UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte HANS-WULF PFEIFFER

Appeal 2008-4420
Application 09/929,267
Technology Center 1700

Decided: January 07, 2009

Before CHARLES F. WARREN, PETER F. KRATZ, and
KAREN M. HASTINGS, *Administrative Patent Judges*.

HASTINGS, *Administrative Patent Judge*.

DECISION ON APPEAL

Appellants appeal under 35 U.S.C. § 134(a) from the Examiner's final rejection of claims 1-18. We have jurisdiction under 35 U.S.C. § 6(b).

We AFFIRM.

STATEMENT OF THE CASE

The invention relates to a method for increasing a boundary strength layer of a ceramic workpiece. Claim 1 is illustrative:

1. A method for increasing a boundary layer strength of a ceramic workpiece comprising the steps of:

providing a workpiece consisting of ceramic, the temperature of which is not elevated above room temperature and which does not comprise zirconia;

providing a tool which has at least a partially rounded contour with a predetermined diameter, the tool comprising at least the same order of hardness as the ceramic workpiece;

contacting the ceramic workpiece with the tool within a predetermined surface area, said predetermined surface area being less than the total surface area of the ceramic workpiece and being selected based upon the composition of the workpiece;

producing a plastic deformation on the predetermined surface area; and

generating internal compressive strain within the ceramic workpiece in the vicinity of the predetermined surface area;

wherein the predetermined diameter for the tool does not exceed a critical value ranging from about .1 mm to about 4 mm, the critical value depending upon the composition of the ceramic workpiece selected such that, upon contacting the ceramic workpiece with the tool, generation of damage in the form of brittle fracture processes in the predetermined surface area is substantially avoided and the boundary layer strength of the ceramic workpiece is increased.

The Examiner relies upon the following prior art references:

Rice	5,228,245	Jul. 20, 1993
Thomas	3,573,023	Mar. 30, 1971
Brookes	5,128,083	Jul. 07, 1992
Rokutanda	6,153,023	Nov. 23, 2000
Tanaka (abstract) (hereinafter JP 675)	JP 4108675 A	Apr. 9, 1992

Kingery, W.D. *Introduction to Ceramics* 3 573-575 (2nd ed., 1976) (1960). (hereinafter Kingery textbook)

The Examiner rejected:

a) claims 1-18 under 35 U.S.C. § 112, first paragraph as failing to comply with the enablement requirement;

b) claims 1-18 under 35 U.S.C. § 103(a) as being unpatentable over Brookes in view of Thomas, Rokutanda, and JP 675; and

c) claims 1-18 under 35 U.S.C. § 103(a) as being unpatentable over the combined teachings of Brookes, Thomas, JP 675 and Rice[1].

Appellants do not separately argue with any reasonable specificity the claims in any of the three grounds of rejection on appeal (App. Br. 6-17; Reply Br. 2-11).

Therefore, we select independent claim 1 to decide the issue in each ground of rejection on appeal. 37 C.F.R. § 41.37(c)(1)(vii)(2006).

ISSUES ON APPEAL

Appellant's dispute with each of the Examiner's rejections hinges on the meaning of the claim term "ceramic". Appellant contends that one of ordinary skill in the art would understand that "ceramic" as used in the claims is limited to "true ceramics" (see, e.g., App. Br. 7-8; Exhibit A, Declaration of inventor Mr. Hans Wulf Pfieffer).

The Examiner contends that "ceramics" is a broad term that may include all materials which have as their essential component inorganic

[1] Although the Examiner's statement of this rejection states "Brookes, Thomas, or the abstract of JP [675] in view of Rice" (Ans. 11), it is apparent that this rejection is based on the combined teachings of the four cited references as discussed by the Examiner and Appellant.

nonmetallic materials, including cermets (Ans. 15; Kingery textbook, pp. 3, 573-574).

The Appellant and Examiner also disagree on whether undue experimentation would be required to practice the claimed invention (App. Br. 7-11; Ans. 5-8).

