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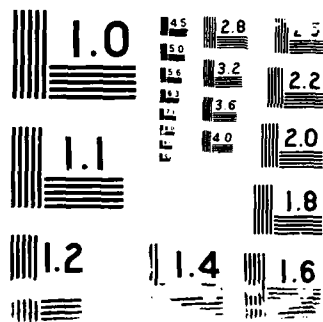
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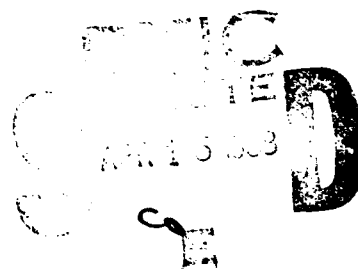
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# SCIENTIFIC BULLETIN



DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH FAR EAST  
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## THE 1987 KYOTO PRIZES

Sandy Kawano

*The Kyoto Prizes were established by the Inamori Foundation to honor and recognize the people who have contributed significantly to mankind's betterment mainly in the fields of advanced technology, basic sciences, and creative arts and moral sciences. This year the Foundation honors Dr. Morris Cohen, a preeminent leader in the field of metallurgy; Dr. Jan Hendrik Oort, a renowned astronomer and astrophysicist; and Mr. Andrzej Wajda, an internationally famous film maker.*

On 10 November 1987 the third annual presentation ceremony for the Kyoto Prizes was held at the Kyoto International Conference Hall. Their Imperial Highnesses Prince and Princess Mikasa were among the distinguished guests in attendance to honor this year's Laureates, Dr. Morris Cohen, Dr. Jan Hendrik Oort, and Mr. Andrzej Wajda.

The Kyoto Prizes were established by the Inamori Foundation, which was founded in 1984 by Kazuo Inamori, chairman of the Kyocera Corporation. The Inamori Foundation was established to encourage and reward outstanding contemporary intellectual and artistic achievements. The aims of the Foundation are to honor and recognize creative activity and to provide concrete support for significant achievements and research. To further these aims, the Foundation has established the Kyoto Prizes as an incentive to outstanding achievement and creativity and has initiated a wide range of activities designed for the support and encouragement of research. These activities include grants for basic research support, research abroad, invitation of scholars from abroad, and research and cultural exchange. Mr. Inamori endowed the Foundation with a gift of about ¥20 billion in cash and Kyocera stock to support the Kyoto Prizes and these grants.

At the focus of Foundation activities are the Kyoto Prizes. It is the Foundation's intent and hope that the Kyoto Prizes will: (1) become internationally recognized as the highest possible accolade for genius and excellence in scholarship; (2) stand as a pinnacle reward for outstanding achievement in advanced technology and basic sciences; and (3) come to be regarded, in the area of the humanities, as the international hallmark of recognition for significant achievements and contributions in the creative arts, as well as in the philosophical, moral, and spiritual areas of our common human tradition.

The Kyoto Prizes, which were first awarded in 1985, are presented annually in the major categories of Advanced Technology, Basic Sciences, and Creative Arts and Moral Sciences. Specific fields from each category are selected annually (this year's fields are Materials Science, Earth Sciences and Astrophysics, and Cinema/Theater). Then candidates are nominated by official Kyoto Prize nominators, recipients are selected and approved, and the awards are announced in June. Each recipient receives the Certificate of Recognition, a medal, and the Prize money (¥45,000,000).

Dr. Morris Cohen, the Laureate in Advanced Technology (Materials Science), was born in Chelsea,

Massachusetts, in 1911. Dr. Cohen received his S.B. degree from the Massachusetts Institute of Technology (MIT) in 1933 then continued on at MIT to receive a Doctor of Science degree in metallurgy in 1936. He began his professional work in 1937 as an assistant professor of metallurgy at MIT, then rose to associate professor (1941-46) and professor (1946-62). In 1962 Prof. Cohen was appointed Ford Professor of Materials Science and Engineering. In 1975 he became Institute Professor, and in 1982 he was bestowed the title of Institute Professor Emeritus.

Prof. Cohen has devoted his life to education and research in materials science and engineering, particularly in physical metallurgy, and now he is the preeminent academic leader in these fields. His research work has created broad and basic new insights into phase transformations and structure-property relationships in materials. He has played a key role in the following areas: the mechanism and kinetics of martensitic and bainitic transformations, tempering phenomena and strengthening mechanisms in ultra-high-strength steels, solid-state alloy thermodynamics, age hardening in alloys, deformation-enhanced diffusion, brittle fracture mechanisms in heterogeneous materials, mechanisms of strain hardening and dynamic recovery, strain-induced transformation and transformation plasticity, grain refinement mechanisms in microalloyed steels, and rapid solidification of crystalline alloys. His research not only laid the scientific groundwork for all of the ultra-high-strength steels in use today, but he is also responsible for advanced materials science research in areas such as shape-memory phenomena and transformation plasticity in metallic, ceramic, and biological systems.

Prof. Cohen has contributed extensively to international programs as well as national projects. He has visited many countries to lecture and advise, and he has been recognized by over 20 major international awards, honorary degrees, and professorships. His tremendous compassion, intellect, and energies have propelled him to the leadership position that he has now and have made him an inspiration to two generations of students and colleagues in the field of materials science and engineering.

Prof. Jan Hendrik Oort, the Laureate in Basic Sciences (Earth Sciences and Astrophysics), was born in 1900 in Franeker, The Netherlands. After graduating from the University of Groningen in 1921, Prof. Oort became an assistant from 1921-22. In 1922 he served as a research assistant at the Observatory of Yale University, then from 1924-30 he was the conservator at Leiden Observatory. Prof. Oort received a Doctor of Science degree from the University of Groningen in 1926. In 1935 he accepted a professorship in astronomy at Leiden University, and in 1945 he also became the director of the Leiden Observatory. Prof. Oort served in both positions until 1970, when he was honored with the title of Professor Emeritus. Also during that time (1958-61), he served as president of the International Astronomical Union.

Prof. Oort has been awarded the Kyoto Prize for his long-standing contributions to astronomy and astrophysics, particularly for his elucidation of the structure and dynamics of the galaxy. He found that the Milky Way is a large stellar system with a disk shape and rapid rotation, in which the sun is located about two-thirds of its radius away from the center. Prof. Oort derived this structure in the late 1920s from optical observation of the

velocities of stars and later quantified it (in the 1950s) by radio observation of the 21-cm hydrogen line. The galactic rotation is characterized by a pair of parameters called the Oort constants, and the motion perpendicular to the galactic disk is dictated by the Oort mass limit, which is the maximum permissible surface mass density in the solar neighborhood.

One of his important contributions to astronomy was the development of radio astronomy. Prof. Oort initiated the 21-cm observation independently of Purcell and designed radio telescopes including interferometers. Using these radio telescopes, he has found high velocity hydrogen clouds falling on the galaxy, expanding features in the galactic center, and various interesting properties of external galaxies. Prof. Oort has also derived the distance to the galactic center, referring to radio and optical data.

In solar system studies in 1950, Prof. Oort showed that there is a nest of comets, called the Oort cloud, at 100,000 AU from the sun that supplies comets when disturbed by passing stars.

Prof. Oort has also devoted himself to the study of supernovae. One of his most striking discoveries was the polarization of light from the Crab Nebula, a remnant of supernova 1054. This proved the theoretical prediction that the electromagnetic emission is due to the synchrotron radiation by relativistic electrons in magnetic fields.

Prof. Oort's scientific achievements have been recognized by several prizes, memberships in several academies, and honorary degrees. His scientific research achievements and enthusiasm, which has let him continue his work to this day, have been an inspiration to astronomers and astrophysicists all over the world.

Mr. Andrzej Wajda, the Laureate in Creative Arts and Moral Sciences (Cinema/Theater), was born in Suwalki, Poland, in 1926. He was 13 when the Nazis invaded Poland, and at 16 he joined the Polish resistance. After the liberation, Mr. Wajda studied painting at the Academy of Fine Arts in Krakow and then dramaturgy at Leon Schiller State Theatre and Film School in Lodz. After graduating in 1954, Mr. Wajda made a series of works, "A Generation," "Canal," and "Ashes and Diamonds," called the Three Resistance Series because the films depict the tragic experiences of his fellow countrymen during and after the war. These works, which vividly portray the way in which fighting and survival situations affect human beings, won worldwide acclaim.

In addition to his "realistic" series, Mr. Wajda has also made a romantic series of films including "Innocent Sorcerers," "Birch Wood," and "The Maids of Wilko," which lyrically express the sorrows and joys of youth. In such films as "Ashes," "The Gates of Paradise," "Land of Promise," and "Danton," Mr. Wajda has used a historical theme to depict human aspirations and frustrations.

The consistent image that runs through all these wide-ranging styles and themes in Mr. Wajda's works is that of deeply motivated persons who confront and challenge major hardships. In his films Mr. Wajda has tried to penetrate and explore the intricacies of human nature. The films "Man of Marble" and "Man of Iron" also contain powerful expressions of the way people have lived under the political and social reform in Poland. Some of his films were produced outside Poland, such as "Danton" in France and "A Love in Germany" in Germany.

Mr. Wajda has also excelled in other areas of theater arts, such as acting and directing. In 1980 at the

International Film Festival in Berlin he was voted Best Actor for his role in "The Conductor." At the International Film Festival in Moscow in 1971 he received the Best Director award for "Birch Wood," and at Cesars 1982 he was voted Best Director for his production of "Danton."

Mr. Wajda's 60th birthday was commemorated in 1986 with "The Exhibition—The Theatre of Andrzej Wajda" and "The Exhibition—Andrzej Wajda's 30 Films 1954–1985," held in various places in Poland. He has recently released "A Chronicle of Amorous Accidents" and is filming "Devils" in France.

Mr. Andrzej Wajda has made a lasting contribution to the field of cinema arts by continually releasing outstanding films made with deep sensitivity and elaborate compositional power. His films appeal strongly for human dignity and freedom of spirit, and his personal commitment to these

ideals prompted his resignation from the public offices of president, Polish Film Association, and representative, Film Unit X. We can expect a continuing flow of Mr. Wajda's creative activity in the future.

According to Mr. Kazuo Inamori, president of the Inamori Foundation, "man has no higher calling than to work for the greater good of all humankind." The achievements of this year's recipients of the Kyoto Prizes exemplify that ideal by contributing significantly to mankind's scientific, cultural, and spiritual betterment.

*Sandy Kawano is the editor of the Scientific Bulletin. Before coming to Japan, she worked for the Naval Civil Engineering Laboratory, Port Hueneme, California, as a Technical Writer-Editor. She has a Bachelor of Arts degree in Liberal Studies from California State University, Northridge.*

## ORGANIC FERROMAGNETS

Minoru Kinoshita and Earl Callen

*Researchers have now succeeded in synthesizing ferromagnets entirely from organic elements—carbon, hydrogen, oxygen, and nitrogen. Curie temperatures, the temperature below which the material is spontaneously magnetically ordered, are above room temperature. So far yields are low, of the order of a percent or less, and the precise composition of the ferromagnetic component is only guessed at. Two steps are necessary: to synthesize stable molecules with unpaired spins and to cause these spins to couple ferromagnetically. Molecular systems with unpaired spins are formed by some researchers by using charge transfer compounds. Other groups use radicals with a spin triplet ground state. Ferromagnetic coupling is achieved by attaching radicals to hydrocarbon chains with  $\pi$  electrons. The same kind of "free electron" mobility that allows for other metallic behavior in organics—high electrical conductivity, superconductivity—may also allow the indirect exchange interaction that is the source of ferromagnetism in the transition metals.*

When we think of magnets we usually think of iron. The ancients did not; they thought of lodestone. And centuries before the Greeks discussed lodestone the Chinese were shaping it into needles and making compasses for marine navigation. While iron is a metal, lodestone—today we call it magnetite—is a ceramic. It is the base of the memory cores for computers.

The element that makes magnetite magnetic is iron. Iron, nickel, and cobalt, elements of the first transition series, are magnetic because their atoms contain an only-partially-filled 3d shell. Ordinarily, energy levels are filled two electrons per level, one with spin up and one with spin down. That is all Pauli exclusion will allow. The next two electrons must fill the next level up, of higher energy. But in an unfilled shell there are degenerate orbital levels of the same energy. These can be filled by electrons of parallel spins without cost in orbital energy. This is Hund's rule. The arrangement "of maximum multiplicity"—with parallel spins—has the lowest intra-atomic exchange energy.

Parallel spins means net spin angular momentum and magnetic moment—magnetic atoms. Further along in the periodic table at the lanthanides there is again a level inversion and a partially filled 4f shell, and atoms with magnetic moments. Today we have rare earth magnets, technologically important ones such as  $\text{SmCo}_5$ , and the even-more-important  $\text{Nd}_2\text{Fe}_{14}\text{B}$ . And still further along, at the actinide level, an incomplete 5f shell leads to the exotic magnetic behavior of uranium and its neighbors.

Since magnetism originates in unfilled orbital angular momentum shells, one might wonder about the orbital contribution to the angular momentum and magnetic moment, in addition to the uncompensated electron spin. In solids the orbital angular momentum of electrons in the 3d shell is largely negated by the electric field of neighboring ions. In the lanthanides and actinides the orbital contribution to the elementary magnetism of an individual atom can add considerably to the contribution from electron spin.

Atomic moments interact with each other. There is always the classical, weak but long range, magnetic dipole-dipole interaction. It is proportional to the entire dipole moment of the atom, not just its spin. "Opposite poles attract." The tendency of the dipolar interaction is to cause the atomic moments to order in some sort of looped, closed arrangement, or antiferromagnetic arrangement, which brings north and south magnetic poles near each other. When there are no other forces between the atomic moments, this ordering will occur only at a sufficiently low temperature—a fraction of a degree—that the dipolar energy exceeds  $kT$ . But in the right circumstances there can also be an electronic, quantum mechanical, "exchange" interaction, and it can be very much larger than the classical dipole interaction. Exchange relates back to the spins, whether there is orbital angular momentum or not. Exchange coupling can be either ferromagnetic—all the spins lie parallel to each other—or antiferromagnetic—any long range ordered structure with no net moment.

And so we have ferromagnets, like iron (even in such a case the dipolar interaction asserts itself by creating "domains"—macroscopic regions in which the magnetization rotates from one to the next, so that the magnetic flux closes on itself inside the material). We have antiferromagnetic insulators, like  $\text{NiO}$ , in which, because of "superexchange," successive spins point alternately "up" and "down," and we have more complicated arrangements. Magnetite is an example of a ferrimagnet, with several kinds of atomic sites with different numbers of atoms per unit volume and different kinds of atoms on the various sites. In such a material, on some sites the moments can point up and on others down, but the moments of these several

"sublattices" need not cancel, as in an antiferromagnet. There are even more complicated arrangements. In the rare earth metals the atomic moments order in exotic angled structures—spiral staircases; progressively opening, blown-out, and closing umbrellas; three-dimensional standing spin waves whose wavelength is incommensurate with the crystal lattice. But in all antiferromagnetic structures there is no net moment. Over a wavelength the moments cancel out.

There is a characteristic temperature at which the thermal energy equals the exchange energy, the energy of interaction between the spins. Below this temperature the moments are ordered and above it they are not. When the ordering is ferromagnetic the ordering temperature is called the Curie temperature,  $T_C$ ; when the ordering is antiferromagnetic the transition temperature is called the Néel temperature,  $T_N$ . Above the phase transition the material is paramagnetic; thermal energy tumbles the moments around so that they point in random directions and average out to zero. Only by application of a magnetic field can a moment be induced. In the paramagnetic phase the induced moment is proportional to the external field strength, and the proportionality constant, the susceptibility  $\chi$ , has a temperature dependence that follows the Curie-Weiss law:

$$\chi = \frac{C}{T - \theta}$$

Here  $C$  is a constant (proportional to the square of the atomic magnetic moment);  $T$  is the absolute temperature; and  $\theta$ , the "paramagnetic Curie temperature," is a measure of the exchange interaction. Positive  $\theta$  means ferromagnetic exchange; negative  $\theta$  means antiferromagnetic interaction. The paramagnetic Curie temperature is

not a physical quantity. It is not the temperature at which the phase transition to the ordered phase actually occurs; it is the extrapolated intercept on the temperature axis, on a plot of the reciprocal of the susceptibility versus temperature, at such temperatures far enough above the transition that the Curie-Weiss law is obeyed. For ferromagnets the actual transition temperature,  $T_C$ , is usually not too far from  $\theta$ . In the case of antiferromagnets the actual transition temperature,  $T_N$ , is often something like  $-\theta$ .

Whether the magnetic arrangement is ferromagnetic or antiferromagnetic, the materials are either metals or insulators and the atomic moments in all cases come from atoms with unfilled shells. Is there any other way to be magnetic? Can magnets be made of atoms with filled shells? Are there organic ferromagnets? That is a natural question in a time of organic semiconductors and ceramic and organic superconductors. Some bacteria are magnetic; they use it to sense the earth's magnetic field for navigation, as do some birds and fish. But all these get their magnetism by incorporating tiny, single domain particles of magnetite. Can ferromagnets be constructed wholly of H, C, N, O, and such? The question resolves itself in two. Unlike metals, organic solids consist of distinct, separable clusters—molecules. So what is needed, first, is for the individual molecules to have magnetic moments. And second, the moments of the molecules must interact ferromagnetically. (Given molecular moments it will be no trick at all to get antiferromagnetic ordering—at some low temperature the dipole-dipole interaction will take care of that. The interesting challenge is to create organic ferromagnets.)

Let's start with the first step, getting the dipole moment. Most organic molecules are diamagnetic. The simplest molecule of all, the

homopolar diatomic molecule,  $H_2$ , illustrates the problem. Its two electrons go into the lowest bonding orbital, one with spin up and one with spin down, a spin singlet—no moment. There is always that strong tendency, but there are exceptions; the ground state of  $O_2$  is a spin triplet (the two outer electron spins are parallel). In fact how about a heteropolar molecule with an odd number of electrons, like NO? NO must be at least a Kramers doublet. That's step one (except that molecules with unpaired spins often cluster in pairs to lower their energy, with one spin up and one spin down again; we will run into this problem later when we discuss galvinoxyl). How about step two? No. In the molecular crystals composed of simple small molecules like  $O_2$  and NO, only the dipole-dipole interaction couples the moments. They order antiferromagnetically.

Ferromagnetism means exchange, which means some sort of electron transfer, or resonance, or valence fluctuation, or electrical conduction. But spin coupling through electron resonance between localized orbitals is almost always antiferromagnetic. (This is again because of the Pauli principle. Superexchange can in principle produce ferromagnetism, but only under circumstances not often realized, and then involving degenerate levels—which means unfilled shells again.) What one needs for ferromagnetic exchange is nonlocalized electrons— $\pi$  electrons free to wander—the same property that characterizes the organic semiconductors with high electron mobility and the organic metals and superconductors. With luck it might happen that  $\pi$  electrons travelling along and between polymer chains might scatter off localized electron spins, thereby providing the same sort of ferromagnetic indirect exchange interaction as the Rudermann — Kittel — Kasuya — Yosida (RKKY) interaction in metals.

Organic ferromagnets seem to have been first discussed by McConnell. In his 1963 paper (Ref 1) McConnell suggested building from a molecule with a net spin moment and spin polarization, such as the allyl radical. His idea was to arrange these in staggered, alternating layers, for exchange coupling reasons. Such a scheme has never been realized, and by 1967 McConnell had presumably rethought the problem and proposed formation of the molecular moment by charge transfer (Ref 2). He conjectured as follows: Suppose an organic solid consists of two kinds of components, one of which has a triplet ground state, as did our illustrative example  $O_2$  and as do cyclopentadienyl (Ref 3) and diphenylcarbene (Ref 4). Now suppose that the solid is ionic, consisting of cation and anion radicals of the two components. Configuration interaction might then mix the triplet ground state in with a triplet ionic state and produce ferromagnetically coupled radicals. One line of search has followed that reasoning, either directly or in modified form (Ref 5). Another approach, that of Mataga (Ref 6), and the more successful so far, has been to form the molecular moment on neutral radicals, and attach these to conjugated long chain pseudo-one-dimensional polymers that allow for  $\pi$  electron mobility. Yoichiro Sato (Ref 7), in an unpublished dissertation, also considered both the neutral radical and charge transfer mechanisms for obtaining unpaired spins in organic systems and discussed the exchange interaction.

