italy	1	2	2	7	2
Taiwan	-3	5	5	8	6
S. Korea	3	8	9	11	12
All other	11	12	20	28	32
Total	7	36	53	62	72
EU-12	2	7	12	21	35
OPEC	1	1	1	1	1
ASEAN	10	4	3	3	8
CBERA	1	1	1	([2])	1
Eastern Europe	([2])	([2])	([2])	([2])	([2])

[1] Import values are based on customs value; export values are based on f.a.s. value, U.S. port of export. U.S. trade with East Germany is included in "Germany" but not "Eastern Europe."
[2] Less than $500.

Note.--Because of rounding, figures may not add to the totals shown.

Source: Compiled from official statistics of the U.S. Department of Commerce.

APPENDIX A
GLOSSARY OF TERMS

GLOSSARY OF TERMS

Ferrite Core Memories
Magnetic ceramics composed of iron oxide compounds which serve as a medium on which digital or analog signals can be recorded or read. Once widely used in computer central processing units and in external memory storage and now principally used in analog recording for audio tapes and magnetic bubble technology.

Grinding
Diamond grinding is required to produce tolerances that are tighter than those achieved in the sintered condition. Typical tolerances can be reduced to as low as 0.0001 in. while special techniques can be used to reach 0.000025 in.

Hot-isostatic pressing (HIP)
A process which combines the isostatic forming and sintering processes by heating ceramic powders under mechanical pressure to produce a part that is stronger, more uniform, and with optimum density. HIP is more costly than other processes and is generally reserved for applications requiring ultimate material properties.

Near-net-shape processing
Any of a number of ceramic forming methods (such as injection-molding) which are used to produce a semi-manufactured part which is close to the final manufactured part. Eliminates the need for extensive grinding or finishing operations.

Sintering
During sintering, pre-formed ceramic compacts are brought to an elevated temperature, typically exceeding 1500°C. over a carefully controlled time/temperature profile. The ceramic compact fuses and reaches designed density.

Sol-gel processing
A ceramic forming process which involves preparing a homogeneous solution, changing the solution to a colloid, converting the colloid to a gel, and converting the gel to a solid through heating. Produces high-purity powders, precise control of particle size and the elimination of extensive grinding or finishing operations.

Surface treating
The most common surface treatment is glazing which involves applying a thin, nonporous glass coat over a sintered ceramic part to produce a surface seal. The melting point of the glaze is lower than that of the ceramic itself.

Vapor Deposition Processes
Processes such as chemical vapor deposition (CVD) and physical vapor deposition (PVD) which are used to deposit a thin coating of material with a desired set of properties to a less expensive substrate. Often used by the machine tool industry to deposit a ceramic coating to a high-speed metal tool bit.

APPENDIX B
EXPLANATION OF TARIFF AND TRADE AGREEMENT TERMS

TARIFF AND TRADE AGREEMENT TERMS

The ***Harmonized Tariff Schedule of the United States*** (HTS) replaced the *Tariff Schedules of the United States* (TSUS) effective January 1, 1989. Chapters 1 through 97 are based upon the internationally adopted Harmonized Commodity Description and Coding System through the 6-digit level of product description, with additional U.S. product subdivisions at the 8-digit level. Chapters 98 and 99 contain special U.S. classification provisions and temporary rate provisions, respectively.

Rates of duty in the ***general*** subcolumn of HTS column 1 are most-favored-nation (MFN) rates; for the most part, they represent the final concession rate from the Tokyo Round of Multilateral Trade Negotiations. Column 1-general duty rates are applicable to imported goods from all nonembargoed countries except those enumerated in general note 3(b) to the HTS plus Serbia and Montenegro, whose products are dutied at the rates set forth in ***column 2***. Goods from Albania, Armenia, Belarus, Bulgaria, the People's Republic of China, the Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Mongolia, Poland, Romania, Russia, Slovakia, Turkmenistan, and Ukraine are currently eligible for MFN treatment, as are the other republics of the former Socialist Federal Republic of Yugoslavia. Among articles dutiable at column 1-general rates, particular products of enumerated countries may be eligible for reduced rates of duty or for duty-free entry under one or more preferential tariff programs. Such tariff treatment is set forth in the ***special*** subcolumn of HTS column 1. Where eligibility for special tariff treatment is not claimed or established, goods are dutiable at column 1-general rates.