The issues arising from these contentions are:

1. Has the Appellant shown that the Examiner reversibly erred in rejecting the claims under 35 U.S.C. 112, first paragraph, because one of ordinary level of skill in the art would have been able to practice the entire breadth of the claimed invention without undue experimentation?

2. Has the Appellant shown that the Examiner reversibly erred in rejecting the claims under 35 U.S.C. 103(a) because the term "ceramic", as used in claim 1, is limited to "true ceramics" as Appellant contends?

We answer both of these questions in the negative.

FINDINGS OF FACTS

The following findings of fact are supported by a preponderance of the evidence. Additional findings of fact as necessary appear in later sections including the analysis portions of the opinion.

1. As found by the Examiner, "ceramics" is a broad term that may include all materials which have as their essential component inorganic nonmetallic materials, including cermets (Ans. 15; Kingery textbook, pp.3,and 573-574).

2. Appellant's Specification provides no explicit definition of ceramics. Appellant's Specification refers to "brittle, hard materials, which *encompass* the *ceramic materials such as* silicon nitrides" (Spec. 2, [0004]; emphasis provided).

3. Appellant's Specification, in the Background to the Invention section, discusses Brookes (Spec. 6, ¶ [0016]). Brookes describes a method for modifying the surface of "hard engineering ceramic materials" (Brookes, col. 1, ll. 5-6). Brookes defines ceramics as:

> These materials include compounds (oxides, carbides, nitrides, borides) of the elements silicon, boron and other *transition metals*, and for the purposes of the present invention can be generally defined as having a room temperature Knoop indentation hardness, using a 1 kg normal load, greater than 1000 kg/mm^2 (or 10 GPa).

(Brookes, col. 1, ll. 7-12; emphasis provided).

4. Tungsten is a transition metal. Brookes' definition of ceramics therefore includes, e.g., tungsten carbide.

5. Appellant's Specification does not distinguish the ceramic materials used in the invention over those described in Brookes.

6. Kirk-Othmer [2] states "Ceramics comprise all engineering materials or products (or portions thereof) that are chemically inorganic, except metals or alloys" and "that there are no distinct boundaries between ceramic and metallic or polymeric materials" (p. 234). Kirk-Othmer lists over 100 materials used in the manufacture of ceramic products including boron carbide and tungsten carbide ("other materials too numerous to list here are [also] used") (p. 251-252).

6. Appellant's Specification states that "the prevailing understanding" regarding "brittle, hard materials" (e.g., ceramic materials) was that a further increase of their strength was not possible (Spec. 2, ¶ [0005]).

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[2] 5 *Kirk-Othmer Encyclopedia of Chemical Technology* 234, 251-252 (3d ed. 1979) (hereinafter Kirk-Othmer).

7. Appellant's Specification also states that:

(a) previous mechanical methods of increasing the strength of the skin or boundary layer of "brittle, hard materials" (e.g., ceramics) has so far neither been known or applied in practice without elevating the temperature of the material (Spec. 3-4, ¶ [0009]);

(b) prior art stated that the increase in boundary layer strength achieved on metal components by shot-peening is not obtained on "ceramic materials" (Spec. 4, ¶ [0010]); and

(c) "In general, brittle, hard materials such as ceramics" do not "have the ability to undergo a plastic deformation at room temperature" (Spec. 4, ¶ [0011]).

8. Appellant's Specification contains **no** working examples of the claimed invention.

9. The amount of experimentation needed to practice the claimed invention over the broad genus of all ceramics which do not comprise zirconia as claimed would be vast.

PRINCIPLES OF LAW

Claim Construction

During examination of a patent application, a claim is given its broadest reasonable construction "'in light of the specification as it would be interpreted by one of ordinary skill in the art.'" *In re Am. Acad. of Sci. Tech. Ctr.*, 367 F.3d 1359, 1364 (Fed. Cir. 2004). Although claims are to be interpreted in light of the specification, limitations from the specification are not to be read into the claims. *See In re Van Geuns*, 988 F.2d 1181, 1184-85 (Fed. Cir. 1993); *see also, e.g., In re Zletz*, 893 F.2d 319, 321-22 (Fed. Cir. 1989). An applicant seeking a narrower construction must either show why

the broader construction is unreasonable or amend the claim to expressly state the scope intended. *In re Morris*, 127 F.3d 1048, 1057 (Fed. Cir. 1997).