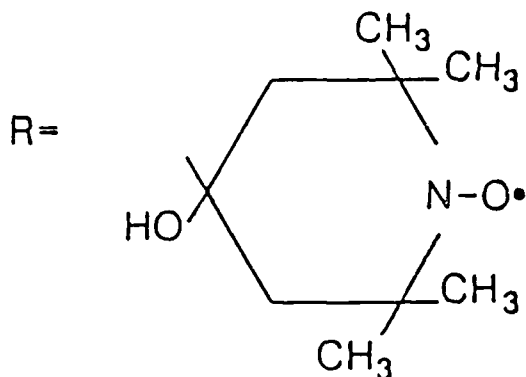
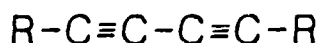
Neutral radicals with spins coupled by metallic exchange has also been the 10-year goal of Ovchinnikov (Ref 8), and now he and his coworkers have indeed produced an organic ferromagnet (Ref 9). The Russians use the much-studied TEMPO radical (2,2,6,6-tetramethyl-4-oxy-4-piperidyl-1-oxyl) and construct the biradical

monomer diTEMPO-DA (see Figure 1a). diTEMPO-DA, which the Russians understandably refer to as BIPO, is a paramagnet and follows the Curie-Weiss law. The paramagnetic Curie temperature is negative, about -2 K. This suggests that BIPO will order antiferromagnetically at some low temperature. (In crystals of these pseudo-one-dimensional molecules the exchange interaction is extremely anisotropic, and the actual three-dimensional ordering occurs at temperatures far below what one might naively expect from the Curie-Weiss intercept.) And indeed it does; below the Néel temperature monomer BIPO is an antiferromagnet.

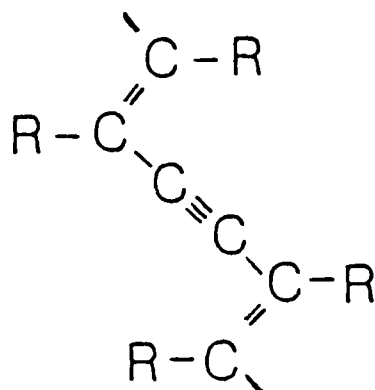
Ovchinnikov and coworkers then polymerize BIPO by exposure to heat, ultraviolet radiation, or a glow discharge and are able to convert between 80 and 100 percent of the monomer to polyBIPO. In polyBIPO the nitroxyl radicals attach to a polydiacetylene chain, perhaps as illustrated in Figure 1b. And polyBIPO is indeed ferromagnetic—or at least 0.1 percent of it is! The Russians quote Curie temperatures ranging from 150 to 190 °C and with indications of ferromagnetic behavior in some fractions up to 310 °C. They conjecture that the low ferromagnetic fraction, the low moment, and the variable Curie temperature may be due to some sort of spin glass formation.

Torrance and coworkers (Ref 10) at IBM San Jose have followed the McConnell charge transfer logic and have achieved success at about the same time as the Russians. Symmetrical 1,3,5-triaminobenzene is reacted with iodine at room temperature. The reaction is complex; there seem to be several reaction paths; the constituents and properties of the resultant black, insoluble polymer vary from batch to batch; and about 2 percent of the final product is ferromagnetic. Torrance

conjectures that this ferromagnetic component is a partially oxidized meta-linked phenyl polymer. Magnetization versus field curves at room temperature look like typical magnetization curves of a soft ferromagnet (very little hysteresis) of low saturation moment. Interpretation of the magnetization versus temperature curves, particularly at higher temperatures, is complicated by the irreversible thermal decomposition of the polymer between 300 and 400 °C. But the Curie point is certainly above room temperature.



(a) Monomer diTEMPO-DA, or BIPO, and the stable nitroxyl radical TEMPO.



(b) PolyBIPO.

Figure 1. The Ovchinnikov method.

Joel Miller of DuPont, in collaboration with Arthur Epstein of Ohio State, Columbus (Ref 11), follows the charge transfer route to attain unpaired spins. They construct a crystal of the donor organometallic ferrocene molecule, decamethylferrocene, and the acceptor molecule, tetracyanoethylene. And at about 5 K the spins do indeed align ferromagnetically. One might protest that Miller and Epstein are breaking the rules—ferrocene contains an iron atom. The iron moment is probably not essential to the ferromagnetism (although the d level degeneracy may very well be). Miller and Epstein would argue that the iron atoms are so far apart as to preclude overlap of their wavefunctions; the moment is the odd electron spin, and the coupling is carried through non-localized electrons.

At least two Japanese groups have been active. We mentioned earlier that diphenylcarbene is a spin triplet (Ref 4). Because of the large intra-atomic exchange, i.e., Hund's rule, the two outer electron spins go in parallel in almost degenerate molecular orbitals of divalent carbon in certain conjugated hydrocarbon structures (Ref 6, 12). And so, by hooking together hydrocarbons, replacing a C-H on each unit by a divalent C, it should be possible to create arbitrarily long molecular chains with two parallel spins on each link. Wasserman et al.; Koichi Itoh and Takeji Takui, of Osaka City University; and Hiizu Iwamura, Tadashi Sugawara, and coworkers at the Institute for Molecular Science, Okazaki, have been investigating progressively higher homologs of such series (Ref 13-16). They have succeeded in hooking together four (Ref 15) and five (Ref 16) carbenes in high spin ( $S=4$  and  $S=5$ ) states (see Figure 2). These high spin molecules are extremely reactive. The trick will be in bringing them together in such a way that they do not react chemically, but yet their spins couple ferromagnetically.

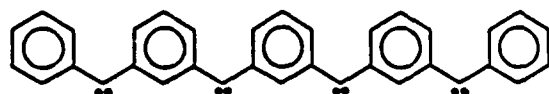


Figure 2. The Itoh and Iwamura method. Polycarbene: chain of four phenyl-carbenes. Each phenyl-carbene radical contains two localized electrons with spins parallel.

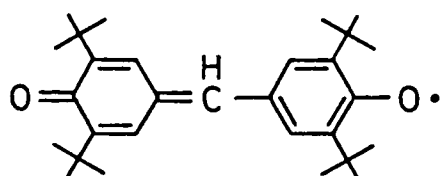
The Iwamura group has experimented with dispersing the polycarbenes with alkyl chains. They introduce octyloxy groups at the para positions of diphenyldiazomethane (Ref 15). This keeps the carbenes apart and is believed to orient them properly for ferromagnetic exchange (Ref 17). But so far this line of attack has not been successful. Electron spin resonance (ESR) and susceptibility measurements show that the carbenes are indeed in the high spin state, but the magnetic interactions between chains are complex. There seem to be both ferromagnetic and antiferromagnetic interactions, and the polymers do not order ferromagnetically at any temperature.

Kunio Awaga, Tadashi Sugano, and Minoru Kinoshita of the Institute for Solid State Physics, University of Tokyo (Ref 18), work with the stable free radical galvinoxyl (4-((3,5-bis(1,1-dimethylethyl)-4-oxo-2,5-cyclohexadien-1-ylidene)methyl)-2,6-bis(1,1-dimethylethyl)phenoxy) (see Figure 3a). There is no orbital contribution to the moment of its one unpaired spin, so the moment is that of  $S=1/2$ . In the crystalline state galvinoxyl molecules stack along the c-axis to form one-dimensional columns. The temperature dependence of the paramagnetic susceptibility of crystals of galvinoxyl follows the Curie-Weiss law, with a positive paramagnetic Curie temperature of 19 K.

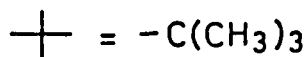
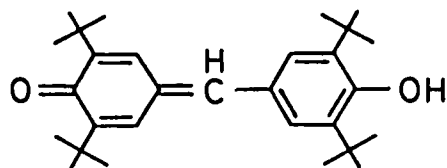
But as the temperature is reduced, at 85 K, the crystal undergoes a first order phase transition, evidently of magnetic and magnetoelastic origin. Below the transition the crystal displays only a much reduced, but still positive, magnetic susceptibility. What seems to be happening is that at the phase transition pairs of galvinoxyls in the stack pull together, with their unpaired spins coupled antiferromagnetically in a ground state singlet. The triplet spin state of each sandwich, which lies only a little above the singlet, can be excited thermally. This is seen in ESR absorption. The small remnant paramagnetic moment below the phase transition appears to be due to those occasional, isolated galvinoxyls caught between coupled pairs in the stacks. These left-over molecules account for the observed ESR doublet resonance.

The approach of the Tokyo group has been to suppress the phase transition by dilution. Hydrogalvinoxyl (see Figure 3b), a precursor of galvinoxyl, but with paired spins and no moment, crystallizes in an identical structure but undergoes no phase transition. In solution, the two compounds mix freely in any ratio, for example, six parts galvinoxyl to one part hydrogalvinoxyl, and crystals of the mixture are easily grown. In the stacks of molecules in the crystal there should then be a random distribution of components peaked around the average spacing, six galvinoxyls separated by a hydrogalvinoxyl. If it occurs—as it does—that the unpaired spins of a galvinoxyl segment form a ferromagnetic unit, like a single large molecular moment, and the hydrogalvinoxyls break the chains, then magnetization measurements should reveal a Gaussian distribution of moments peaked at  $J=S=3$  (on average, six molecules in a unit, each with spin  $1/2$ , times the Bohr magneton, of course). In crystals containing 85 percent galvinoxyl or less, the magnetic phase transition is suppressed to below 2 K. The

paramagnetic clusters again obey a Curie-Weiss law, with positive and only slightly reduced temperature intercept, 14 K or so (see Figure 4). In the diluted crystal the ESR spectrum shows that the ferromagnetic interaction has been preserved; the ground state is the triplet, and the singlet lies slightly above. ESR also reveals a much increased number of doublets. The introduction of hydrogalvinoxyl increases the number of galvinoxyls that are left out of a pair, for example in segments of an odd number of galvinoxyls. The Tokyo group is studying under what conditions ferromagnetic intermolecular interaction is possible. All of this has been deeply revealing, but so far no ferromagnetism.



(a) The molecular structure of galvinoxyl.



(b) Hydrogalvinoxyl.

Figure 3. The Tokyo method.\*

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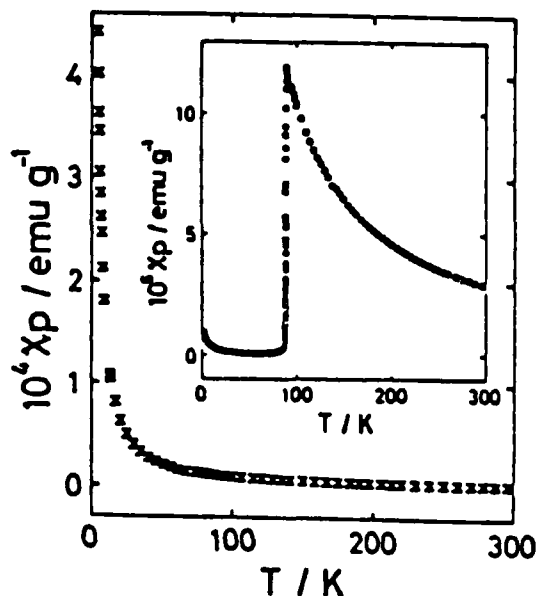


Figure 4. The temperature dependence of the magnetic susceptibility of the 6:1 mixed galvinoxyl/hydrogalvinoxyl crystal. The insert shows the susceptibility of pure galvinoxyl.\*

One may ask where the quest for organic ferromagnets will lead. It seems likely that in the not-too-distant future we will know how to produce organic ferromagnets with Curie points above room temperature, or tailored to need, and with significant yields, not the 0.1 or 2 percent now obtained. Whether these will have sufficiently high saturation moments, or be stable, or be cheap, or lightweight, or have unique biological or medical applications, or some other as-yet-unforeseen attractive feature, is an open question, one that in the writers' opinion it is too soon to ask. (But we would not bet on organics as substitutes for iron magnets.) We also think that is the wrong way to phrase the question. The

right question is: "Is the search for organic ferromagnets a fruitful one?" The answer to that question is already in. The quest has opened up whole new fields of inquiry and yielded whole new classes of compounds. And it is far from over.

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## THE COCHIN REGIONAL CENTER OF THE INDIAN NATIONAL INSTITUTE OF OCEANOGRAPHY

Wayne V. Burt

*The Cochin Regional Center of the Indian National Institute of Oceanography is responsible for studying the coastal oceanography of the State of Kerala on the southwest coast of India and Indian islands in the Arabian Sea. Marine biologists at the center are engaged in plankton sorting and identification and are also studying coastal and estuarine waters, with special attention being given to environmental pollution and increasing the yield of aquatic resources. Coastal erosion is also being investigated.*

### INTRODUCTION

Integrated oceanographic research activities began in India in 1962 with the Indian participation in the International Indian Ocean Expedition (IIOE). Cochin was selected to be the main center for shore-based activities of the Indian participation in IIOE.

The Indian Council for Scientific and Industrial Research established a new institute, called the Indian Ocean Biological Center (IOBC), in Cochin. This center soon became the first of its kind in the world. From the beginning it was largely devoted to the study of planktonic organisms in the Arabian Sea, the Indian Ocean, and the Bay of Bengal. With the assistance of experts from many other countries, it soon became world famous for its expertise in sorting and identifying the plankton in the samples taken by the ships of various nations that took part in the International Indian Ocean Expedition.

When the Indian National Institute of Oceanography (NIO), with headquarters in Goa, was established in 1966, IOBC was renamed and became a regional center of NIO. It was given the responsibility of studying the coastal oceanography of the long (550-km), narrow State of Kerala on the southwest coast of India and the Amindivi, Cannanore, Minicoy, and other islands in the Arabian Sea that belong to India.

Dr. N. Khrishan Kutty is the Scientist-in-Charge of the Cochin center. My guide at the center was Dr. Udaya Varma, a physical oceanographer. The center has a staff of 60 persons. About one-third of these are marine biologists engaged in plankton sorting and identification. While study of the plankton of the Indian Ocean region continues to be one of the major activities of the center, the center has diversified its research programs, taking into consideration problems of regional importance. The center has placed considerable importance on estuarine and coastal research because of the vital role the extensive backwaters, estuaries, and coastal regions of Kerala play in developmental activities.

Oceanographic problems of regional importance include coastal zone management and problems associated with the 200-mile exclusive economic zone off the coast of Kerala and around the offlying islands.

### MARINE BIOLOGY

A majority of the marine biologists at the center are still engaged in plankton sorting and identification. A number of these sorters have been working at the center for over 20 years and are especially renowned for their ability to identify fish eggs and larvae from commercially important species of fish in the waters around India. A

knowledge of the recruitment potential given by the abundance of eggs and larvae is important in the management of the fisheries as fishery efforts increase and fishing technology improves.

The efforts of sorting fish eggs and larvae at the center may soon receive a shot in the arm. The National Marine Fisheries Service of the U.S. National Atmospheric and Oceanographic Administration is currently endeavoring to set up a joint Indo-U.S. initiative to use PL480 funds (rupees belonging to the United States) to increase the efforts in the study of the distribution of eggs and larvae of commercially important species of fish in the Indian Ocean area.

In addition to the specialized study of plankton, the biologists are, with the help of the chemists, studying coastal and estuarine waters. Special attention is being given to environmental pollution and increasing the yield of aquatic resources. Studies of primary production, benthic and intertidal ecology, fish population dynamics, fish and prawn culture and related physiological problems, and the distribution of pollution on recreational beaches are all underway.

The area off the southwest coast of India is one of the most complex regions of the world's oceans. It is exposed to the extreme fury of the southwest summer monsoon, which causes major coastal erosion problems and changes in underwater topography near shore. These problems will be discussed below. The coastal currents generated by the monsoon winds are accompanied by a complicated system of upwelling. This upwelling and vertical mixing by the strong monsoon winds bring an abundance of nutrients to the surface. This abundance of fertilizers results in a high level of phytoplankton productivity. All levels of the marine food chain are enhanced, from phytoplankton to commercially important food fishes.

## COASTAL EROSION

The study of beach erosion along the coast is complicated by the formation, movement, and dissolution of mud banks in the shallow water off the Kerala coast. The changes in the mud banks bring about major changes in the nearshore underwater topography which, in turn, result in transitory temporal changes in wave refraction patterns along the coast. Wave energy is focused at different locations at different times, causing irregular rates of erosion and deposition both in space and time. Usually major erosion takes place during the monsoon seasons, with maximum erosion during July and August. During the process of erosion most of the material appears to be transported offshore and the same materials appear to be deposited back on the beach when an erosion phase is over.

Over a long period of time the beaches appear to be stable unless man interferes. An interesting case in point is the experience with the offshore island of Kavaratti. It is a small sand island once surrounded by a continuous coral reef. The principal axis of the cucumber-shaped island is oriented in a southwest to northeast direction. It is about 7 km long and only 1/2 to 1 km wide. During the southwest monsoon, sand is moved from the southwestern tip of the island to the northeastern tip. After the monsoon is over the littoral currents slowly transport the sand back to its premonsoon distribution. A shipping channel was cut through the coral reef near the northeastern tip of the island. There is evidence that sand is lost through the channel during the monsoon and not recovered. If this process continues long enough the island could slowly disappear.

All the problems of beach protection are compounded by the variability of the wave forces acting on the beach at any given time and place.

## COASTAL POLLUTION

Except for a few large inland cities, the coastal zone is the most thickly populated region of the Indian subcontinent, especially along the southwest coast of Kerala. A decade-long, year-round study has recently been completed of the pollution on the beaches and in the surfzone in the environment of 10 bays and 20 beaches that are located between the southern tip of India up the west coast to the northern tip of Kerala. The rationale for the study was the importance of the beaches for tourism, which is a major industry in the area. The country needs more beaches that are safe for tourists. The results of the study showed that the shores and nearshore waters of bays where fishing villages are located are as much as an order of magnitude more polluted with human waste than the nearby beaches and inshore waters. Also, even on the cleaner beaches, the amount of pollution increases markedly at the start of the monsoon rainy season when local runoff increases directly over the beaches, washing the pollution from the land to the sea.

One of the novel recommendations resulting from the study was that inhabitants of the coast, especially those living under unhygienic conditions, should be moved back from the coast. There should be an uninhabited 1/2-km-wide strip along the beach with free access to the sea.

The center is currently housed in two old mansions in the center of the city of Ernakulum, the only major city of Cochin. The State has given the center a place on the water to build a new laboratory, which has not materialized yet. The center is, however, moving to newer and larger quarters within the city.

The address of the center is: National Institute of Oceanography, Regional Centre, Pullepady Cross Road, P.O. No. 1913, Cochin - 530 017.

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## RECENT RESEARCH ON SiC WHISKER-REINFORCED CERAMIC COMPOSITES IN JAPAN

Shigehiko Yamada

*Research on SiC whisker-reinforced ceramic composites has gained momentum in the past few years since the development of an industrial process for obtaining the whiskers. In this article recent activities in this field of ceramic composites are summarized. Composite matrices of glass and glass-ceramics, alumina, zirconia, silicon nitride, silicon carbide, mullite, spinel, and aluminum nitride are discussed.*

### INTRODUCTION

About 20 years ago, Krochmal of the Air Force Materials Laboratory (AFML) reviewed and assessed fiber-reinforced ceramics and their potential (Ref 1) even before carbon fiber was industrialized. No suitable material was found, although there was a wide variety of reinforcers and matrices. About 5 years ago, when silicon carbide whiskers ( $\text{SiC}_w$ ) were introduced as an industrial material in Japan, researchers at the Osaka Government Industrial Research Institute (GIRI) developed a  $\text{SiC}_w$ -reinforced  $\text{Si}_3\text{N}_4$ , which can be regarded as pioneering work in this field (Ref 2,3). Watts reported that research and development (R&D) work on  $\text{SiC}_w$  was rekindled by the discovery of an industrial process for obtaining the whiskers (Ref 4). Since then, particularly in the past 2 to 3 years, quite a few papers on various kinds of matrices were published. New products of this type of composite using  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  have appeared in industry, which may suggest the importance of ceramic composites. In this article recent activities in this field in Japan are summarized in as much detail as possible, with foreign research mentioned for reference only.