The ***Generalized System of Preferences*** (GSP) affords nonreciprocal tariff preferences to developing countries to aid their economic development and to diversify and expand their production and exports. The U.S. GSP, enacted in title V of the Trade Act of 1974 and renewed in the Trade and Tariff Act of 1984, applies to merchandise imported on or after January 1, 1976 and before September 30, 1994. Indicated by the symbol "A" or "A*" in the special subcolumn of column 1, the GSP provides duty-free entry to eligible articles the product of and imported directly from designated beneficiary developing countries, as set forth in general note 4 to the HTS.

The ***Caribbean Basin Economic Recovery Act*** (CBERA) affords nonreciprocal tariff preferences to developing countries in the Caribbean Basin area to aid their economic development and to diversify and expand their production and exports. The CBERA, enacted in title II of Public Law 98-67, implemented by Presidential Proclamation 5133 of November 30, 1983, and amended by the Customs and Trade Act of 1990, applies to merchandise entered, or withdrawn from warehouse for consumption, on or after January 1, 1984; this tariff preference program has no expiration date. Indicated by the symbol "E" or "E*" in the special subcolumn of column 1, the CBERA provides duty-free entry to eligible articles, and reduced-duty treatment to certain other articles, which are the product of and imported directly from designated countries, as set forth in general note 7 to the HTS.

Preferential rates of duty in the special subcolumn of column 1 followed by the symbol "IL" are applicable to products of Israel under the ***United States-Israel Free Trade Area Implementation Act*** of 1985 (IFTA), as provided in general note 8 to the HTS. Where no rate of duty is provided for products of Israel in the special subcolumn for a particular provision, the rate of duty in the general subcolumn of column 1 applies.

Preferential nonreciprocal duty-free or reduced-duty treatment in the special subcolumn of column 1 followed by the symbol "J" or "J*" in parentheses is afforded to eligible articles the product of designated beneficiary countries under the ***Andean Trade Preference Act*** (ATPA), enacted in title II of Public Law 102-182 and implemented by Presidential Proclamation 6455 of July 2, 1992 (effective July 22, 1992), as set forth in general note 11 to the HTS.

Preferential rates of duty in the special subcolumn of column 1 followed by the symbol "CA" are applicable to eligible goods of Canada, and those followed by the symbol "MX" are applicable to eligible goods of Mexico, under the ***North American Free Trade Agreement***, as provided in general note 12 to the HTS, effective January 1, 1994.

Other special tariff treatment applies to particular ***products of insular possessions*** (general note

3(a)(iv)), goods covered by the ***Automotive Products Trade Act*** (APTA) (general note 5) and the ***Agreement on Trade in Civil Aircraft*** (ATCA) (general note 6), and ***articles imported from freely associated states*** (general note 10).

The ***General Agreement on Tariffs and Trade*** (GATT) (61 Stat. (pt. 5) A58; 8 UST (pt. 2) 1786) is a multilateral agreement setting forth basic principles governing international trade among its signatories. The GATT's main obligations relate to most-favored-nation treatment, the maintenance of scheduled concession rates of duty, and national (nondiscriminatory) treatment for imported products; the GATT also provides the legal framework for customs valuation standards, "escape clause" (emergency) actions, antidumping and countervailing duties, and other measures. Results of GATT-sponsored multilateral tariff negotiations are set forth by way of separate schedules of concessions for each participating contracting party, with the U.S. schedule designated as Schedule XX.

Officially known as "The Arrangement Regarding International Trade in Textiles," the ***Multifiber Arrangement*** (MFA) provides a framework for the negotiation of bilateral agreements between importing and producing countries, or for unilateral action by importing countries in the absence of an agreement. These bilateral agreements establish quantitative limits on imports of textiles and apparel, of cotton and other vegetable fibers, wool, man-made fibers and silk blends, in order to prevent market disruption in the importing countries—restrictions that would otherwise be a departure from GATT provisions. The United States has bilateral agreements with many supplying countries, including the four largest suppliers: China, Hong Kong, the Republic of Korea, and Taiwan.