"Absent an express definition in their specification, the fact that appellants can point to definitions or usages that conform to their interpretation does not make the PTO's definition unreasonable when the PTO can point to other sources that support its interpretation." *Id.* at 1056.

Enablement

"To be enabling, the specification of a patent must teach those skilled in the art how to make and use the **full scope** of the claimed invention without 'undue experimentation."' *Genentech, Inc. v. Novo Nordisk, A/S*, 108 F.3d 1361, 1365 (Fed. Cir. 1997) (quoting *In re Wright*, 999 F.2d 1557, 1561 (Fed. Cir. 1993) (emphasis added).

As stated in *In re Wands*, 858 F.2d 731 (Fed. Cir. 1988):

> Factors to be considered in determining whether a disclosure would require undue experimentation . . . include (1) the quantity of experimentation necessary, (2) the amount of direction or guidance presented, (3) the presence or absence of working examples, (4) the nature of the invention, (5) the state of the prior art, (6) the relative skill of those in the art, (7) the predictability or unpredictability of the art, and (8) the breadth of the claims.
> *Id.* at 737.

All of the factors need not be reviewed when determining whether a disclosure is enabling. *Amgen, Inc. v. Chugai Pharm. Co.*, 927 F.2d 1200, 1213 (Fed. Cir. 1991) (noting that the Wands factors "are illustrative, not mandatory. What is relevant depends on the facts").

ANALYSIS

The first underlying question is one of claim interpretation. Appellant contends that the Examiner has taken an unreasonable interpretation regarding the meaning of the word "ceramic". Appellant proposes that his invention is limited to "true ceramics" and excludes, e.g., tungsten carbide. We disagree. Appellant has failed to provide a specific definition of ceramics in the Specification. "It is the applicant's burden to precisely define the invention, not the PTO's." *In re Morris*, 127 F.3d at 1056 ("The problem in this case is that appellants failed to make their intended meaning explicitly clear.")

"Ceramics" encompasses a wide variety of materials (FF 1-6). Indeed, Appellant's discussion of Brookes in the Specification implicitly endorses Brookes' broad definition of a ceramic material (FF 3-5).

We therefore agreewith the Examiner that the invention as claimed encompasses increasing the boundary layer strength of any ceramic material in accordance with the Examiner's reasonable textbook definition of ceramics, so long as the ceramic "does not comprise zirconia" as recited in claim 1.

Issue 1- Enablement

After having properly determined the scope of the claim at issue, we turn to the issue of enablement. In order to establish a prima facie case of non-enablement, the Examiner must provide a reasonable explanation as to why the scope of protection provided by a claim is not adequately enabled by the disclosure. *See In re Wright*, 999 F.2d at 1561-62. An Appellant who chooses broad language must make sure the broad claims are fully enabled. The threshold step in resolving this issue is to determine whether the

Examiner has met his burden of proof by advancing acceptable reasoning inconsistent with enablement.

In the present case, it is the Examiner's position that the Specification does not set forth sufficient guidance and teachings to enable how to make and/or use a process for increasing the boundary strength layer of a ceramic workpiece (which does not comprise zirconia) at room temperature without undue experimentation (Ans. 5-8). The Examiner bases this determination on several factors, including that: the skilled artisan would not expect mechanical deformation to increase the boundary strength layer of ceramics, there are no working examples, and the genus of ceramic materials encompassed by the claim is very large (*id*.; *see also*, Ans. 11-14).

The Examiner has therefore determined that, based on the Specification and state of the art, it would require undue experimentation to practice the claimed invention within the scope of the pending claims, which broadly encompasses all ceramics that do not comprise zirconia.