### GLASS AND GLASS-CERAMIC MATRICES

Sakamoto and Ito (Ref 5) glassified  $25\text{MgO}-21\text{Al}_2\text{O}_3-54\text{SiO}_2$  (wt.) by heating at  $1,550^\circ\text{C}$  for 3 hours, followed by pulverizing to  $2\text{ }\mu\text{m}$  by ball-milling and mixing with 0 to 50 percent of  $\text{SiC}_w$  in the wet state. Hot-pressing at 880 and  $1,180^\circ\text{C}$  for 1 hour at 340 MPa was carried out. Figure 1 shows the results, where a typical improvement in the  $\text{SiC}_w$  content at up to 30 wt. % can be seen. Higher concentrations of  $\text{SiC}_w$  (40 to 50 wt. %) made the densification difficult, giving lower strength and  $K_{IC}$  values which are, however, still higher than those of the matrix itself.

Oka et al. (Ref 6) and Yamada (Ref 7) prepared  $\text{SiC}_w$  in situ with excess  $\text{SiO}_2$  mixed with a limited amount of carbon black so that a homogeneous mixture could be made. Hot-pressing of the mixture was not easy because of the chemical reaction between  $\text{SiC}_w$  and  $\text{SiO}_2$  and also because of the big difference in their coefficient of thermal expansion (CTE), but a 40- by 50- by 5-mm specimen was successfully obtained. Figure 2 shows the prepared  $\text{SiC}_w$  in situ in  $\text{SiO}_2$  particles, like a spider's web over the particles.

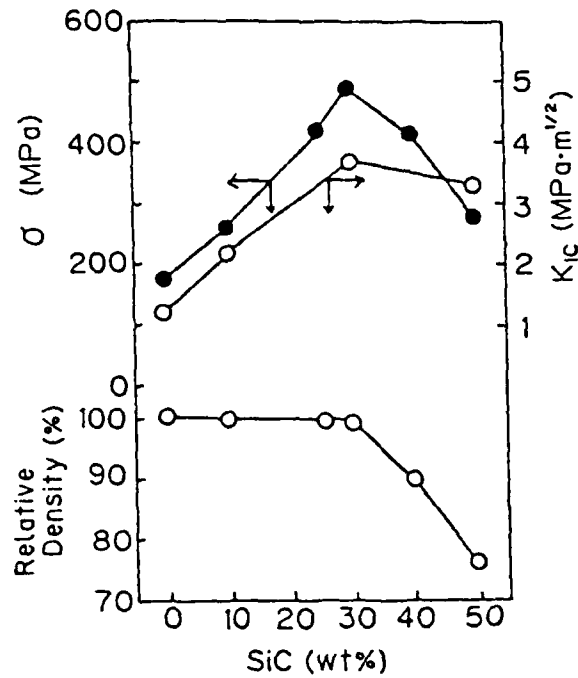


Figure 1. Strength, fracture toughness, and relative density of the composite (from Ref 5).

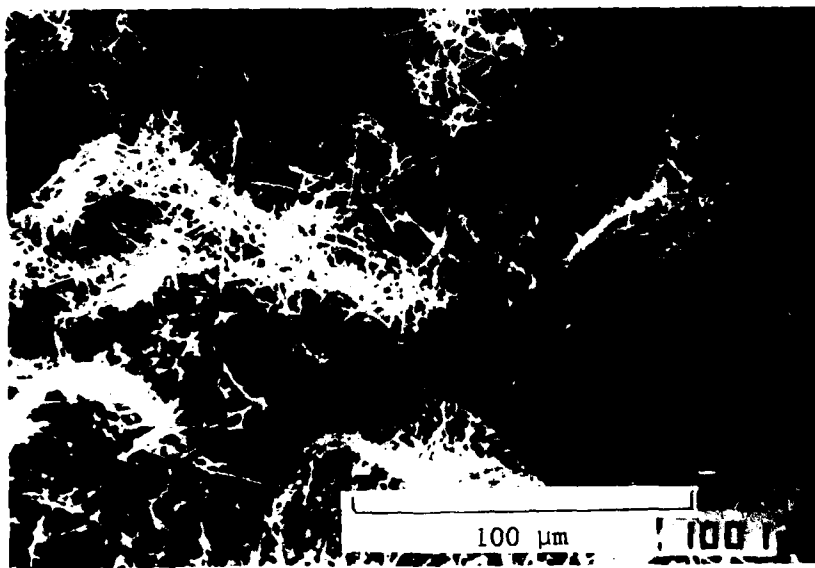


Figure 2.  $\text{SiC}_w$  prepared in situ in  $\text{SiO}_2$  (from Ref 6).

In experiments conducted by Kagawa et al. (Ref 8,9),  $\text{SiC}_w$  and  $\text{Si}_3\text{N}_4$  were mixed with 40-percent colloidal silica, which was added to silica-glass powder and sintered. Fifteen vol % of  $\text{Si}_3\text{N}_4$ -reinforced CGW# 7740 gave a  $K_{IC}$  of 2.5  $\text{MPa m}^{1/2}$  in comparison with a  $K_{IC}$  of about 1  $\text{MPa m}^{1/2}$  for the matrix itself. A difference in acoustic emission (AE) waves was observed as illustrated in Figure 3, which was obtained by an indentation test. This difference may suggest that the improvement in  $K_{IC}$  was due to the formation of microcracks, which are assumed to occur by the increase in event accounts.

Researchers from Ceramiques Techniques Desmarquest (Ref 10) developed a composite  $\text{SiC}_w/\text{SiO}_2$  as an industrial product, continuously prepared in a plant, for the exhaust liners of cars (Ref 11). Gadkaree and Chyung (Ref 12) investigated several kinds of glass and glass-ceramic matrices with  $\text{SiC}_w$ . Layden and Prewo (Ref 13) experimented with alumino- and boro-silicates.

#### ALUMINA MATRIX

Figure 4 shows the reinforcing effect of  $\text{SiC}$  in comparison with mullite and zirconia matrices. The variance of strength decreased as the  $\text{SiC}_w$  content increased, perhaps because the sintering (hot-pressing) process had a restraining effect on particulate growth. However, no improvement of strength could be observed, differing from the other matrices (Ref 14). Pull-out of  $\text{SiC}_w$  was observed only in the case of alumina. Yasuda et al. (Ref 15) coated the whiskers with carbon using the chemical vapor deposition (CVD) procedure to clarify the pull-out effect.

In experiments performed by Inoue et al. (Ref 16), a mixture of  $\text{Al}_2\text{O}_3$ , partially stabilized zirconia

(PSZ), and  $\text{SiC}_w$  (70:15:15 vol %) was ball-milled; bending strength as high as 1,181 MPa ( $n=20$ ) was obtained.  $K_{IC}$ , as well as high temperature strength (1,200 °C), was also determined. They concluded that the instability of  $\text{ZnO}_2$  in the phase transformation matched the stress field.

In other experiments, Inoue and Nonaka (Ref 17) investigated the difference in toughening mechanisms by using two kinds of  $\text{ZnO}_2$  crystals. With tetragonal zirconia polycrystals (TZP), which retained a tetragonal structure at room temperature, tensile stress was formed by a difference in CTE ( $\alpha\text{-SiC}_w < \alpha\text{-ZrO}_2$ ) in the matrix phase, giving the pull-out effect of the whiskers. On the other hand,  $\text{ZrO}_2$  without stabilizers transformed to a monoclinic structure at room temperature. As a result, the flexural strength of the TZP was 1,191 MPa, while the value for  $\text{ZrO}_2$  was only 651 MPa. The  $K_{IC}$  values were 8.43 and 6.57  $\text{MPa m}^{1/2}$ , respectively. The maximum strength of 1,437 MPa was obtained by using heat treatment.

At the 1987 New Materials Exhibition in Tokyo, in May 1987, Riken Company presented its new product,  $\text{SiC}_w$ -reinforced alumina containing zirconia. Sumitomo Cement Company also presented a  $\text{SiC}_w/\text{Al}_2\text{O}_3$  composite at the exhibition, but no details were available.

Figures 5 and 6 show the change in flexural strength and the change in fracture toughness, respectively, as a function of volume fraction, where pull-out of the whiskers was observed (Ref 18).

Figure 7 shows the results of research by Matsubara et al. (Ref 19). The specimens were hot-pressed (H.P.) at 1,850 and 1,900 °C for 30 minutes at 20 MPa. The  $K_{IC}$  values at 1,900 °C were lower because of the lack of pull-out, which was due to the higher sintering temperature; this may suggest the importance of the pull-out effect.

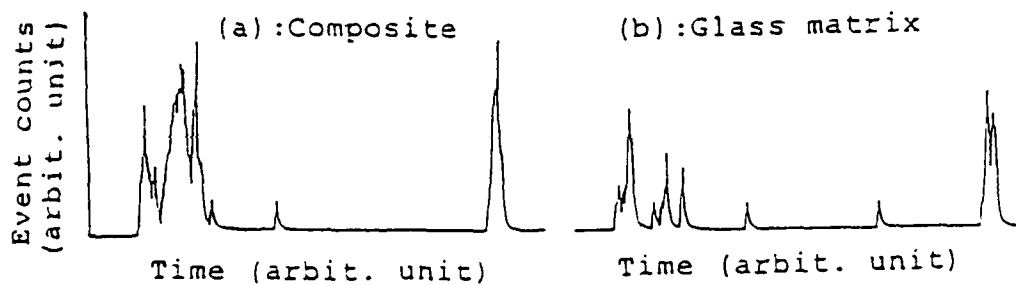


Figure 3. Detected acoustic emission events during the loading/unloading process of the Vicker's indentation test (from Ref 9; reprinted with permission from the Iron and Steel Institute of Japan).

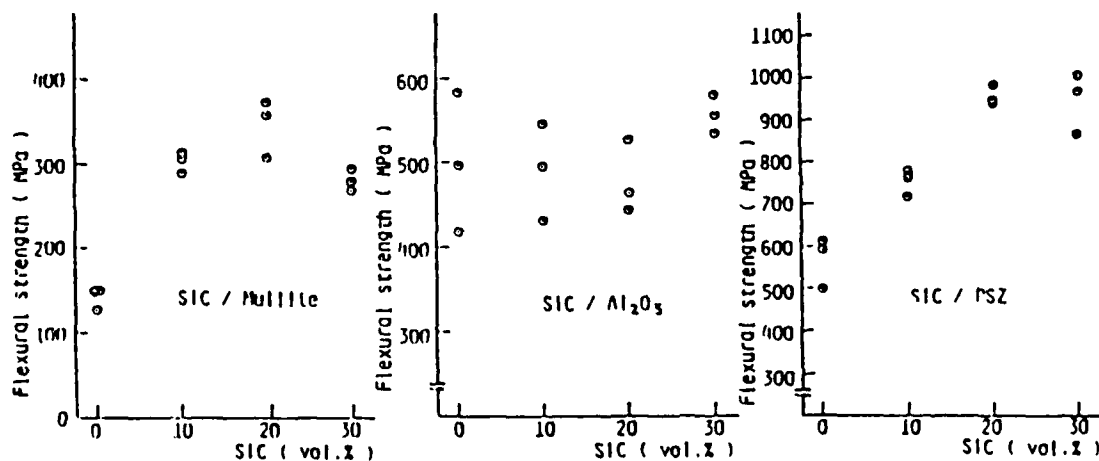


Figure 4. Flexural strength of hot-pressed SiC whisker/oxide ceramic composites at room temperature (from Ref 14).

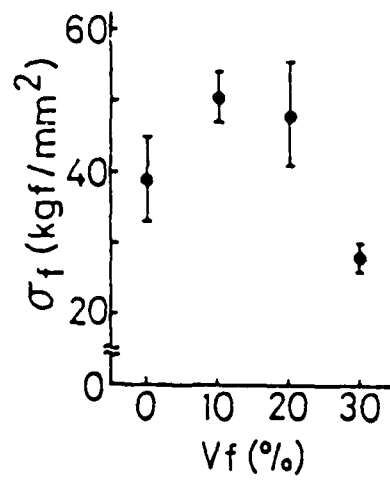


Figure 5. Change in flexural strength as a function of volume fraction,  $V_f$ , of  $\text{SiC}_w$  (from Ref 18).

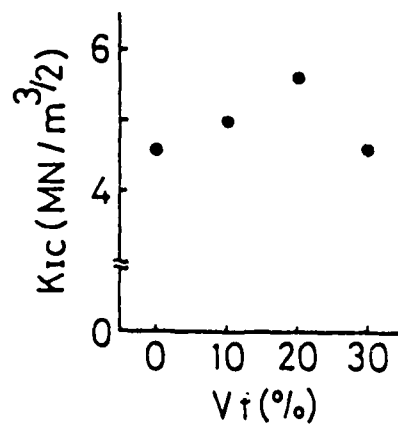


Figure 6. Change in fracture toughness,  $K_{IC}$ , as a function of  $V_f$  of  $\text{SiC}_w$  (from Ref 18).

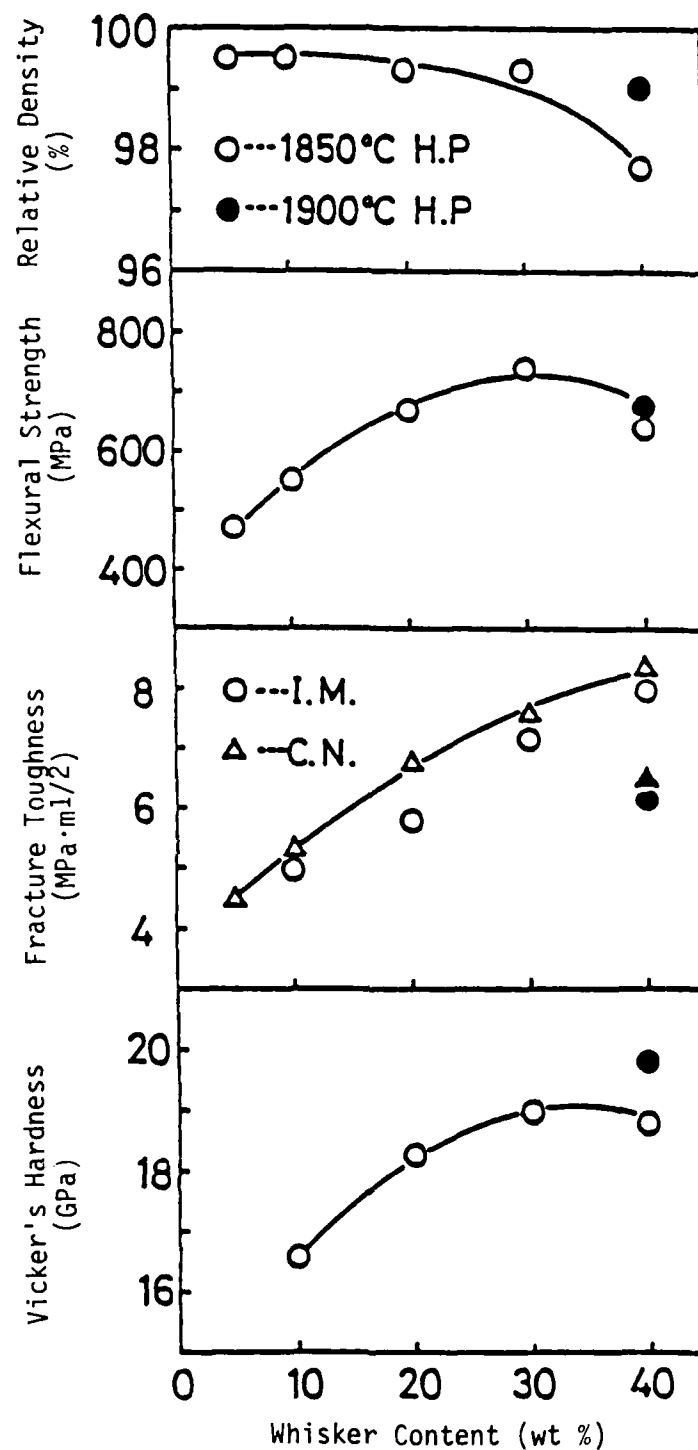


Figure 7. Change in physical properties as a function of  $\text{SiC}_w$  content (from Ref 19).

Iwamoto et al. (Ref 20) added 1.5 and 3.0 percent of  $\text{SiC}_w$  and  $\text{Si}_3\text{N}_4$  to  $\text{Al}_2\text{O}_3$  for plasma spraying to toughen the formed film. Figure 8 shows an increase in the number of cycles until the film was broken by a thermal shock between 1,373 K and room temperature (duration = 60 seconds) with water spray. Figure 9 shows another improvement obtained by a falling down test of a 110-gram steel ball, dropped from a height of 825 mm. A maximum increase of four times the number of ball impacts can be seen.

Becher and Wei's work (Ref 21,22) is now very famous, and Becher recently collaborated with Tiegs (Ref 23) on further research. Other work of interest includes Homeny et al. (Ref 24), Porter et al. (Ref 25), and Chokshi and Porter (Ref 26).

### ZIRCONIA MATRIX

As illustrated in Figure 4, PSZ was compared with mullite and alumina matrices (Ref 14). Further work by Yasuda et al. (Ref 27) is summarized in Figures 10 and 11. It should be noted that higher strength was observed at elevated temperatures in the 30-vol %  $\text{SiC}_w$  specimen (Figure 11) than at room temperature (Figure 10).

As shown in Figures 12 and 13, at sintering temperatures of 1,400 and 1,500 °C, no increase in strength or fracture toughness could be observed due to insufficient densification (Ref 28).

In research conducted by Akimune et al. (Ref 29), the relationship between the microstructure determined by both scanning electron microscopy (SEM) and transmission electron microscopy (TEM) and the mechanical properties of  $\text{SiC}_w/\text{TZP}$  was investigated and Figure 14 was obtained. The Weibull coefficient increased as the  $\text{SiC}_w$  content increased, which may be due to the uniformity of critical size. The increase in  $K_{IC}$  related to the tetragonal-monoclinic transformation

by TEM was also discussed. In the case of 30 vol % of  $\text{SiC}_w$ , crack deflection was considered to contribute to the toughening rather than the transformation effect.

Miyagawa et al. (Ref 30) obtained some interesting results during their research, as illustrated in Figures 15 and 16. The lower value of strength, 30  $V_f$  (%), at room temperature is based on the higher porosity of the composite.

The work of Claussen et al. (Ref 31) is well known and was carried out at almost the same time as initial research in Japan (Ref 14). The author learned that Claussen used a new mixer, called a tumbling mixer, which will be mentioned later.

### SILICON NITRIDE MATRIX

As described in the INTRODUCTION section, this type of composite was created by a Japanese research group (Ref 2,3) in 1982. In 1986 and 1987, several relevant papers were presented.

At the beginning stage,  $\text{SiC}_w$  were prepared by Tamari and others in their laboratory by CVD. At the same time, an industrial version of  $\text{SiC}_w$  was prepared in a pilot plant in which the author was employed. Tamari and Ueno proved that there was no difference between the  $\text{SiC}_w$  prepared experimentally or industrially, making it possible for the manufacturer to market  $\text{SiC}_w$  as an industrial product. In addition to the change in mechanical properties by reinforcing, they found:

- Weibull coefficient was high, over 24, indicating higher reliability of the composite.
- Wear property was improved, as shown in Figure 17 (Ref 32).
- Electrical discharge machining of the  $\text{Si}_3\text{N}_4$  composite became possible because of the electrical conductivity of the SiC component (Ref 33).

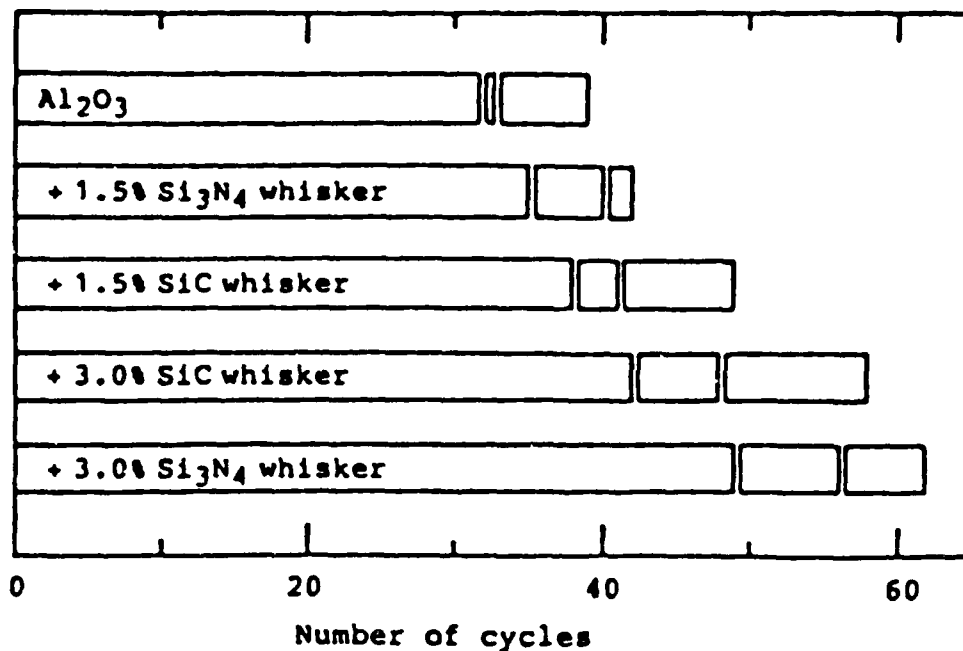


Figure 8. Results of thermal shock test on the sprayed film (from Ref 20).

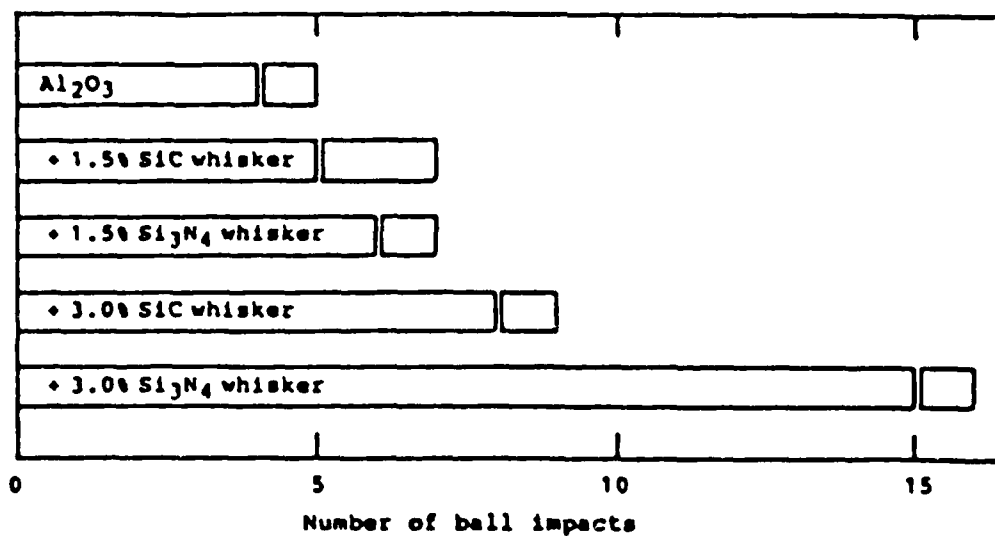


Figure 9. Results of falling down test on the sprayed film (from Ref 20).

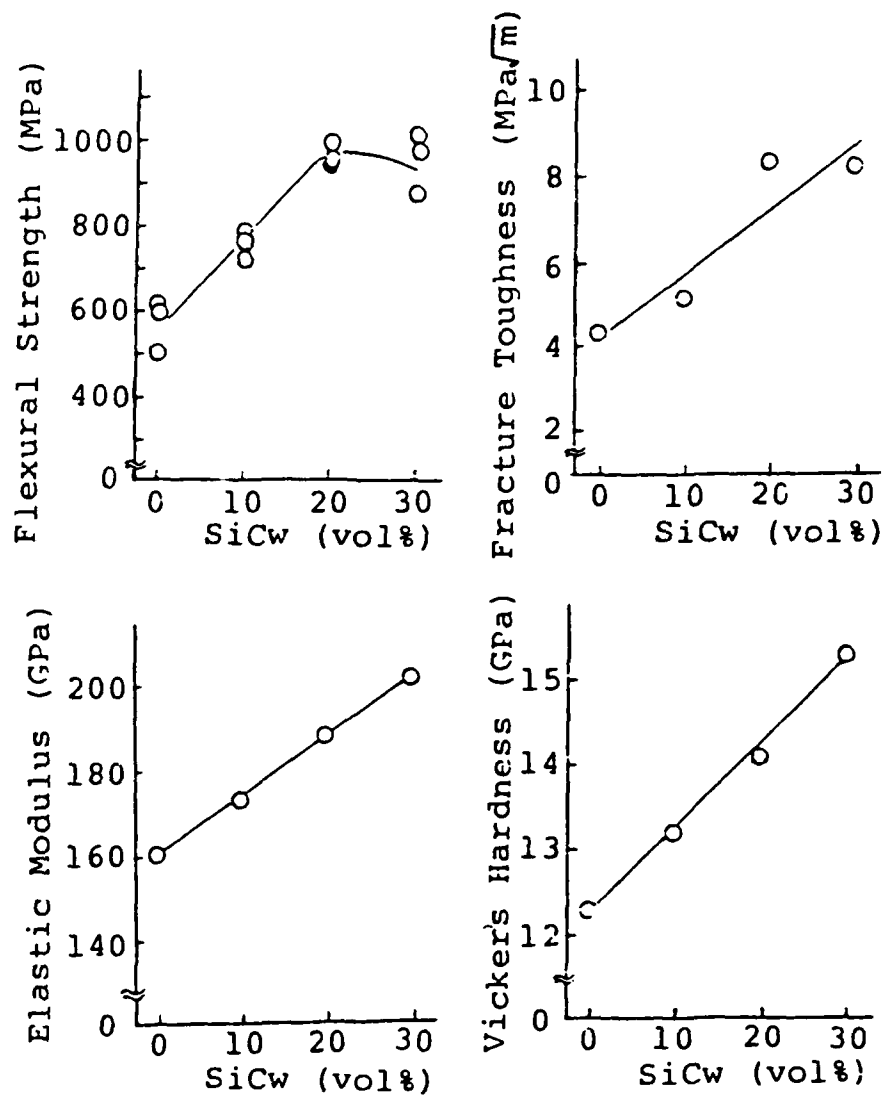


Figure 10. Mechanical properties of SiC<sub>w</sub>/PSZ composites at room temperature (from Ref 15).

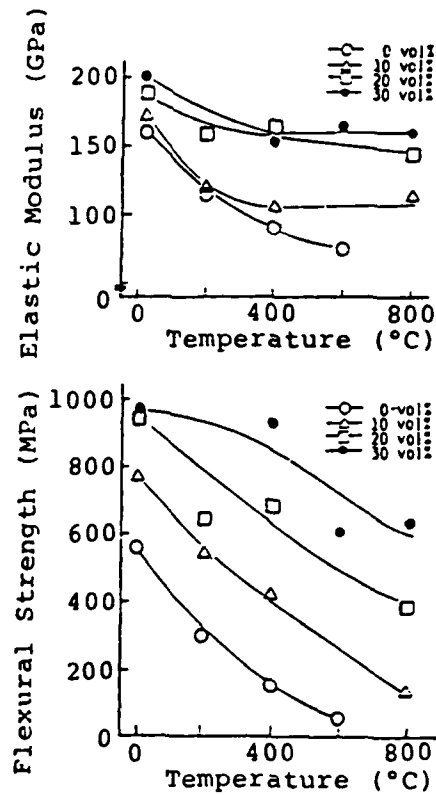


Figure 11. Elastic modulus and flexural strength of  $\text{SiC}_w/\text{PSZ}$  composites at elevated temperature (from Ref 15).

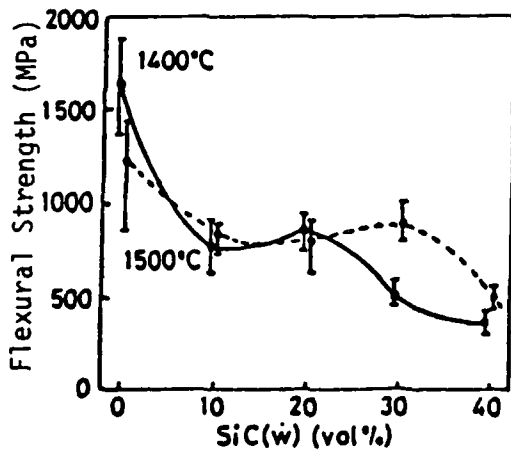


Figure 12. Change in flexural strength (from Ref 28).

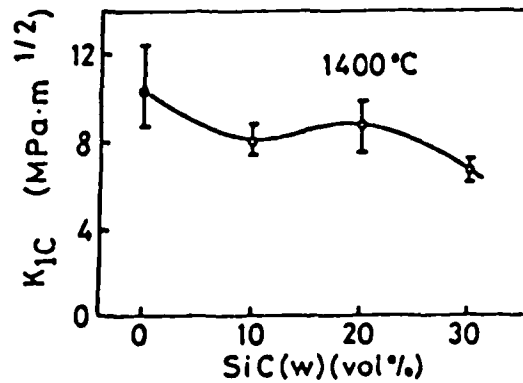


Figure 13. Change in fracture toughness (from Ref 28).

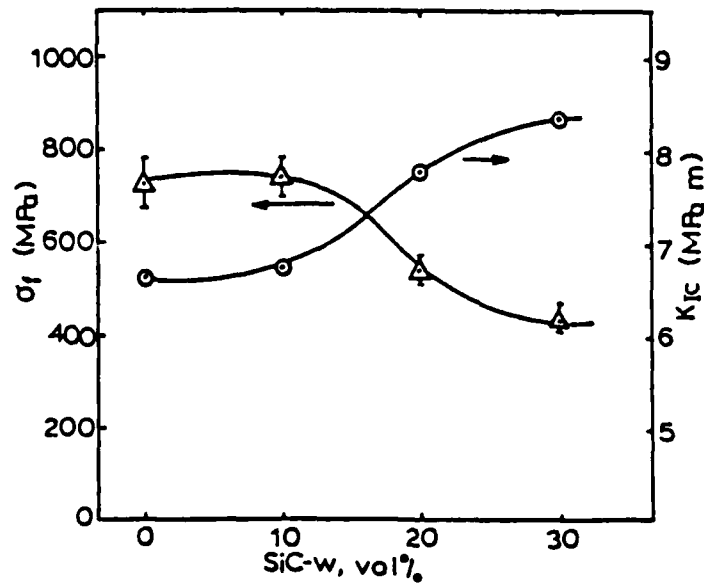


Figure 14. Flexural strength and fracture toughness of the composite (from Ref 29).

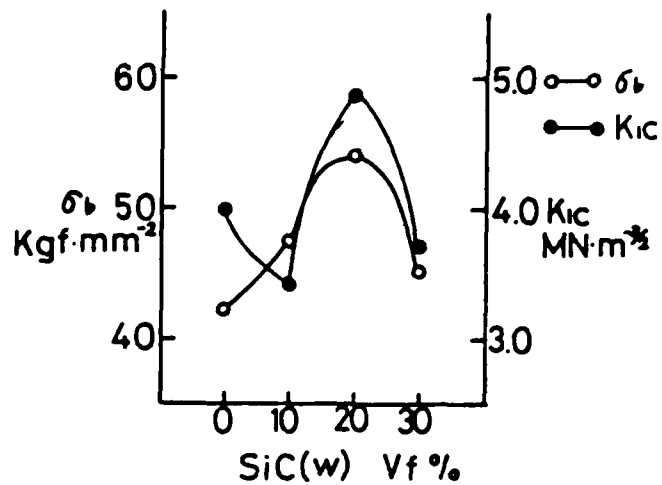


Figure 15. Flexural strength and fracture toughness at room temperature (from Ref 30).

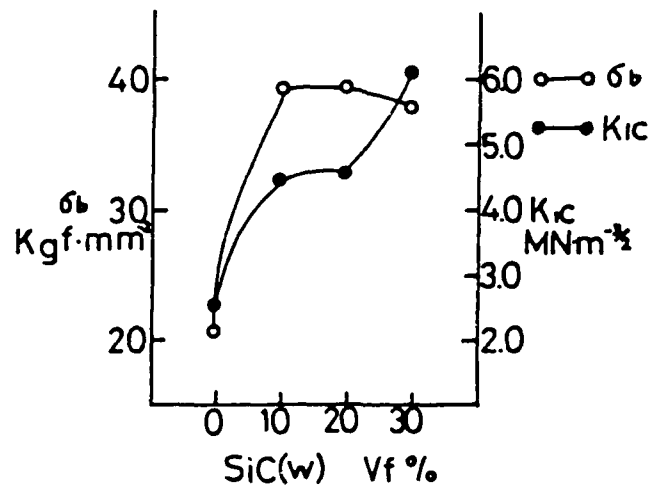


Figure 16. Flexural strength and fracture toughness at 1,300 °C (from Ref 30).

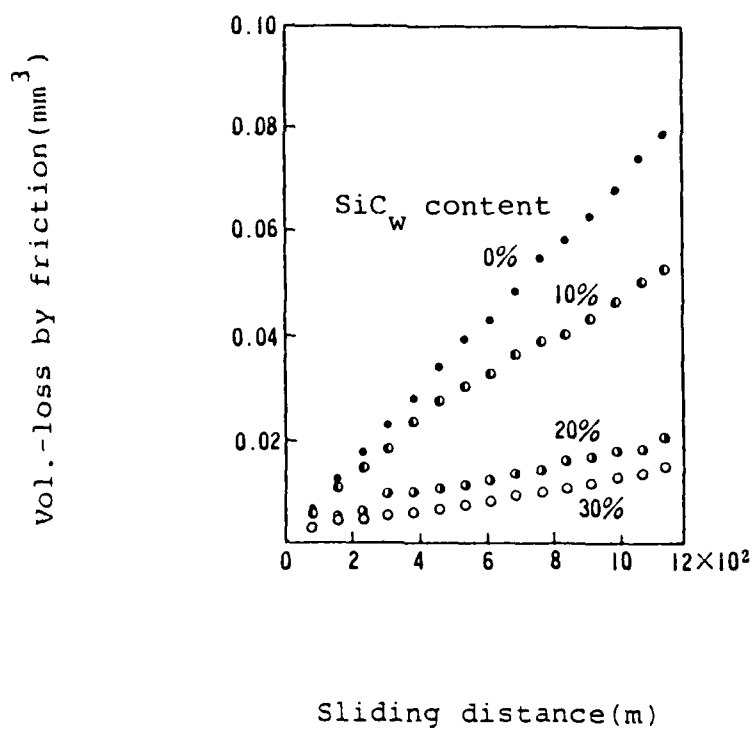


Figure 17. A wear property of SiC<sub>w</sub>/Si<sub>3</sub>N<sub>4</sub> (from Ref 32).

Further work on sintering in a normal atmosphere, aimed at obtaining complicated shapes and larger sizes, was carried out, resulting in Figures 18 and 19. Larger amounts of sintering aids ( $Y_2O_3$  and  $La_2O_3$ ) were needed for this application than for hot-pressing (Ref 34,35).

Thermal properties, such as thermal shock resistivity, thermal conductivity, and thermal expansion up to 1,400 °C, as well as resistivity versus air oxidation at 1,300 and 1,400 °C for 24 hours were also investigated (Ref 36,37). Figure 20 shows an example of  $K_{IC}$ . By using SEM, it was concluded that thicker whiskers were desired, although a length of only 10  $\mu m$  was enough (Ref 38).

The first successful structural ceramics application of  $Si_3N_4$  for a turbocharger in Japan is well known (Ref 11), and efforts to toughen this composite will be made enthusiastically.

In other research by Kandori et al. (Ref 39), an injection molding process was applied, giving a preferred orientation of  $SiC_w$  in  $Si_3N_4$ , although the  $SiC_w$  content was as low as 10 percent. Hot isostatic pressing (HIPing) was also carried out; however, as seen in Figure 21, the flexural strength had improved even before HIPing, perhaps because of the orientation.

Yonezawa et al. (Ref 40) used the sintering aids  $Y_2O_3$  and  $Al_2O_3$  for hot-pressing. Table 1 summarizes the results. Figure 22 illustrates the relationship between temperature and strength of the specimens listed in Table 2 (Ref 41).

Without any sintering aids, the silicon nitride was cold isostatically pressed (CIPed) under 200 MPa, calcinated at 1,200 °C for 2 hours under  $10^{-5}$  Torr, and then HIPed under 180 MPa at 1,900 °C for 3 hours. The results are summarized and shown in Figures 23 to 25 (Ref 42).

As mentioned in the GLASS AND GLASS-CERAMIC MATRICES section (see Figure 2), in-situ preparation in  $Si_3N_4$  matrix powder was carried out to make a homogeneous mixture of solids having different sizes and shapes as  $SiC_w$  and  $Si_3N_4$  fine powder. In comparison with regular physical mixing, this process, called chemical mixing, produced the results illustrated in Figure 26. A tumbling mixer was used for effective deagglomeration (Ref 43,44). Further research is being conducted from an economical standpoint.

In research activities outside of Japan, Shalek et al. (Ref 45) are concerned with fracture toughness and its surface energy as a function of  $SiC_w$  content up to 40 vol %. Lundberg et al. (Ref 46) investigated HIPed  $SiC_w/Si_3N_4$  composites. Buljan et al. (Ref 47) clarified the relationship between density and hot-pressing time as well as  $K_{IC}$  and modulus of rupture (MOR) as functions of  $SiC_w$  content.

## SILICON CARBIDE MATRIX

In this area, only the work of Sodeoka et al. (Ref 48,49) has been published. Figures 27 to 29 show the results of this research. Lower values of toughness and strength at  $SiC_w$  contents over 30 percent are considered to be due to crystal growth on the surface of the whiskers, although the density is high enough, as observed in Figure 29.

## MULLITE MATRIX

In addition to their earlier research, as shown in Figure 4 (Ref 14), Kimura et al. (Ref 50) reported other work on the sol-gel method by using ortho-methyl-silicate and aluminum sec-butoxide. At almost the same time, Wei and Becher (Ref 22) improved  $K_{IC}$  from 2.2 to 4.6 MPa  $m^{1/2}$  in comparison with alumina matrix reinforced by  $SiC_w$ .

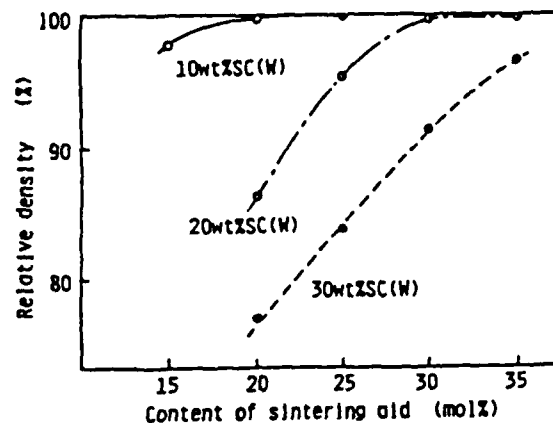


Figure 18. Relationship between  $\text{SiC}_w$  content and amount of sintering aid (from Ref 34).

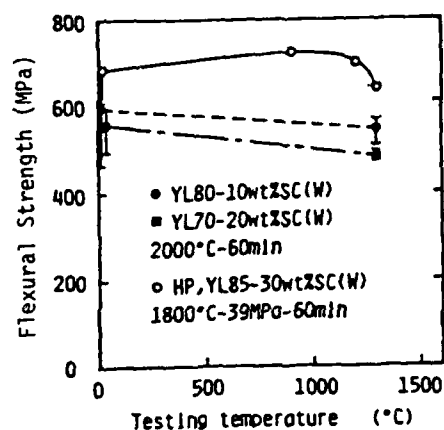


Figure 19. Change in strength versus temperature (from Ref 34).

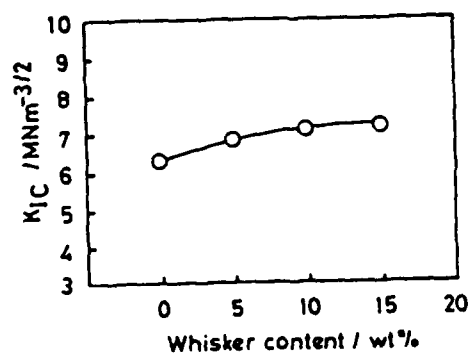


Figure 20. Variation of  $K_{IC}$  with the whisker content. Data obtained from chevron notch method (from Ref 38).