Appellant’s contentions that the Specification includes specifics relating to the method as claimed are not persuasive (App. Br. 8-9; Reply Br. 6). While the Specification describes some parameters for a tool for use in the process, the Specification provides **no** working examples as guidance. Further, the Specification does not describe to those of ordinary skill in the art what force was used to treat any specific ceramic material, nor what “predetermined surface area” was used of any specific ceramic material. The mere statement that “it was possible” to demonstrate a 15% increase in boundary layer strength of “silicon nitrite” (Spec. 8, ¶ [0025]) does not reasonably appear to teach one how to make and/or use the invention for

silicon nitrite, and certainly not for all ceramics that exclude zirconia as claimed.

It would also appear that the nature of the invention, mechanically treating ceramics at room temperature to increase their boundary layer strength, is generally an unpredictable technology. Appellant's Specification repeatedly indicates that it was generally accepted that "hard, brittle" ceramics, such as silicon nitrides, could **not** be successfully mechanically treated at room temperature.

Thus, the Examiner's position appears to be reasonable. Appellant has not shown that the Examiner erred in establishing that it would require undue experimentation on the part of one of ordinary skill in the art to determine how to use the claimed method at room temperature on any and all ceramics which do not comprise zirconia, in order to practice the method of the invention within the full scope of claims 1-18.

Issue 2- Obviousness

ADDITIONAL PRINCIPLES OF LAW

A claimed invention is not patentable if the subject matter of the claimed invention would have been obvious to a person having ordinary skill in the art. 35 U.S.C. § 103(a); *KSR Int'l Co. v. Teleflex Inc.*, 127 S. Ct. 1727, 1730-31 (2007); *Graham v. John Deere Co. of Kansas City*, 383 U.S. 1, 17-18 (1966).

Under 35 U.S.C. § 103, the factual inquiry into obviousness requires a determination of: (1) the scope and content of the prior art; (2) the differences between the claimed subject matter and the prior art; (3) the level of ordinary skill in the art; and (4) secondary considerations. *See Graham v. John Deere Co.*, 383 U.S. 1, 17-18 (1966).

"The combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results." *KSR Int'l Co. v. Teleflex, Inc.*, 127 S. Ct. 1727, 1739 (2007). The question to be asked is "whether the improvement is more than the predictable use of prior art elements according to their established functions." *KSR*, 127 S. Ct. at 1740.

It is a basic principle that the question under 35 U.S.C. § 103 is not merely what the references expressly teach but what they would have suggested to one of ordinary skill in the art at the time the invention was made. *See Merck & Co. v. Biocraft Labs., Inc.*, 874 F.2d 804, 807 (Fed. Cir. 1989) ("in a section 103 inquiry, 'the fact that a specific [embodiment] is taught to be preferred is not controlling, since all disclosures of the prior art, including unpreferred embodiments, must be considered."' (quoting *In re Lamberti*, 545 F.2d 747, 750 (CCPA 1976))).

Nor is it necessary that suggestion or motivation be found within the four corners of the references themselves. "The obviousness analysis cannot be confined by a formalistic conception of the words teaching, suggestion, and motivation, or by overemphasis on the importance of . . . the explicit content of issued patents." *KSR*, 127 S. Ct. at 1741. The Supreme Court also noted in *KSR* that an obviousness analysis "need not seek out precise teachings directed to the specific subject matter of the challenged claim, for a court can take account of the inferences and creative steps that a person of ordinary skill in the art would employ." *Id*.

ADDITIONAL FINDINGS OF FACT

10. As found by the Examiner, Brookes describes a method of mechanically deforming a ceramic workpiece to increase the boundary layer

strength as claimed except that (a) Brookes does not explicitly teach the diameter of the tool, and (b) Brookes does not explicitly teach performing the method at room temperature.

11. Brookes teaches the temperature "will *usually be* in the range of 0.3 Tm [i.e., the melting temperature of the ceramic] to 0.5 Tm" (col. 2, ll. 32-34; emphasis provided).

12. Thomas describes that surface hardening by a mechanical deformation process (e.g., via shot peening) for some ceramics (e.g., tungsten carbide, boron carbide) can occur at room temperature, whereas other ceramics require an elevated temperature (col. 3, ll. 49-65).

13. Rokutanda describes that 0.2mm to 0.35mm diameter of a shot (i.e., the tool) for a shot peening surface hardening process is conventional (Fig. 3; col. 1, ll. 30-36).

14. One of ordinary skill in the art would have appreciated that the diameter of the shot (i.e., the tool) is a known result effective variable (e.g., Rokutanda, Fig. 3; col. 1, 24-28).

15. One of ordinary skill in the art would have appreciated that surface hardening (e.g., via shot peening) of ceramic workpieces may be applied to only a "predetermined area" of the workpiece (see, e.g., JP 675, abstract)

16. One of ordinary skill in the art would have known that mechanical deformation surface hardening of ceramics via grit blasting (e.g., with .05mm to .58mm particle size) is known (Rice; col. 3, ll. 46-50; col. 4, ll. 8-11). Rice describes that "*[a]ny* transformation toughened material may be treated"; "*ceramics are particularly suitable* for treatment" and ceramic

materials containing zirconia are "especially preferred" (Rice, col. 2, ll. 15-50; col. 3, ll. 20-25; emphasis provided).

ANALYSIS

Appellant's dispute with the Examiner's § 103 rejections hinges on the meaning of the claim term "ceramic". Appellant contends that the Examiner has taken an unreasonably broad interpretation regarding the meaning of the word "ceramic". However, we find no basis in the claim language or in the disclosure in the Specification on which to read the disputed language in the narrow sense urged by Appellant for all the reasons previously discussed.

We agree with the Examiner's factual findings and conclusion of obviousness with respect to the § 103 rejections (i.e., the rejection based on the combined teachings of Brookes, Thomas, Rokutanda and JP 675 and the alternative rejection based on the combined teachings of Brookes, Thomas, JP 675 and Rice).

Appellant's contention that Thomas directly teaches "that the Examiner's proposed modification cannot be done with a ceramic" is not well taken (App. Br. 12-13). Claim 1, when read in its broadest reasonably light, includes treating a workpiece consisting of ceramics such as boron carbide, or tungsten carbide. These materials are taught and/or suggested by Thomas to be amenable to mechanical deformation at room temperature (FF 12).

Appellant's contend that the "method taught in Rice includes zirconia in each case and will not work for ceramics at room temperature unless they contain zirconia" (App. Br. 16). This is not persuasive, since Rice also describes treating ceramics that do not contain zirconia (FF 16).

The test for obviousness is what the combined teachings of the references would have suggested to one of ordinary skill in the art. Here, the combined teachings of the applied prior art exemplify that all the claimed steps are known in the art of surface hardening materials including ceramic materials. Thus, to modify Brookes for the reasons proposed by the Examiner would have been prima facie obvious (Ans. 8-11).

One of ordinary skill in the art is a person of ordinary creativity, not an automaton. *KSR*, 127 S. Ct. at 1742. The claim encompasses a vast number of ceramic materials and also does not require that any specific amount of strength increase is achieved. An artisan would have appreciated that a surface hardening process as rendered obvious by the combined teachings of the applied prior art would have reasonably been expected to increase a boundary layer strength to at least some extent of at least some ceramics at room temperature.

Therefore, for the foregoing reasons and those stated in the Answer, we agree with the Examiner's findings and legal conclusion of obviousness of claim 1 (as well as all other not separately argued claims) based on the combined teachings of Brookes, Thomas, Rokutanda, and JP 675 and as alternatively based on Brookes, Thomas, JP 675, and Rice.

CONCLUSION

Appellant has not shown that the Examiner reversibly erred in rejecting the claims under 35 U.S.C. 112, first paragraph, because one of ordinary level of skill in the art would have been able to practice the entire breadth of the claimed invention without undue experimentation.

Appellant has also not shown that the Examiner reversibly erred because the term "ceramic" as used in claim 1 is limited to "true ceramics".