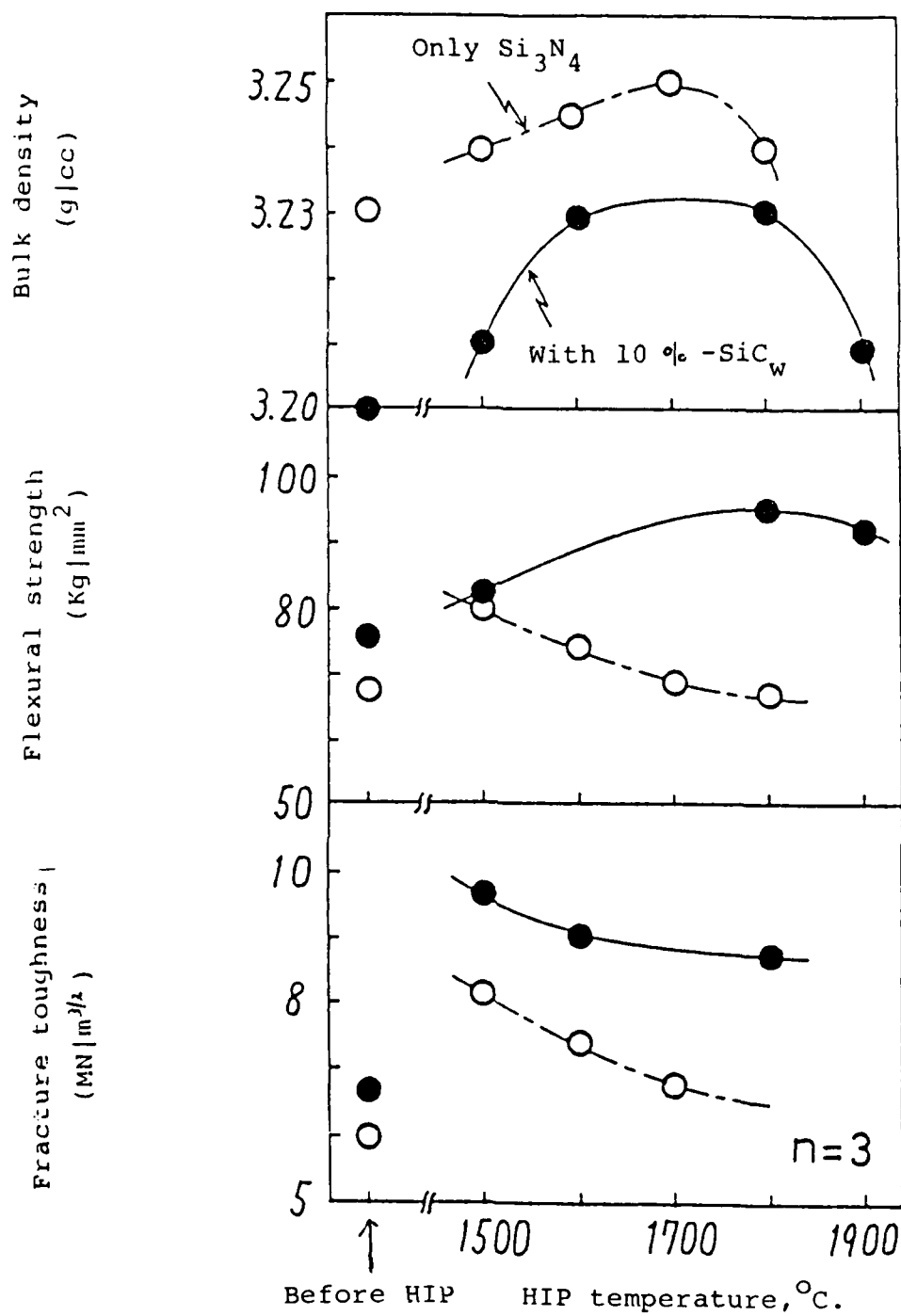


Figure 21. Bulk density, strength, and fracture toughness as a function of HIP temperature (from Ref 39).

Table 1. Several Properties of Hot-Pressed Materials

| Material                                                                                                    | Bulk Density<br>(g/cm <sup>3</sup> ) | Strength<br>at Room<br>Temperature<br>(kg/mm <sup>2</sup> ) | K <sub>IC</sub><br>(MPa m <sup>1/2</sup> ) |
|-------------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------|--------------------------------------------|
| a. Si <sub>3</sub> N <sub>4</sub> + 5% Y <sub>2</sub> O <sub>3</sub><br>+ 2% Al <sub>2</sub> O <sub>3</sub> | 3.26                                 | 102                                                         | 9.0                                        |
| b. a + 40% SiC whiskers                                                                                     | 2.87                                 | 84                                                          | 7.5                                        |
| c. b + 5% Y <sub>2</sub> O <sub>3</sub>                                                                     | 2.86                                 | 83                                                          | 7.3                                        |
| d. b + 5% Al <sub>2</sub> O <sub>3</sub>                                                                    | 3.22                                 | 121                                                         | 8.8                                        |
| e. b + 5% MgO                                                                                               | 3.22                                 | 118                                                         | 8.3                                        |
| f. b + 5% AlN                                                                                               | 3.12                                 | 86                                                          | 8.3                                        |

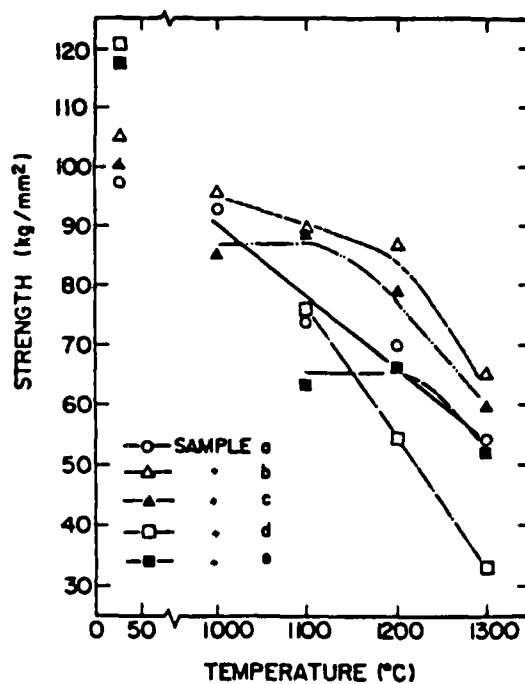


Figure 22. Temperature dependency of flexural strength (from Ref 41).

Table 2. Composition and Bulk Density of Sintered Specimens in Figure 22

| Sample | Composition                                                                                           | Bulk Density (g/cm <sup>3</sup> ) |
|--------|-------------------------------------------------------------------------------------------------------|-----------------------------------|
| a      | Si <sub>3</sub> N <sub>4</sub> + 5% Y <sub>2</sub> O <sub>3</sub> + 2% Al <sub>2</sub> O <sub>3</sub> | 3.26                              |
| b      | a + 20% whisker                                                                                       | 3.21                              |
| c      | a + 20% whisker + 5% MgO                                                                              | 3.23                              |
| d      | a + 40% whisker + 5% Al <sub>2</sub> O <sub>3</sub>                                                   | 3.22                              |
| e      | a + 40% whisker + 5% MgO                                                                              | 3.22                              |

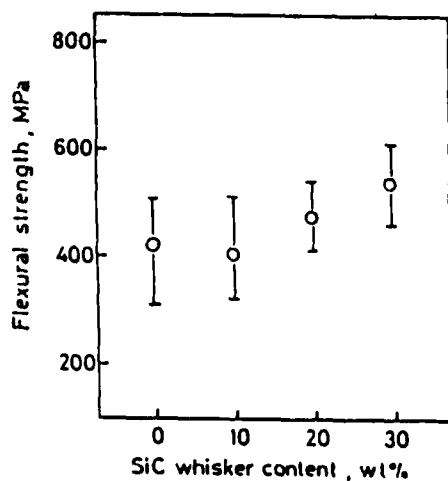


Figure 24. Flexural strength as a function of SiC<sub>w</sub> content (from Ref 42).

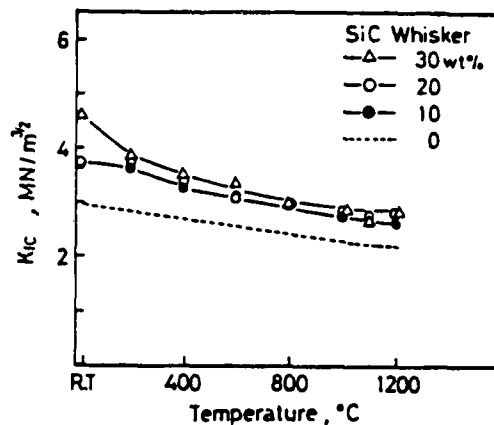


Figure 23. Temperature dependency of fracture toughness (from Ref 42).

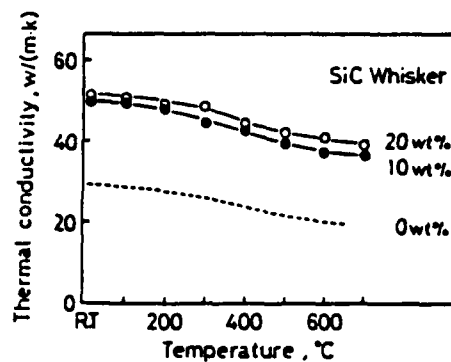


Figure 25. Temperature dependency of thermal conductivity (from Ref 42).

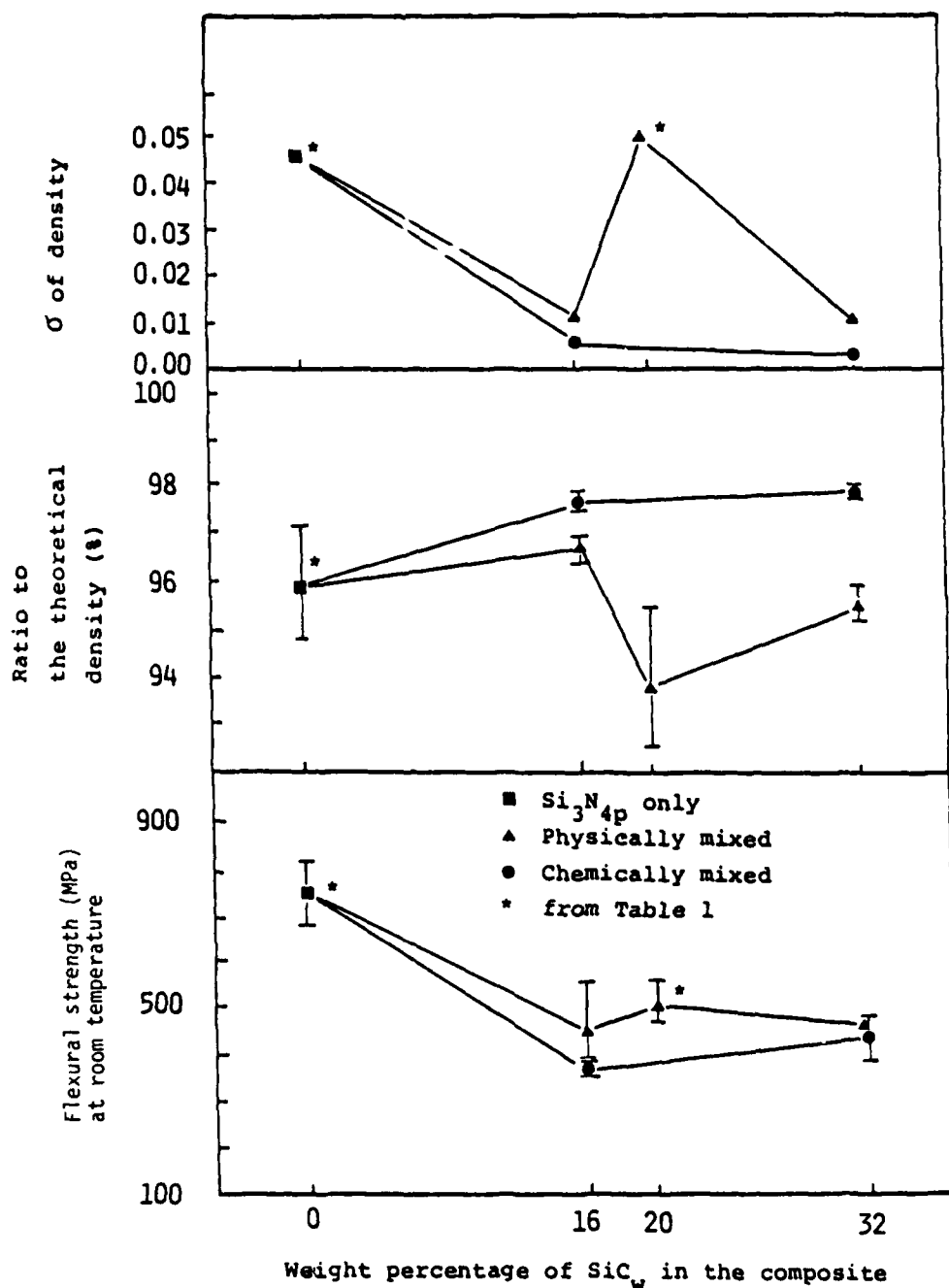


Figure 26. Density, its standard deviation, and bending strength of hot-pressed pieces derived from both mixing procedures using  $Y_2O_3 + La_2O_3$  as sintering aids (from Ref 44).

Note: A big difference in pore size distribution of the compressed green bodies of both mixing procedures was also made clear.

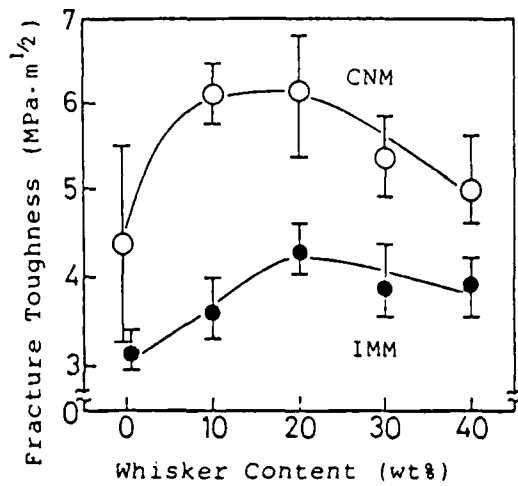


Figure 27.  $K_{IC}$  and  $SiC_w$  content (CN method:  $n = 4$ ; IM method:  $n = 10$ ) (from Ref 49).

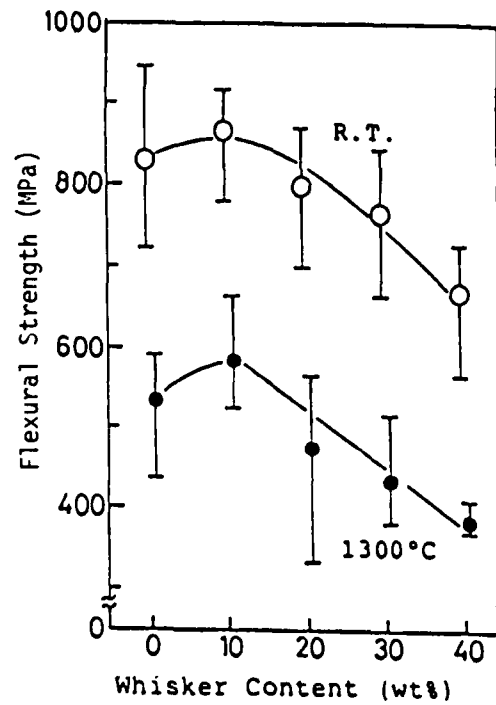


Figure 28. Flexural strength and  $SiC_w$  content (R.T.:  $n = 12$ ; 1,300 °C:  $n = 8$ ) (from Ref 49).

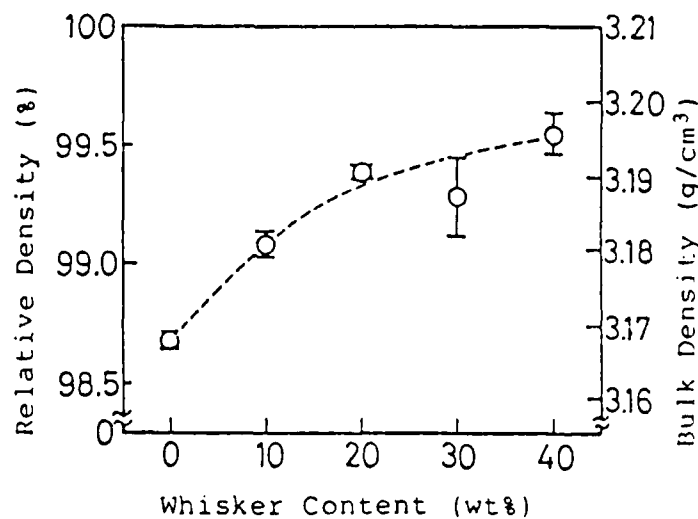


Figure 29. Density and  $SiC_w$  content (CN method:  $n = 4$ ; IM method:  $n = 10$ ) (from Ref 49).

Figures 30 and 31 show the results obtained by Kanzaki et al. (Ref 51). Figure 30 shows the positive effect of the reinforcement, whereas the effect at higher temperatures was found to be negative as shown in Figure 31.

Recently, Kamiaka et al. (Ref 52) presented data, summarized in Figures 32 to 34, showing the sintered SiC/mullite composite under normal pressure in comparison with the hot-pressed results in Figures 30 and 31. The relationship between the results in Figures 32 to 34 and the observation of fractured surfaces by SEM was also discussed.

### **SPINEL MATRIX**

Nakano et al. (Ref 53) reported a flexural strength (214 MPa) 1.5 times higher for hot-pressed spinel containing 20 vol % of SiC<sub>w</sub>. The results, shown in Figures 35 and 36 and obtained in collaboration with Kato, Hayashi, and others, are in comparison with alumina matrix composites (Ref 18). Less porosity (as low as 0.2 percent) was obtained with spinel derivatives than with alumina derivatives. Inoue et al. (Ref 54) and Claussen and Petzow (Ref 55) also performed research in this area.

### **CORDIERITE MATRIX**

No research has been performed in Japan, although Claussen and Petzow (Ref 55) published their results.

### **ALUMINUM NITRIDE MATRIX**

Nishida et al. (Ref 56) reported the results shown in Table 3 and in Figure 37. Hot-pressing was carried out at 1,800 °C for 30 minutes under 200 kgf/cm<sup>2</sup> after ball-milling. Table 3 suggests that the addition of a small

amount of Y<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> enabled the densification. The reinforcing effect shown in Figure 37 was a result of the greater pull-out of SiC<sub>w</sub> observed at higher temperatures by SEM of the fracture surfaces. According to research by them on a MgO matrix, the reinforcing effect was not so high, probably because of the smaller difference in the modulus of each component, AlN and SiC<sub>w</sub>, even at high temperatures (Ref 57).

### **MOLYBDENUM DISILICIDE (MoSi<sub>2</sub>) MATRIX**

Japanese research efforts in this area have not been published. The research by Gac and Petrovic (Ref 58) concerned an improvement in strength and toughness, leading to the conclusion that this type of composite is a feasible one.

### **CONCLUSION**

About one-third of the literature on SiC whisker-reinforced ceramic composites has been published since the beginning of 1987, which suggests renewed interest in the feasibility of using these composites in structural ceramic applications. Professor T. Ishii, of Tokyo University, described the history of world technology as a long stream of technological civilization, originating in the ancient times and migrating through the Mediterranean civilization, to the Renaissance, to the "Century of America," and finally arriving at the "Age of the Pacific Ocean" (Ref 59). Applying his concept of "from the Atlantic to the Pacific" to the study of ceramic composites, we must make the effort to further develop this high-tech material by steadily collaborating with American research groups.