Appellant has therefore not shown that the Examiner erred because the applied prior art does not render obvious the method for treating a workpiece "consisting of ceramic . . . which does not comprise zirconia" as claimed.

It follows that we sustain the § 112 rejection of claims 1-18 as well as the § 103 rejections of claims 1-18 advanced by the Examiner in this appeal.

ORDER

The Primary Examiner's decision is affirmed.

No time period for taking any subsequent action in connection with this appeal maybe extended under 37 C.F.R. § 1.136(a)(1)(iv).

AFFIRMED

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Notice of References Cited	Application/Control No. 09/929,267	Applicant(s)/Patent Under Reexamination	
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U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification	
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Kirk-Othmer Encyclopedia of Chemical Technology, 1979, John Wiley & Sons, 3d ed., Vol. 5, p. 234, 251-252.
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*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
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CERAMICS

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SCOPE

"Ceramics comprise all engineering materials or products (or portions thereof) that are chemically inorganic, except metals and alloys, and are usually rendered serviceable through high-temperature processing" (1). Ceramic materials are normally composed of both cationic and anionic species. The primary difference between ceramics and other materials is the nature of their chemical bonding (2–5).

Although there are no distinct boundaries between ceramic and metallic or polymeric materials, it is instructive to compare them in terms of the service requirements in engineering design (3). As a class of materials, ceramics are better electrical and thermal insulators and more stable in chemical and thermal environments than are metals (see Cement). Metals usually have comparable tensile and compressive strengths, whereas ceramics are normally appreciably stronger in compression than in tension. Ceramics exhibit greater rigidity, hardness and temperature stability than polymers; however, polymerization occurs in ceramics, especially in glasses (see Glass; Glass-ceramics).

Modern ceramics encompass a wide variety of materials and products ranging from single crystals and dense polycrystalline materials, through glass-bonded aggregates to insulating foams and wholly vitreous substances (4–7). Such a range of microstructural characteristics allows the considerable versatility evidenced in the range of manufactured industrial products.

On the basis of available statistics, the value of this industrial output, in terms of the value of products shipped during 1975, approximated 25.2 billion dollars. The breakdown by major product classifications is given in Figure 1. Although several of the product areas do not have large dollar values as compared to many industrial commodities, they are nevertheless vital to an industrial economy. Two notable examples are the refractories necessary for the reduction of ores in the metallurgical industries and abrasives (qv) which allow the mass production of machine parts.

The magnitude of the ceramic industry is by no means completely represented by the data in Figure 1. For instance, dielectric and magnetic components in electrical and electronic products, enameled parts of household appliances, refractories in heating systems and fuel materials and other parts of nuclear reactors (qv) are all components of finished goods which should be, but are not currently classified as ceramics (see Enamels; Refractories).

As late as the 1930s, ceramic technology was primarily perceived as applied high-temperature silicate chemistry. Although silicate materials continue to be the inexpensive high-tonnage backbone of the industry, the desire for high performance ceramic materials, particularly those having improved electrical, electronic, piezoelectric, and magnetic and, more recently, electro-optic, pyroelectric, and laser properties has increased steadily in the last ten to twenty years (see Ceramics as

electrical materials). The present urgency to develop materials for energy production, conversion and storage apparatus has stimulated the evolution of solid electrolytes for batteries (qv), refractories for magnetohydrodynamic generators and coal gasification devices (see Coal), strong dense ceramics for high efficiency turbine parts, and new glasses for solar collector panels (see Solar energy). In these newer ceramics, the greatest emphasis has been given to the oxide systems; however, considerable progress has also been made in the synthesis and employment of the borides, carbides, nitrides, and silicides (see Boron compounds, refractory; Carbides; Nitrides; Silicon and silicides).

The development, purification, and utilization of materials often requires the evolution of new processing techniques. Particle preparation, extrusion, dry pressing, slip casting, and sintering remain as important techniques in the ceramic industry, but they have been joined by freeze drying, thermal evaporation or sputtering, and chemical vapor deposition to produce high purity materials or thin films or complex shapes, respectively. Furthermore, the growth of single crystals, improved densification techniques and the glass–ceramic process have led to pore-free crystalline or nearly crystalline ceramics having dramatically improved properties.

Ceramics are frequently termed ionic solids, ie, possessing ionic bonding. In reality the bonding varies as a function of the polarizing power of the cations and the polarizability of the anions and is almost totally ionic in CsF and covalent in SiC. In the layer silicates such as the clays, van der Waals forces also bond the layers together. When these materials are subjected to firing processes, pyrochemical changes result in the formation of new crystalline aggregates dispersed in a vitreous matrix, each having its own ionic-covalent bonding.

Empiricism remains an intrinsic aspect of ceramic technology; however, the latter now involves the cooperative talents of the ceramic scientist, chemist, metallurgist, and solid state physicist in order to effect a more fundamental understanding of these materials. Manufacturing is now highly mechanized with several industries having fully automated, computer-controlled processing (see Instrumentation and control).

The following articles present generalized and unifying characteristics of ceramic technology by means of discussions of raw materials, processing, thermal treatment, and properties.

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RAW MATERIALS

The principal raw materials of the ceramic industry are clay (including shale and mudstone), silica, and feldspar (see Clays). Since clay is used in the production of a large variety of products, such as whitewares, refractories (qv), structural clay products, pottery, stoneware, and fillers, greater tonnages of it are used than all of the other ceramic raw materials combined. Most of the whiteware products including wall tile, floor tile, hard porcelain, electrical porcelain, translucent porcelain, and tableware are produced from combinations of these three ingredients and are known as triaxial ware. Figure 1 is a triaxial (ternary) composition diagram showing areas of commercial whiteware products. Clay, silica, and feldspar are also used in many other products including nontriaxial whiteware, glass (qv), glazes, vitreous enamel (qv), refractories, and fine ceramics.

Other raw materials include a wide variety of rocks, minerals, and synthetic compounds used in the manufacture of abrasives (qv), special refractories, lime, cement (qv), electrical ceramics, magnetic products (see Magnetic materials), and optical ceramics (see Amorphous magnetic alloys; Glassy metals). A discussion of ceramic raw materials classified according to usage is very difficult because most ingredients have more than one use; therefore, for clarity and simplicity, the following discussion is divided into three main groups: clays; nonclay minerals; and special materials. A list of minerals and compounds described in this article including CAS Registry Numbers is provided at the end of the article.

burnup without swelling. Uranium oxide also has good retention of fission products, low fabrication cost, and no crystallographic modifications in inert atmospheres. Its poor thermal conductivity has, however, been its chief disadvantage and consequently considerable research has been directed toward the uranium carbide, nitrides, sulfides, phosphides, and combinations of carbides, nitrides, and oxides (see Nuclear reactors; Uranium).

Electronic Ceramic Materials. Ferrites (qv) with improved magnetic properties have been developed in recent years and have contributed much to the advancement of the electronics field. The ferrites have the general formula $MO.Fe_2O_3$ where M is a divalent metal atom. Thus, some typical ferrites are $ZnO.Fe_2O_3$, $FeO.Fe_2O_3$, and $NiO.Fe_2O_3$. Substitution of nonmagnetic ferrites in magnetic ferrites (6), such as the replacement of part of the nickel monoxide in the nickel ferrite with zinc oxide, improves the magnetic properties of the material (see Magnetic materials). The ferrites are readily fabricated into many shapes by sintering techniques and are used for cores in low-loss coils operating at high frequencies and for strong permanent magnets.

The titanates, principally $BaTiO_3$, have been used in the electronic industry for the manufacture of ceramic capacitors of high capacitance because of the very high dielectric constant. In addition to this usage, $BaTiO_3$ is used for transducers for the conversion of electrical energy into mechanical energy and vice versa. Such transducers are used in ultrasonic cleaners (see Ultrasonics), sonar and depth-sounding apparatus, and accelerometers (see Ceramics as electrical materials).

Other materials too numerous to list here are used in the ceramic industry. *Ceramic Age* (7) has classified over 450 materials used in the manufacture of ceramic products.