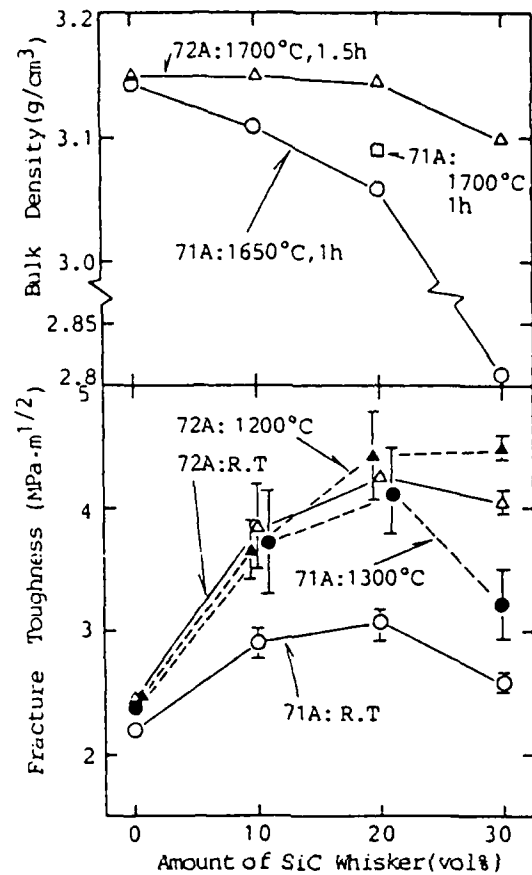


Figure 30. Density and fracture toughness versus  $SiC_w$  content (from Ref 51).

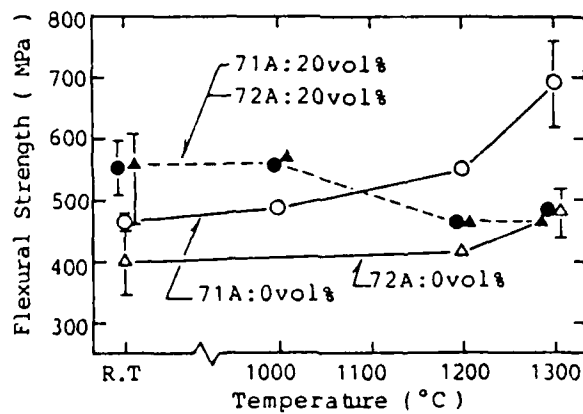


Figure 31. Change in flexural strength at higher temperatures (from Ref 51).

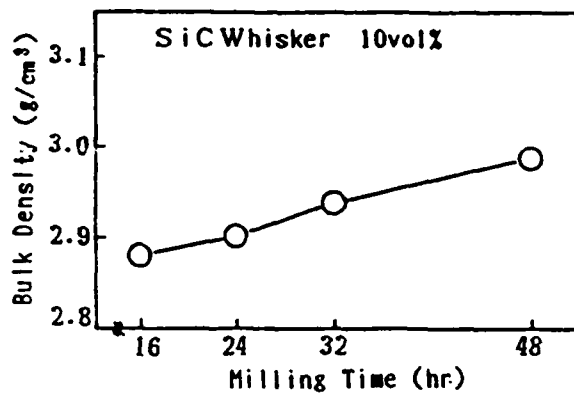


Figure 32. Bulk density versus milling time (from Ref 52).

Figure 33. Flexural strength versus milling time (from Ref 52).

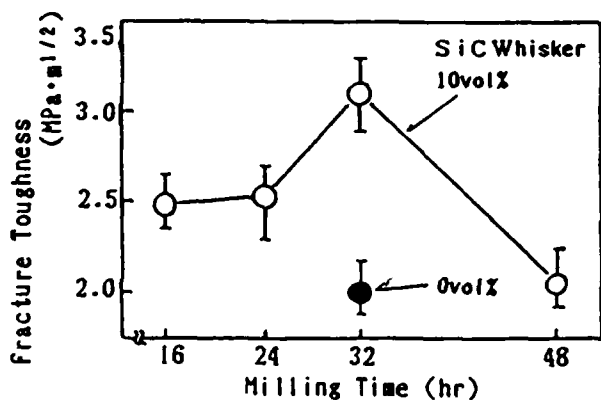
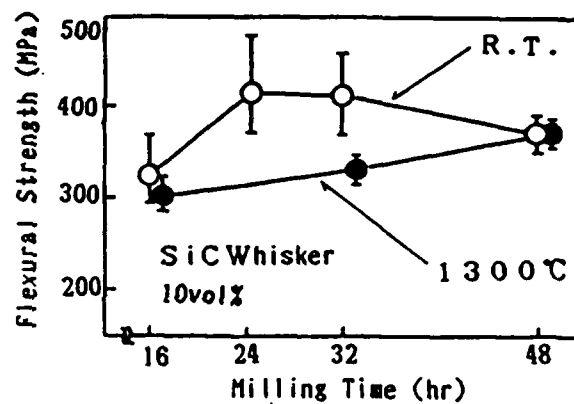


Figure 34. Fracture toughness versus milling time (from Ref 53).

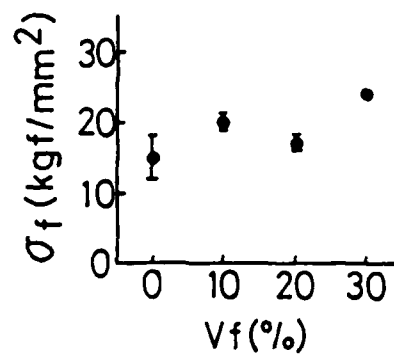


Figure 35. Flexural strength versus volume fraction,  $V_f$ , of  $\text{SiC}_w$  (from Ref 53).

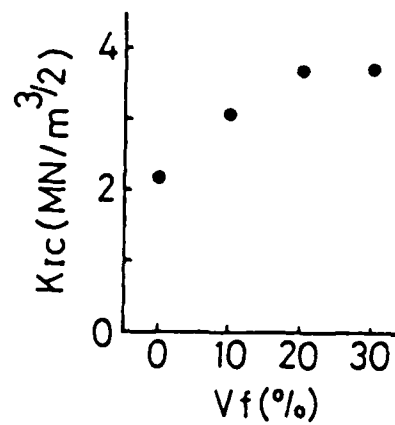


Figure 36. Fracture toughness versus  $V_f$  of  $\text{SiC}_w$  (from Ref 53).

Table 3. Chemical Component and Density of Sintered Material

| Chemical Component (wt. %) |                  |                               |                  | Density (g/cm <sup>3</sup> ) |
|----------------------------|------------------|-------------------------------|------------------|------------------------------|
| AlN                        | SiC <sub>w</sub> | Y <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> |                              |
| 100                        |                  |                               |                  | 3.25                         |
| 80                         | 20               |                               |                  | 3.18                         |
| 70                         | 30               |                               |                  | 3.05                         |
| 50                         | 50               |                               |                  | 2.55                         |
| 70                         | 20               | 5                             | 5                | 3.40                         |
| 50                         | 40               | 5                             | 5                | 3.39                         |

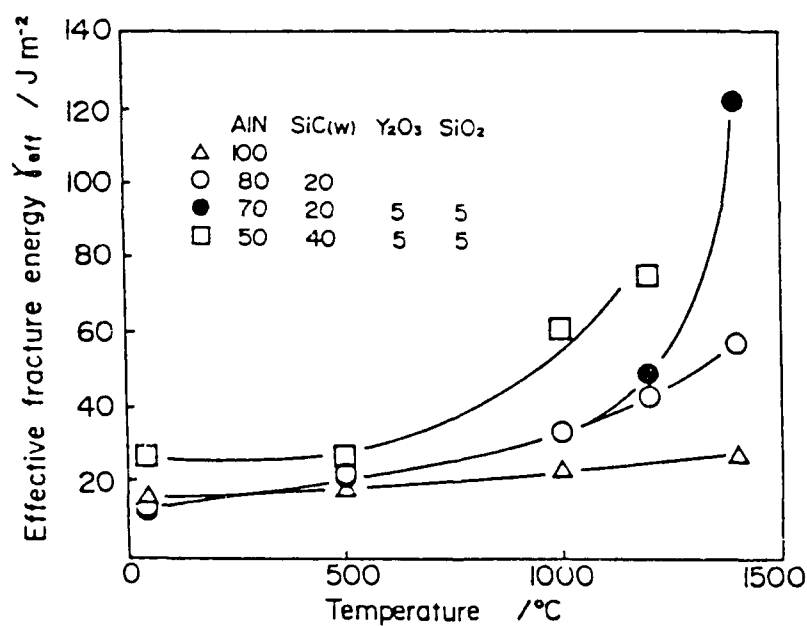


Figure 37. Change in effective fracture energy of  $SiC_w/AlN$  as a function of temperature (from Ref 57).

## ACKNOWLEDGMENT

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# THE TECHNOLOGICAL UNIVERSITY OF NAGAOKA

Alan L. Dragoo

*The Technological University of Nagaoka (TUN) was established in the early 1970s to strengthen creativity in science and technology. In addition to the academic programs, several centers conduct research and support the interdisciplinary program at TUN. This article describes some of the research being conducted at these centers.*

## INTRODUCTION

During a visit to Japan in March 1987, it was my pleasure to visit the Technological University of Nagaoka (TUN) for a day as the guest of Dr. Kozo Ishizaki. I visited several laboratories during the course of an afternoon and talked with researchers there. Due to the brief time spent at TUN, the following account can only present a superficial and incomplete description of the areas of research that I had the privilege to view.

TUN was established in October 1976 as a government university under the Ministry of Education to strengthen creativity in science and technology. Shinroku Saito, who is president emeritus of the Tokyo Institute of Technology, is president of TUN.

The establishment of the university was brought about in the early 1970s by the Research Committee Concerning Graduate Schools of Technology, the Preparatory Office for the Graduate School of Technology at the Tokyo Institute of Technology, and revision of the National School Education Law. Many of the original faculty as well as research equipment came from the Tokyo Institute of Technology.

Today the TUN campus consists of a network of modern buildings that are interconnected by covered walkways. The faculty has grown with the addition of younger members from a

variety of universities and backgrounds. Many of the laboratories contain instruments of recent manufacture.

The curriculum at TUN is designed to attain the goal of training engineers and scientists who are innovative and creative but who are also trained to transform new ideas into practical applications. To accomplish this goal, the curriculum is interdisciplinary and includes required "on-the-job" experience in industry. The student body is small, about 1,300 students, and of high intellectual caliber. There are about 180 faculty members.

Most students enter TUN as third-year undergraduate students upon completion of 5-year technical college programs. These entering students are roughly equivalent to students who have completed 2 years of undergraduate engineering study in the U.S. A small number of students are admitted from 3-year technical high schools as first-year undergraduates. The enrollment system is intended to provide a student body heavily weighted to upper level undergraduate and graduate level students so that high academic and research ability is present in the university's technical program.

Areas of study include mechanical systems engineering, planning and production engineering, electrical and electronic systems engineering, electronic (materials) engineering, material

science and technology, and civil engineering. In addition to the academic programs, several centers, such as the Analysis Center described below, conduct research and support the interdisciplinary program at TUN.

As a new technological university, the laboratories at TUN are very well equipped. Brief descriptions of some of the laboratories are presented here.

## LABORATORY VISITS

### Material Science

Research is being carried out on powder synthesis and preparation, hot-pressing and hot-isostatic pressing (HIP), microstructural development, and physical and chemical characterization of surfaces.

Electron diffraction and lattice imaging studies on Sr-Ba ferrite intergrowth, the electronic structure of vanadium oxides, and ceramic metal interfaces were described by Dr. Yoshihiko Hirotsu. Dr. Hirotsu's research interests include the solid state chemistry of electronic and structural ceramics. A JEOL JAMP-13 Auger spectrometer recently was acquired for this work.

Other instruments for materials characterization include a laser flash apparatus for measurement of heat capacity and thermal conductivity. This instrument is being used to study sintering effects on alpha/beta silicon nitride composition.

An ESM-3200 Elionix scanning electron microscope (SEM), which is equipped with two detectors, provides a capability for depth profile analysis with a resolution of 2 nm.

Dr. Ishizaki is constructing a HIP map (temperature-pressure-time) for the sintering of silicon nitride and silicon carbide. The HIP apparatus used is a NKK-ASEA instrument, with operating capabilities of 2,000 °C and

200 MPa (2,000 atm), and with chamber dimensions of 152 mm diameter by 305 mm high. A Fujidempage-10 hot-press provides a means for sintering materials with sustained temperatures of 2,200 °C and loads of 10 metric tons. The hot-press uses inductively heated graphite molds with either 25- or 50-mm internal diameters.

Starting powders for these studies are produced at TUN or are obtained from commercial sources. TUN synthesis methods include an arc plasma unit that has been used to generate SiC, Fe, Si<sub>3</sub>N<sub>4</sub>, SiO<sub>2</sub>, and Si powders. An Ar/H<sub>2</sub> plasma with an effective temperature in excess of 10<sup>4</sup> °C impinges on a suitable substrate, and powder is obtained as a condensate from the evaporated or sublimed material.

### Ion Beam Physics

A description of the ion beam apparatus, ETIGO-II, was provided by Dr. Yatsui. This ion beam unit is rated at 3 MeV and is the largest in Japan. Studies of ion pulses are in progress. A projected fusion device, ETIGO-IV, will incorporate 36 of the ETIGO-II type ion beam units.

### Analysis Center

Research in the Analysis Center includes catalytic materials and metal organic complexes. Several projects on the surface science of materials were described by Dr. Inoue. Investigations of the effects of electric fields and of illumination on surface states of semiconducting oxides are being carried out. Gas adsorption is studied by temperature programmed desorption (TPD) in which a gas is adsorbed on a cooled sample, the sample is heated at a programmed linear rate, the current proportional to the rate of desorption is measured, and the heat of desorption is obtained. A SIMS unit, in which a beam

of heavy ions impinges obliquely on the surface of a material, is used to examine the effect of adsorbed gases on the composition of molecular fragments sputtered from the surface of the substrate. Sputtering units are available for the production of thin oxide films.

A Rigaku x-ray generator is equipped with both a small-angle x-ray scattering unit and a goniometer for x-ray diffraction. A JEOL nmr spectrometer, using H, C, or  $^{19}\text{F}$  resonances, is used for identification of structures in organic compounds and organometallic complexes. This fully automated instrument enables data to be rapidly collected and displayed. Elemental analysis is provided with a JEOL Superprobe 733 equipped with two wavelength dispersive x-ray spectrometers and an energy dispersive spectrometer. A Shimadzu Auto GCMS-6020s, which is presently only equipped with a port for liquid injection, is scheduled to be directly coupled to a gas train. A Hitachi IMA-S ion microanalyzer equipped with a 10-keV ion source and dual tandem mass analyzers is available for depth profiling of compositions. The tandem mass analyzer enables the resolution of different isotopic masses to be achieved.

## CONCLUSION

TUN is dedicated to the education of creative scientists and engineers. To do this, it has a highly focused program and an academically advanced student body. The small size of the university and its interdisciplinary program foster a sense of awareness and collaboration between departments. The research

laboratories I visited appeared to be well-equipped with near state-of-the-art equipment. From the standpoints of its high caliber student body and faculty and its research facilities, TUN appears well-positioned to achieve its goal of training innovative, practically oriented engineers and scientists.

## ACKNOWLEDGMENT

I wish to thank Prof. Ishizaki for the opportunity to visit the Technological University of Nagaoka and for providing corrections to this report.

*Alan Dragoo has a background in both chemistry and physics, having earned B.S. (1961) and M.S. (1963) degrees in chemistry from the University of Michigan and a Ph.D. in physics from the University of Maryland (1975). He has 24 years of research experience at the National Bureau of Standards, both before and after receiving the Ph.D. His work has included experimental and theoretical studies of mass transport in ionic crystals, theoretical work on the Marangoni effect (convective flow in liquids which is driven thermally or chemically through surface tension gradients), measurements of elastic constants, theoretical modeling of chemical bonds in ionic compounds, preparation and characterization of highly dense and pure ceramic research materials, and experimental x-ray diffraction studies of phases formed on silicon carbide ceramics by corrosive reactions. He has been the author or coauthor of 22 papers in his field. Dr. Dragoo is currently Group Leader of the Ceramic Powder Characterization Group.*

# FIRST INTERNATIONAL WORKSHOP ON MULLITE: NEW DEVELOPMENTS FOR AN OLD MATERIAL

Edward S. Chen

*The First International Workshop on Mullite focused on four major topics: phase equilibria, crystal structure, processing and properties, and composites. This article summarizes some of the more interesting developments, problems, and opportunities presented at the workshop.*

## INTRODUCTION

The First International Workshop on Mullite was held on 9-10 November 1987 in Tokyo, Japan. The workshop agenda included 24 oral presentations and 40 poster sessions focusing on four major topics: phase equilibria, crystal structure, processing and properties, and composites. Considering the potential of mullite for structural applications, the current workshop devoted a major portion of the program to recent advancements in the processing and characterization of the physical and mechanical properties of mullite. The following summary reflects some of the more interesting developments, problems, and opportunities.

## PHASE EQUILIBRIA

Mullite belongs to the  $\text{Al}_2\text{O}_3$ - $\text{SiO}_2$  system for which a simple, albeit controversial, phase relationship is known. It forms in the solid solution range between 71.8 and 74.3 wt. %  $\text{Al}_2\text{O}_3$  approximating the 3:2 ( $3\text{Al}_2\text{O}_3$ - $2\text{SiO}_2$ ) and the 2:1 ( $2\text{Al}_2\text{O}_3$ - $\text{SiO}_2$ ) alloys. However, leading researchers disagree on the melting point of mullite, the reported values of which vary from 1,825 to 1,890 °C. Dr. Pask, University of California at Berkeley, suggested in concert with others in his field that one should consider the experimental data to be correct but that such data should be interpreted from both a metastable and a thermodynamically stable system viewpoint. Dr. Pask also emphasized the need to

look beyond the 3:2 mullite alloy to examine the influence of precipitated  $\alpha\text{Al}_2\text{O}_3$  and glassy  $\text{SiO}_2$  in the two phase regions at higher and lower  $\text{Al}_2\text{O}_3$  concentrations.

## PROCESSING

As with all ceramics, mullite can be produced optimally when proper procedures are applied to each of the processing categories of powder synthesis, consolidation, drying, and sintering. In powder synthesis, it is necessary to produce high purity fine powders and this can be done through sol-gel, hydrothermal, chemical vapor deposition (CVD), and pyrolytic techniques. A fine powder is desirable because it increases the surface energy of the particulate system and thus the driving force for sintering. Under these conditions, sintering occurs at a lower temperature, reaction kinetics are accelerated, and a finer grained ceramic is produced. As powder size decreases, however, powder agglomeration increases. When this occurs, one finds that the packing density of the green compacts cannot be optimized and an intolerable number of pores persist in the sintered product.

Recent studies have illustrated the potential of reducing particle agglomeration using colloidal consolidation methods. One such development was reported by Kureha Chemical Industry Company. Kureha succeeded in producing uniform colloidal dispersions by stabilizing the powder particles with a polymeric coating. Using this procedure, Kureha

produced green mullite compacts by filtration where the sintered product reached 99.8 percent of theoretical density.

An important consideration in the preparation of mullite is to reduce manufacturing costs in order that mullite may compete successfully with other ceramics. One approach is to use reaction sintering whereby MgO, TiO<sub>2</sub>, and ZrO<sub>2</sub> are added to produce consolidation through a liquid phase. Two benefits come to mind. First, reaction sintering enables one to use conventional pressureless sintering techniques and at reduced temperatures. Second, it is a particularly effective method of incorporating ZrO<sub>2</sub> into the mullite matrix to provide improved mechanical properties. Several papers reported on such improvements. The astonishing development is that the improved properties did not come about through the anticipated (t-ZrO<sub>2</sub>) transformation toughening. Instead, homogeneous monoclinic ZrO<sub>2</sub> dispersions intertwined with a crosslinked arrangement of mullite grains were found. Within this arrangement, crack propagation must follow a tortuous path and crack detection and bridging mechanisms contribute to the enhancement of strength.

## STRENGTHENING

Mullite is a ceramic that is often overlooked for high temperature applications in spite of its impressive properties such as refractoriness, chemical inertness, thermal stability, and creep resistance. In actuality, it only needs to have improved fracture toughness and strength to have an impact in this application. In the current workshop, conclusions drawn from studies on mullite strengthening using ZrO<sub>2</sub> alloying, SiC whisker reinforcement, and diphasic mullite with amorphous SiO<sub>2</sub> tend to support this view. In general, all three

procedures produced favorable room temperature property improvements. Typically, bending strengths were increased from 200 to over 500 MPa and fracture toughness values, K<sub>IC</sub>, were improved from 2 to 7 MPa/m.