Mineral or compound	CAS Registry No.	Mineral or compound	CAS Registry No.
silica	[*7631-86-9*]	olivine	[*1317-71-1*]
kaolinite	[*1318-74-7*]	anthophyllite	[*17068-78-9*]
montmorillonite	[*1318-93-0*]	tremolite	[*14567-73-8*]
illite	[*12173-60-3*]	actinolite	[*13768-00-8*]
gibbsite	[*14762-49-3*]	chrysolite	[*25666-97-1*]
diaspore	[*14457-84-2*]	forsterite	[*15118-03-3*]
bauxite	[*1318-16-7*]	fayalite	[*13918-37-1*]
halloysite	[*12244-16-5*]	spodumene	[*1302-37-0*]
dickite	[*1318-45-2*]	lepidolite	[*1317-64-2*]
nacrite	[*12279-65-1*]	amblygonite	[*1302-58-5*]
nontronite	[*12174-06-1*]	petalite	[*1302-66-5*]
beidellite	[*12172-85-9*]	barite	[*13462-86-7*]
hectorite	[*12173-47-6*]	witherite	[*14941-39-0*]
saponite	[*1319-41-1*]	fluorspar	[*14542-23-5*]
bentonite	[*1302-78-9*]	apatite	[*1306-05-4*]
muscovite	[*1318-94-1*]	baddeleyite	[*12036-23-6*]
hydromicas	[*12173-56-7*]	zirkite	[*1314-23-4*]
phengite	[*12174-17-3*]	zircon	[*1490-68-2*]
brammallite	[*12197-36-3*]	titania	[*13463-67-7*]
glaucomite	[*1317-57-3*]	rutile	[*1317-80-2*]
celadonite	[*12173-00-1*]	brookite	[*12188-41-9*]

quartz	[14808-60-7]
biotite	[1302-27-8]
limonite	[1317-63-1]
vermiculite	[1318-00-9]
aluminum oxide	[1344-28-1]
calcium oxide	[1305-78-8]
magnesium oxide	[1309-48-4]
iron oxide	[1309-37-1]
mullite	[1302-93-8]
tridymite	[15468-32-3]
cristobalite	[14464-46-1]
hydrated silica	[10279-57-9]
albite	[12244-10-9]
nephelite	[1302-72-3]
anorthite	[1302-54-1]
magnesite	[13717-00-5]
magnesium chloride	[7786-30-3]
orthoclase	[61076-95-7]
calcium carbonate	[13397-26-7]
gypsum	[13397-24-5]
plaster of Paris	[26499-65-0]
chromite	[1308-31-2]
andalusite	[12183-80-1]
sillimanite	[12141-45-6]
kyanite	[1302-76-7]
pyrophyllite	[12269-78-2]
talc	[14807-96-6]
asbestos	[1332-21-4]
anatase	[1317-70-0]
thoria	[1314-20-1]
graphite	[7440-44-0]
silicon carbide	[409-21-2]
boron carbide	[12069-32-8]
zirconium carbide	[12070-14-3]
hafnium carbide	[12069-85-1]
tantalum carbide	[12070-06-3]
vanadium carbide	[12070-10-9]
molybdenum carbide	[12069-89-5]
tungsten carbide	[12070-12-1]
niobium carbide	[12069-94-2]
beryllium nitride	[1304-54-7]
boron nitride	[10043-11-5]
aluminum nitride	[24304-00-5]
silicon nitride	[12033-89-5]
cerium sulfide	[12014-82-3]
thorium sulfide	[12039-06-4]
magnesia spinel	[1302-67-6]
uranium oxide	[1344-57-6]
carbon dioxide	[124-38-9]
hydrogen	[1333-74-0]
uranium carbides	[12070-09-6] and [12071-33-9]
uranium nitrides	[25658-43-9] and [12033-83-9]
uranium sulfide	[12039-11-1]
uranium phosphides	[12037-69-3] and [12037-84-2]
barium titanate	[12047-27-7]

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