While the strengthening procedures produced comparable room temperature property data, this was not the case at high temperatures. In reaction sintered alloys, the tendency to form an intergranular amorphous phase in MgO-ZrO<sub>2</sub>-mullite and the recrystallization of aluminum titanate in TiO<sub>2</sub>-ZrO<sub>2</sub>-mullite alloys are detrimental to strength at temperatures above 800 °C. A possible solution is to use higher purity powders to minimize interactions between impurities and the amorphous phases. SiC whisker reinforcement showed a small negative coefficient of strength up to 1,000 °C, at which temperature the bending strength was still 450 MPa. However, SiC whisker reinforcement is lacking in two respects. One is an unexplained tenfold decrease in creep resistance. The other is the decomposition of SiC in mullite at temperatures above 1,400 °C. The obvious solution here is to switch to an oxide whisker for reinforcement. Perhaps the most dramatic development is that reported by the Government Industrial Research Institute of Nagoya and the Technical Research Laboratory of Mino Yogyo Company on the characterization of mullite in the two-phase region (68 wt. % Al<sub>2</sub>O<sub>3</sub>), where one component is a glassy SiO<sub>2</sub> phase. The bending strength of this alloy peaks at 1,300 °C at about 475 MPa. The high temperature strength of this alloy compares favorably with gas pressure sintered Si<sub>3</sub>N<sub>4</sub> currently used in turbine rotors.

Figure 1 compares the flexural strengths of gas pressure sintered Si<sub>3</sub>N<sub>4</sub> prepared by NGK and Mitsubishi with mullite produced by the sintering of spray-dried powder containing 68 wt. % Al<sub>2</sub>O<sub>3</sub>. The NGK data were obtained at

0.5 mm/min using a three-point bend test. The test conditions for the remaining two curves were not specified. One should not look at this figure and make an arbitrary judgment on which material is better since such judgments depend on application requirements. Nevertheless, when one considers that the inlet temperature of the Garret turbine engine peaks at 1,370 °C, the current developments in mullite assume greater importance.

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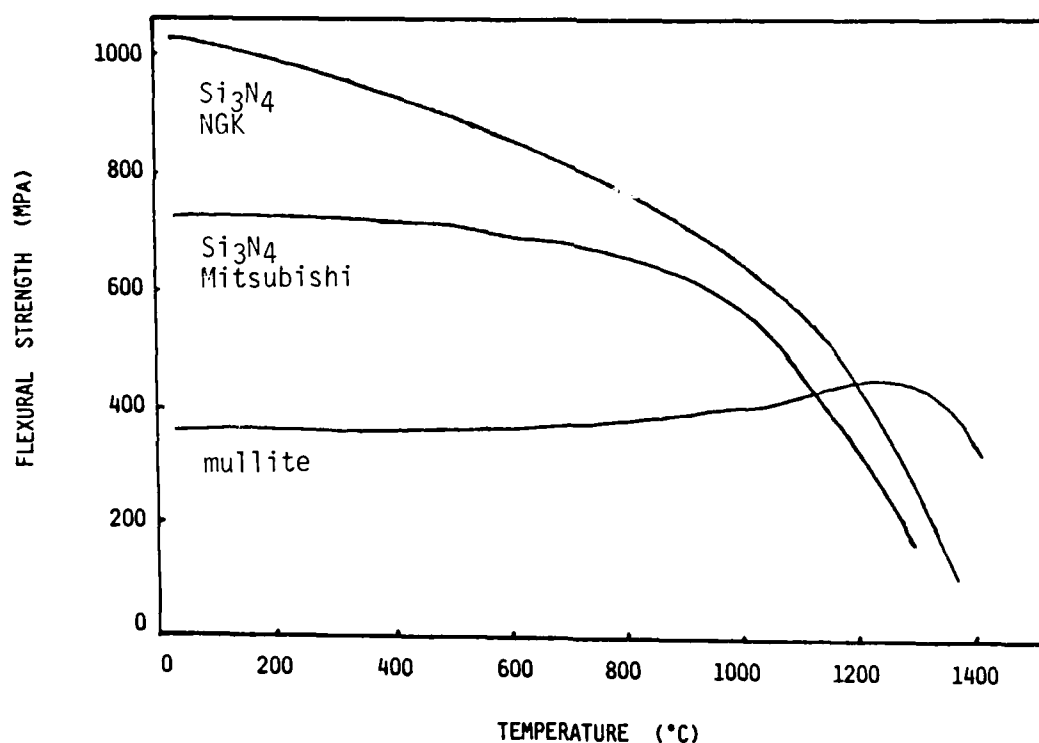


Figure 1. Comparisons of flexural strengths of gas pressure sintered Si<sub>3</sub>N<sub>4</sub> prepared by NGK and Mitsubishi with mullite produced by sintering of spray-dried powder containing 68 wt. % Al<sub>2</sub>O<sub>3</sub>.

## SOLAR PHYSICS ACTIVITIES IN JAPAN

Tokio Tsubaki

*This article describes the major solar observatories in Japan and surveys the research activities in solar physics during the past 5 years.*

### INTRODUCTION

The Astronomical Society of Japan is composed of three types of memberships, special, ordinary, and corporate, consisting, respectively, of 660, 1,588, and 50 members as of 30 June 1987. The special membership corresponds to the mixture of junior, associate, full, and emeritus memberships as in the American Astronomical Society, and the ordinary membership is mostly for amateur astronomers. Most of the research has been conducted by the special members, although amateur astronomers have been making a great contribution to some fields, such as in discovering a new comet or a nova event. The society makes it a rule to hold a general meeting twice a year, in the spring and fall, during which the overall aspects of research activities progressing in Japan are discussed.

In this article, the major observatories are described and the current activities in solar physics that were discussed in papers given at the general meetings of the Astronomical Society of Japan are surveyed.

### SOLAR OBSERVATORIES

Several important solar observatories are now in active service both for optical and radio observations.

#### Norikura Solar Observatory

Located on top of Norikura Mountains ( $137^{\circ}33.3'$  E.,  $36^{\circ}6.8'$  N.) at an altitude of 2,876 meters, this observatory belongs to Tokyo

Astronomical Observatory, University of Tokyo. This facility has a 25-cm Coudé type coronagraph and attached spectrograph, which are used for observing not only the corona but various phenomena appearing at the chromospheric and photospheric levels, such as prominences, spicules, faculae, sunspots, and flares. Another 10-cm coronagraph is mainly used for obtaining monochromatic images of the corona in Fe XIV 5303 coronal emission.

#### Hida Observatory

This observatory, which is part of the Faculty of Science, University of Kyoto, is located at  $137^{\circ}18'$  E.,  $36^{\circ}5'$  N. and 1,276 meters above sea level in the mountainous area of Hida, about 20 km west of the Norikura Solar Observatory. The principal instrument is the 60-cm domeless solar telescope, which is equipped with two spectrographs, a vertical and horizontal. The domeless structure, cooled tower surface, and evacuated optical channel suppress air turbulence around and inside the telescope, resulting in high resolution. Because of the high resolution, this telescope is being used by many researchers from various institutes in Japan.

#### Okayama Astrophysical Observatory

The Okayama Astrophysical Observatory, a station of the Tokyo Astronomical Observatory, University of Tokyo, is located on Mt. Chikurinji at  $133^{\circ}35.8'$  E.,  $34^{\circ}34.4'$  N. and 360 meters above sea level. The

principal instruments are a 60-cm Coudé telescope and a 10-meter horizontal Littrow spectrograph to which a vector magnetograph has been recently installed. The magnetograph, which is a unique instrument in this country, supplies daily magnetic data on the sun.

#### **Kwasan Observatory**

A sister observatory of Hida Observatory, also belonging to the Faculty of Science, University of Kyoto, this facility is located on a small hill in the city of Kyoto, about 200 meters above sea level. A 50-cm horizontal telescope with a 70-cm coelostat and a 15-meter spectrograph are the main instruments. This system is now used not only for solar research but for educational purposes for the students at Kyoto University.

#### **Nobeyama Solar Radio Observatory**

This observatory, a station of Tokyo Astronomical Observatory, is located on Nobeyama Heights at an altitude of 1,350 meters. Two sets of radio telescopes are the principal instruments: one is a 160-MHz interferometer consisting of 17 parabolic antennas of 6- to 8-meter apertures, and the other is a 17-GHz interferometer with 17 sets of 1.2-meter antennas. These instruments are used not only for obtaining a high resolution image but also for observing radio emissions over a wide wavelength range.

#### **Toyokawa Observatory, the Research Institute of Atmospherics**

The Toyokawa Observatory, located in the city of Toyokawa, belongs to Nagoya University. The observatory contains two sets of radio heliographs with fine resolution. The

3.75-GHz heliograph, with a spatial resolution of 1 arc minute, consists of 52 sets of 3-meter-aperture parabolic antennas; the 9.4-GHz heliograph consists of 50 sets of 1.2-meter-aperture antennas. Besides these, there is another telescope for observing radio flux simultaneously at the following four wavelength ranges: 1,000, 2,000, 3,750, and 9,400 MHz.

#### **Others**

There are some other observation facilities that are smaller but more convenient for daily observations because they are installed at each institute. For example, a radio telescope (interferometer) is installed on the campus of Nagoya University for making observations at millimeter wavelength range. At Shiga University, a 30-cm-aperture vertical telescope with 50-cm coelostat and 7-meter horizontal spectrograph was installed recently. At other institutes, 10- to 20-cm solar telescopes are being used not only for research but for educational purposes.

### **RESEARCH ACTIVITIES**

Table 1 summarizes the number of papers on solar physics and the total number of papers, both presented at the general meetings held during the past 5 years and during the same period 20 years ago, along with the corresponding number of special members.

As seen in this table, the percentage of solar physics papers compared to those in all fields has decreased from about 20 to 12 percent during the past 20 years, thereby suggesting that solar physics activities have considerably diminished at least in the sense of relative numbers. Note, however, that the actual numbers have increased from about 30 to 52 papers a

year, that is, by a factor of 1.75. The total number of papers and the membership have increased during this period by factors of 2.81 and 2.17, respectively. It is clear from these results that research activities in other fields, such as galaxy, high energy astrophysics, cosmology, and observation or data-reduction facilities, have increased at a much higher rate.

For surveying research activities on solar physics, a statistical analysis has been made of the papers presented during the past 5 years at the general meetings of the Astronomical Society of Japan. The results are summarized in Table 2.

As clearly shown in this table, the outstanding research field during the past 5 years has been the investigation of flares, a dynamic, explosive phenomenon of the active chromosphere. The reason for such a flurry of activity in this field is the flare observation satellite, HINOTORI, meaning firebird, sunbird, or phoenix. HINOTORI was successfully launched in early 1981 when the sun's activity was at its maximum phase and provided an enormous number of flare observations in the wavelength ranges from hard to soft x-ray. Using these data, a lot of flare research was carried out by the extended collaboration of many people from many institutes.

Table 1. Number of Papers Presented at the General Meetings and the Number of Special Members of the Astronomical Society of Japan

| Year       | Solar Physics | All Fields | No. of Members | Year       | Solar Physics | All Fields | No. of Members |
|------------|---------------|------------|----------------|------------|---------------|------------|----------------|
| 1962       | 41            | 141        | 252            | 1982       | 54            | 386        | 521            |
| 63         | 26            | 163        | 257            | 83         | 52            | 419        | 538            |
| 64         | 27            | 149        | 250            | 84         | 53            | 420        | 549            |
| 65         | 21            | 129        | 260            | 85         | 50            | 445        | 569            |
| 66         | 34            | 169        | 265            | 86         | 51            | 443        | 604            |
| Total      | 149           | 751        | --             | Total      | 260           | 2113       | --             |
| Mean       | 29.8          | 150.2      | 256.8          | Mean       | 52.0          | 422.6      | 556.2          |
| % of Total | 19.8          |            |                | % of Total | 12.3          |            |                |

Table 2. Number of Papers in Nine Prominent Research Fields or Topics of Solar Physics Presented During the Past 5 Years at the General Meetings of the Astronomical Society of Japan

| Research Field                | 1982 | 1983 | 1984 | 1985 | 1986 | Total | Percentage of Total |
|-------------------------------|------|------|------|------|------|-------|---------------------|
| Theoretical studies           | 6    | 3    | 3    | 5    | 3    | 20    | 7.7                 |
| Sunspot & magnetic field      | 3    | 4    | 3    | 5    | 6    | 21    | 8.1                 |
| Spicule & surge               | 1    | 3    | 1    | 2    | 6    | 13    | 5.0                 |
| Prominence                    | 4    | 3    | 6    | 3    | 8    | 24    | 9.2                 |
| Corona                        | 3    | 4    | 2    | 9    | 6    | 24    | 9.2                 |
| Solar wind & IPS <sup>a</sup> | 3    | 2    | 0    | 3    | 3    | 11    | 4.2                 |
| Flare                         | 20   | 19   | 23   | 16   | 8    | 86    | 33.1                |
| Radio & x-ray burst           | 8    | 7    | 6    | 2    | 3    | 26    | 10.0                |
| Other fields                  | 6    | 7    | 9    | 5    | 8    | 35    | 13.5                |
| Total                         | 54   | 52   | 53   | 50   | 51   | 260   | 100                 |

<sup>a</sup>IPS = Interplanetary space.

The second prominent topic, radio and x-ray burst, also has an important relationship, more or less, with the results from HINOTORI. Since it is well known that the time profile of the radio burst coincides well with that of the x-ray burst, cooperative work with a ground-based radio telescope was extensively carried out. These observations, together with the results of the Solar Maximum Mission (SMM) satellite, have brought a number of new findings to the investigations of flare and burst.

Research for clarifying the physical structures of the corona, prominences, spicules, and surges has continued, mainly by using optical

telescopes such as the domeless solar telescope at the Hida Observatory and the coronagraph at the Norikura Solar Observatory. The research topics include periodic oscillations, energy releases, internal motions, evolutions, temperatures, and so on. Using the vector magnetograph, which was recently attached to the Coudé telescope at the Okayama Astrophysical Observatory, magnetic structures inside and around sunspots have been studied energetically. It should be noted here that a lot of effort had been made to develop, construct, and adjust the instrument before public use.

Theoretical studies have also continued to elucidate the physical process changing slowly in the convection zone, which is the origin of the solar cycle, one of the biggest problems still unknown. Global oscillations and helio seismology are the newest tools for studying the sun's deep interior. Combinations of theories and observations are being applied to the research on solar wind and interplanetary space. In this case, most observations have been made at the Toyokawa Observatory.

### INSTITUTE ACTIVITIES

Statistical analyses have been made to see how many papers have been presented by each institute at the general meetings during the past 5 years. For a paper written by two or more authors belonging to different institutes, fractional numbers ( $=1/\text{numbers of coauthors}$ ) were equally given to each institute; that is, no special weight was given even to the first author. The results are summarized in Table 3.

As seen in Table 3, there are three big groups showing prominent activities in the field of solar physics: Tokyo University, Nagoya University, and Kyoto University, each having a productive share of 36.5, 11.7, and 25.8 percent, respectively. Note, however, that since these groups are composed, respectively, of the observatory and the department, contributions both by the graduate students and by the peripheral researchers graduated from the corresponding department are considerable.

The Institute of Space and Astronautical Sciences contributed greatly to constructing, launching, and

operating the satellite HINOTORI, but there are very few solar physics majors on the staff. There are many minor institutes with only one or two solar physicists showing relatively good activities, such as the Department of Physics, Rikkyo University, and the Department of Earth Science, Shiga University. It should also be mentioned here that the recent increase of activity by other institutes depends considerably on the fact that studies done by collaborating with foreign researchers have increased greatly.

*Tokio Tsubaki, from Tokyo, Japan, graduated from the School of Science, University of Kyoto, in 1959; he continued graduate studies there in astrophysics (emphasizing solar physics) until the end of 1964, when he accepted a position as a lecturer at Ohita University, Faculty of Education. In 1967 he was awarded a Ph.D. degree from the University of Kyoto for his thesis titled "A New Model of the Coronal Condensation." After being promoted to an associate professor, Dr. Tsubaki accepted a position with the Faculty of Education, Shiga University, where he was promoted to a professor in 1976. To further his studies of the solar corona, Dr. Tsubaki joined several Kyoto University expeditions to observe solar eclipses (the South Pacific, 1965; Mexico, 1970; West Africa, 1973). Between 1973 and 1975, he was a postdoctoral research associate of the National Academy of Science/National Research Council of the United States doing coronal research at Sacramento Peak Observatory, Sunspot, New Mexico. Dr. Tsubaki's current research interests include detecting oscillatory phenomena in the solar corona and prominences.*

Table 3. Number of Solar Physics Papers per Institute  
Presented During the Past 5 Years at the General  
Meetings of the Astronomical Society of Japan

| Institute                                                   | 1982 | 1983 | 1984 | 1985 | 1986 | Total | Percentage<br>of Total |
|-------------------------------------------------------------|------|------|------|------|------|-------|------------------------|
| Tokyo Astronomical<br>Observatory,<br>Tokyo University      | 13.2 | 12.5 | 14.9 | 13.2 | 12.6 | 66.4  | 25.5                   |
| Department of<br>Astronomy,<br>Tokyo University             | 8.9  | 8.8  | 4.4  | 3.6  | 2.8  | 28.5  | 11.0                   |
| Institute of Space &<br>Astronautical Science               | 3.4  | 0.9  | 1.2  | 0.0  | 0.3  | 5.8   | 2.2                    |
| Department of Physics,<br>Rikkyo University                 | 1.7  | 1.8  | 1.2  | 1.3  | 2.2  | 8.2   | 3.1                    |
| Research Institute<br>of Atmospherics,<br>Nagoya University | 4.0  | 3.8  | 3.9  | 3.9  | 4.6  | 20.2  | 7.8                    |
| Department of<br>Astrophysics,<br>Nagoya University         | 2.4  | 4.8  | 3.0  | 0.0  | 0.0  | 10.2  | 3.9                    |
| Department of Earth<br>Science,<br>Shiga University         | 0.5  | 0.0  | 1.3  | 2.7  | 4.9  | 9.4   | 3.6                    |
| Kwasan & Hida<br>Observatories,<br>Kyoto University         | 7.0  | 8.9  | 11.3 | 10.2 | 8.0  | 45.4  | 17.5                   |
| Department of<br>Astronomy,<br>Kyoto University             | 6.0  | 4.6  | 3.3  | 2.1  | 5.6  | 21.6  | 8.3                    |
| Other Institutes                                            | 6.9  | 5.8  | 8.4  | 13.1 | 10.0 | 44.2  | 17.0                   |
| Total                                                       | 54.0 | 51.9 | 52.9 | 50.1 | 51.0 | 259.9 | 99.9                   |

## A REVIEW OF THE STATE-OF-THE-ART IN ROLLING ELEMENT BEARING TECHNOLOGY IN JAPAN

James F. Dill, Robert A. Harmon, and Edward Mark Lenoe

*Recently the authors had the opportunity to attend the International Exhibits at the 1987 Nagoya Ceramics Fair and to participate in the International Workshop for Advanced Materials in the same city. In addition, a preliminary survey of rolling element bearing technology in Japan was conducted. For this purpose three principal bearing manufacturers, two ceramic materials suppliers, and one aircraft engine manufacturer were visited. In the aircraft quality bearing area, based on the facilities visited and the ensuing discussions, there is no question that all three companies have the capability to produce bearings of the quality required for the highest performance applications. The depth of understanding and level of sophistication of research into bearing dynamics, fatigue life, failure modes, and advanced materials demonstrated the very solid basis of bearing technology in Japan. Fundamental input and research support from leading universities and research institutes were an integral part of the research and development structure within each organization and its sphere of influence. Regarding ceramics, the capability to produce high-performance, spindle-quality, ceramic bearing components clearly exists in Japan. All of the companies visited are in the process of testing or introducing both hybrid steel/ceramic and full ceramic bearings into appropriate markets. Limited quantities of silicon nitride rolling element bearings have been in production over the last 2 to 4 years. It was evident that bearing suppliers in Japan are strong world-wide corporations intent on successful development of advanced technology.*

### BACKGROUND

Rolling element bearings, while not typically viewed as high tech products, are a critical component for a wide range of both commercial and military systems. Automobiles, trucks, airplanes, electric motors, ships, machine tools, robots, microchip processing systems, satellites, rockets, the list could go on for pages. Our lives are influenced daily by systems that depend on the availability of highly reliable, low noise, low cost rolling element bearings.

As might be expected, some of the most demanding applications for rolling element bearings are in the aerospace industry and in particular

aircraft turbine engines. Both commercial and military aircraft turbine engines require highly reliable rolling element bearings for their performance. Since a bearing failure in an aircraft turbine engine could seriously risk aircraft safety, a zero failure philosophy is followed in designing and manufacturing these bearings. At the same time, these systems require bearings to operate under some of the most demanding conditions of speed, load, and temperature. To meet the demands of aircraft turbine engine manufacturers, bearing companies have been forced to achieve levels of precision found in few other industries and to use materials of the highest quality (essentially inclusion and void free).

Dimensional measurements in the micron range are routine in the rolling element bearing industry and measurements to 0.1 micron or less are relatively common. Surface finishes required are even more precise with levels as low as 0.005 micron being achieved on some components. To insure material quality and cleanliness, the steel is typically either double vacuum melted or electroslag remelted; in addition, it is frequently ultrasonically inspected to insure that the desired quality is achieved.

In addition to these high demands for precision and material quality, each bearing used in the mainshaft section of a turbine engine is a unique, application-specific design. Frequently, many special features, such as special mounting brackets or flanges or at times even portions of the engine structure, are included in the bearing design. This requirement for application-specific designs results in small lot size orders for any given bearing.

This combination of high precision, small lot sizes, and special design features makes the aircraft bearing business very labor and capital intensive. While prices for aircraft quality bearings can be quite high (frequently in the \$1,000 to \$10,000 range for a single bearing), manufacturing costs are also high at the same time because the bearing industry world-wide is very competitive and profit margins are small. Because of the age of facilities and current economic conditions, coupled with the nature of this business, it has become increasingly difficult for U.S. bearing suppliers to compete with foreign bearing manufacturers. Foreign suppliers have captured much of the higher profit, lower performance bearing business, leaving only the smaller, high-precision business to U.S. suppliers. With their production base reduced, U.S. suppliers

have found it harder than ever to invest in modernizing their high-precision bearing plants, resulting in the current situation where there is now concern that this business will also be lost to overseas suppliers.

At the same time, while competition for current bearing production is becoming increasingly difficult for U.S. suppliers, advanced systems are being developed that could significantly change requirements over the next 5 to 10 years. Therefore, any efforts to modernize the U.S. bearing industry must consider not only how to make current products better and at lower cost but also what production capabilities will be required to meet these future requirements.

To assess the capabilities of U.S. bearing suppliers relative to their foreign competition, to determine the status of the bearing industry world-wide, and to assess future directions in bearing technology, we undertook a review of bearing technology in Japan. The results of this review are discussed in this article. Topics covered include: general comments on the Japanese bearing industry; observations on Japanese aircraft quality bearing manufacturing; and observations on ceramic bearing technology, which is an important technology for meeting future systems needs.

## SURVEY OF JAPANESE INDUSTRY

To achieve a realistic perspective on the status, trends, and outlook for precision rolling element bearings and the related production facilities in Japan, the principal bearing manufacturers were identified; visits were arranged with:

- Nippon Seiko K.K. (NSK), Research Center and Precision Bearing Production Facility in Fujisawa

- Nippon Seiko K.K. (NSK), Otsu Production Plant near Kyoto
- Koyo Seiko Co., Ltd., Kokubu Plant near Osaka
- NTN-Toyo Bearing Co., Ltd., Kuwana Plant

To add perspective, two materials suppliers and the major Japanese aircraft engine manufacturer were also visited:

- Kyocera Corporation in Kyoto
- Toshiba Corporation, New Materials Department in Yokohama
- Ishikawajima-Harima Heavy Industries (IHI) in Tokyo

Members of our group participating in the visits are included as Appendix A. A list of key personnel contacted at each company is given in Appendix B.

In addition, visits were made to the international exhibits at the Nagoya Ceramic Fair, and Dr. James Dill of Mechanical Technology, Inc. (MTI), presented an invited lecture to the International Workshop for Advanced Materials Technology-Ceramics II: Characterization of Ceramics and Development of International Standards. His topic was "High Temperature Testing in Tribology." This was also held in Nagoya. These activities took place from 9-19 March 1987.

## OBSERVATIONS AND RESULTS

The three bearing companies visited comprise the three largest Japanese suppliers. NSK is the largest in Japan and one of the largest bearing companies world-wide. NTN is second in size in Japan, and Koyo is somewhat smaller.

In general, significant research was being conducted at all three companies. The most impressive facilities were found at NSK in Fujisawa. All three companies viewed their business on a world-wide basis and in general had both international production facilities and distribution networks in addition to their Japanese facilities.

In the aircraft quality bearing area, two of the companies had facilities that had been constructed very recently, one having been opened in the last 6 months and the second completed within the last 2 years. These facilities, in general, had primarily new machines; the machines were mainly of Japanese manufacture although some were from U.S. and European suppliers. Based on the facilities visited and the experience discussed, there is no question that all three companies have the capability to produce bearings of the quality required for the highest performance military applications. *Relative to production for military applications of their products, all of the companies pointed out that the Japanese constitution restricts them for exporting goods for this purpose.* Because of this restriction, all three companies are emphasizing marketing and production for the commercial aviation market.

The depth of understanding and sophistication of the research into the areas of bearing dynamics, fatigue life, modes of failure, and advanced materials shows that the current high level of bearing technology in Japan is on a broad solid footing. Fundamental input and research support from leading universities and research institutes are an integral part of the research and development structure within each organization and its sphere of influence. Constant attention to high quality and performance permeates all of the organizations visited.

Recent technical publications from some of the companies visited are indicative of the technical depth and detail being focused on rolling element bearings and their related technologies. A list of some recent references provided during visits is included as Appendix C. In general, the focus is on understanding the details of materials properties and characteristics and their influence on the behavior, performance, and life of bearings in the environment of the application. In bridging the gap from properties to application, a number of test rigs and simulators are used to examine the behavior of materials and components under simulated environmental operating conditions. Feedback from failure mode analyses and analytical investigations is used to improve the design and to better predict the life and reliability of their products.

The following is a list of highlights, significant observations, and apparent trends based on the various plant visits.

#### **General Bearing Industry Comments**

- The Japanese bearing companies visited were all full-range bearing manufacturers, each producing bearings ranging in quality level from ABEC 1 to ABEC 9. As in the United States, Japanese aircraft bearing production involves small lot sizes of special bearing designs for each application. In the production of such special bearings, there is close cooperation with the customer.
- As in the United States, each bearing manufacturer has a group of trusted subcontractors and suppliers it depends upon. Some subcontracted items include material stock, finished rolling elements, retainers, retainer plating, and race forging.
- The Japanese bearing companies use primarily Japanese steel suppliers, but they will purchase steel from either U.S. or European sources if necessary. U.S. sources mentioned included Latrobe and Carpenter. There are Japanese suppliers of all major bearing materials capable of meeting the tightest aircraft specifications. Two Japanese suppliers cited were Hitachi Metals and Daido Steel.
- Bearing manufacturers produce components from a full range of materials including typical U.S. alloys (52100, M-50, and 440C), European alloys such as 18-4-1, and Japanese alloys such as SUJ2 and SKH4. They are also beginning to work with the new carburizing alloy M-50NiL, developed in the United States specifically for the high shaft speed aircraft bearing application.
- Production facilities for ABEC 1 bearings (for applications like commercial and automotive equipment) are highly automated. Pride was taken in the care with which the process was monitored. In one area, it was pointed out that while there were 21 processes involved in machining a particular part, there were 23 inspection processes to insure that the part was correct.
- In the automated production line, all gauging was in line and primarily between processes. Parts that didn't meet a specified tolerance were automatically rejected. If a machine started producing parts out of tolerance because of misadjustment or tool wear, a warning light would come on to notify a machine operator. Machine operators would monitor the performance of a series of machines on a given production line, performing adjustments as necessary.

- In manufacturing general-purpose bearings, production progress, rates, and outages were monitored and posted in various areas of the plant. These charts showed performance for the given area as well as overall plant performance. The goal of the staff was to produce no rejected parts, which while not achieved was approached very closely.
- As in the United States, ball manufacture is treated as a specialized operation and is usually handled off-site by a specialty plant or separate company. No detailed information was gathered on ball manufacture.

#### Aircraft Engine Bearings

- Because of the higher precision required and the smaller lot sizes, high-performance bearings for aircraft engines, other aerospace applications, and precision spindles were generally manufactured in separate facilities.
- At present, U.S. operations for the companies visited are directed toward manufacture of ABEC 1 bearings. Because of the large differences in the facilities required for aircraft bearing production in comparison to existing U.S. facilities, it would make more sense to build a new facility, if a Japanese supplier wanted to set up production of these bearings in the United States, than to modify an existing facility. If there was a strong business reason to set up an aircraft bearing plant in the United States, Japanese suppliers would seriously consider it.
- All of the bearing companies seem to be tracking turbine engine development trends on a global basis and are keeping up with performance and quality advancements as they evolve.
- Use of the latest CNC machine tools and computer control of production processes were observed. Some postprocess inspection at the machine level was observed. However, as in the United States, inspection was not highly automated because of the small lot sizes generally involved in production. The general trend is toward more automation in all aspects of production including machining, process flow monitoring, production planning, and product design. Some use of automated guided vehicles for parts transfer between work stations and shop floor computer terminals for parts tracking, machining instructions transfer, and statistical process control data collection was observed.
- Production facilities were in general very clean and well maintained. In one facility that focused on final grind and assembly of aircraft and other high-performance bearings, definite efforts were noted at maintaining almost a "clean room" type grinding facility. Final inspection and assembly were all done in clean room environments as is typical in high-performance bearing production.
- "Just-in-time" philosophy was followed in manufacturing, resulting in very little product stored on the shop floor. Efforts to keep parts moving smoothly through production rather than waiting at a machine before the next step can be performed seemed to be quite effective.
- In terms of production, similar concerns were expressed to those most frequently mentioned by U.S. manufacturers. Among these were needs for automated surface quality inspection, simplified and more standardized marking, and non-destructive evaluation (NDE) for carburized materials.

- In the research and development area for steel bearings, the need for improved corrosion resistance for aircraft quality bearings and an interest in alternative processing techniques, including hard turning, were expressed.
- Top quality research into the origin and progression of fatigue in bearings is being conducted. In many applications, surface-initiated fatigue has been found to be more prevalent than subsurface fatigue, while to date most fatigue life theories only deal with subsurface-originated failures. This research, using x-ray and eddy current measurements, is leading toward an ability to predict the remaining life in a bearing. It has already permitted a much more detailed understanding of fatigue mechanisms to be developed and the relative importance of surface and subsurface mechanisms to be accounted for in different applications. Understanding developed from this research is being used in practical ways to improve bearing performance. A line of sealed, clean bearings for general-purpose use was developed to improve life via reduction of the probability of surface-initiated failure based on this research.
- Fatigue research shows that in cases where surface-initiated fatigue is the primary failure mode, improvements in the substrate material produce less life improvement than is found when the same improved material is used where subsurface failures are the primary life limitation. Only by reducing or eliminating surface-initiated failures can the full life potential of a bearing material be achieved.
- There was recognition of the possible need for higher temperature bearings and lubricants for advanced aircraft turbine engines including solid-lubricated ceramic bearings. However, while some very impressive work is being done in ceramic materials, to date Japanese work on solid lubrication appears to be less extensive than that in progress in the United States.
- In addition to work on ceramic bearings and solid lubrication, research was also underway on gas and magnetic bearings.
- A number of applications of hard coatings like TiN were described including one involving solid-lubricated, hard-coated, high-temperature steel races with ceramic rolling elements. Table 1 summarizes some of the more interesting applications described.

#### Ceramic Bearings

- All of the companies visited are in the process of testing or introducing both hybrid steel/ceramic and full ceramic bearings into the appropriate markets. Limited quantities of silicon nitride rolling element bearings have been in production over the last 2 to 4 years. One of the key suppliers of silicon nitride materials to the bearing companies is Toshiba. Komeya and Kotani (1986) (see Appendix C, Ref 2) reported that in 1975 silicon nitride powder of acceptable purity, size, and shape distribution was not commercially available. Therefore, Toshiba studied synthesis of powder. These preliminary experiments were based on a silica reduction method comprising  $\text{SiO}_2 + \text{C} + \text{N}_2 \rightarrow \text{Si}_3\text{N}_4 + \text{CO}$ . However, grain morphology

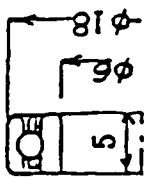
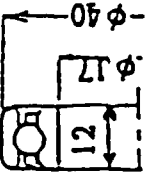
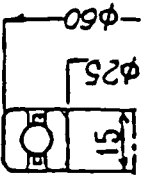
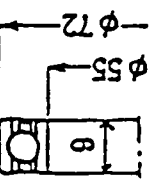
control was difficult. Finally good microstructural control was achieved by adding fine grains of  $\text{Si}_3\text{N}_4$  in mixing  $\text{SiO}_2 + \text{C}$ . The result was a powder of 98 percent alpha phase. For manufacturing ceramic bearings, a powder mixture is prepared by adding 5 wt %  $\text{Al}_2\text{O}_3$  to the  $\alpha\text{-Si}_3\text{N}_4$  powder. In addition to serving as a sintering aid, when  $\alpha\text{-Si}_3\text{N}_4$  is sintered with  $\text{Y}_2\text{O}_3$ , crystal grains are elongated and this tends to result in higher fracture toughness. Hot pressing and pressureless sintering are applicable.

- Kyocera is also developing ceramic materials for bearing applications. Some of the other companies displaying ceramic bearing components at the Nagoya Fine Ceramic Fair included: Koba; Showa Denko; Tyko, Ltd.; Kawasaki Heavy Industries; Ube; Nippon Steel; and Koba Electrics. European companies showing bearing components included: ESK (Federal Republic of Germany) and Lucas Cookson Syalon, Ltd. (United Kingdom). There were no U.S. ceramic exhibitors.
- There was a consensus that hipped  $\text{Si}_3\text{N}_4$  is the best material for rolling element bearing performance. The materials regarded as most promising all had  $\text{Al}_2\text{O}_3 + \text{Y}_2\text{O}_3$  additives. Data indicated that this material has higher strength than materials with  $\text{MgO}$  additives.
- In general, both races and rolling elements were produced in rough blanks shaped like the final component rather than being machined out of bulk material. While research is ongoing in near net shape forming of components, at present there is too much shrinkage and distortion during hipping to permit it. The ultimate goal of ceramic bearing

development is to achieve near net shape technology, thereby reducing the machining necessary to produce a final part. Because much of the ceramic machining involves expensive diamond grinding, reducing the rough stock removal required could significantly impact the cost of ceramic components.

- Some important characteristics of bearing quality silicon nitride are given in Tables 2 to 5 and Figures 1 to 3. While Japanese researchers were aware of and interested in using ceramics with solid lubricants at elevated temperatures, the primary emphasis of the current work described involved use of either steel/ceramic hybrid bearings or all ceramic bearings with either liquid or grease lubrication.
- The main incentives described for using ceramic materials in conventional applications included:
  - The lower density of the rolling elements reduces the centrifugal forces of the balls on the outer race to about 40 percent of that for steel balls. At high speeds, this can lead to a longer bearing life.
  - The low coefficient of thermal expansion permits operating with a higher thermal gradient for a given internal clearance.
  - Higher elastic modulus reduces the Hertzian contact area and lowers lubricated heat generation allowing a hybrid steel/ceramic bearing to be operated at about 20 to 25 percent higher speeds than an all steel bearing under the same lubrication conditions. Figure 4 shows comparative data for a grease-lubricated ACH016C size bearing.

Table 1. Application Examples

| Item                  | Construction                                                                          |                 |                                                       | Properties                                          |                     |             |                  |               | Operating Conditions |                |                                 |
|-----------------------|---------------------------------------------------------------------------------------|-----------------|-------------------------------------------------------|-----------------------------------------------------|---------------------|-------------|------------------|---------------|----------------------|----------------|---------------------------------|
|                       | Diagram<br>(dimensions in mm)                                                         | Materials       |                                                       | Heat Resistant                                      | Corrosion Resistant | Lightweight | Self-Lubricating | Anti-Magnetic | Temperature<br>(°C)  | Speed<br>(rpm) | Others                          |
|                       |                                                                                       | Rolling Element | Inner & Outer Ring                                    |                                                     |                     |             |                  |               |                      |                |                                 |
| Turbocharger          |    | Ceramics        | Heat-Resistant Steel (SKH4)                           | Brass                                               | X                   |             |                  |               | 10-200               | 200,000        | Solid lubrication in the future |
| Gas Turbine Engine    |    | Ceramics        | Heat-Resistant Steel + Surface Treatment (SKH4 + TiN) | Heat-Resistant Material + Surface Treatment (Cr2O3) | X                   |             | X                |               | 350-450              | 50-200         | Solid lubrication (no oil)      |
| Gas Turbine Engine    |   | Ceramics        | Ceramics                                              | Heat-Resistant Steel                                | X                   |             | X                |               | 20-130               | 1,000-10,000   | 500 kg                          |
| Centrifugal Separator |  | Ceramics        | Heat-Resistant Steel + Surface Treatment (SKH4 + TiN) | Graphite                                            | X                   |             | X                | X             | 400                  | 10,000         | Solid lubrication (no oil)      |
| Diesel Engine         |                                                                                       | Ceramics        | Heat-Resistant Steel                                  | Graphite                                            | X                   |             | X                |               |                      |                |                                 |

Courtesy of Koyo Seiko Co., Ltd.

Table 2. Characteristics of Silicon Nitride (after Ref 2)

| Item                                                | Characteristic                        |
|-----------------------------------------------------|---------------------------------------|
| Density                                             | 3.21 g/cm <sup>3</sup>                |
| Coefficient of thermal expansion (25-1,000 °C)      | $3.2 \times 10^{-6}$ 1/°C             |
| Thermal conductivity (RT)                           | 29.3 W/m·k                            |
| Modulus of elasticity (RT)                          | $3.2 \times 10^4$ kgf/mm <sup>2</sup> |
| Poisson ratio (RT)                                  | 0.26                                  |
| Three-point bending strength (Weibull modulus) (RT) | 106 (15) kgf/mm <sup>2</sup>          |
| Hardness (RT)                                       | 1,800 kgf/mm <sup>2</sup>             |
| K <sub>IC</sub>                                     | ~7 MPam <sup>1/2</sup>                |
| ΔT <sub>C</sub>                                     | 900 °C                                |

- The higher elastic modulus of the rolling elements coupled with smaller internal clearance requirements due to the low ceramic thermal expansion results in a higher bearing stiffness, which permits better shaft control in high-speed spindles. Better shaft control, in turn, results in better machining accuracy.
- The capability to produce high-performance, spindle-quality, ceramic bearing components clearly exists in Japan. Some bearing suppliers also produce special spindles with hybrid ceramic bearings.

- Production numbers have reached a level where reasonable confidence has been developed that satisfactory quality ceramic components can be produced consistently. One manufacturer cited experience running life tests on "over a hundred" of both full ceramic and steel/ceramic hybrid bearings.
- A 100-hour test has been completed by IHI of an aircraft engine gearbox with 8 full ceramic bearings and 11 hybrid bearings to gain experience with their performance in a real machine. At the time of our visit, 50 hours of the test had been completed and no noticeable wear was observed. Test bearings were described as basically appearing like new.
- Recently, additional testing has been completed and close inspection of the disassembled transmission box showed fully successful results with no apparent damage.
- Efforts have been made to develop materials with crystalline grain boundaries rather than glassy ones. While this was described as desirable, it was not clear whether crystalline grain boundaries had actually been achieved in bearing-quality ceramic materials.
- Development of improved NDE methods is an important remaining requirement in the development of these materials. Toshiba is doing considerable work in this area, including work on an x-ray CT scanner for material evaluation.
- There was considerable interest in the solid-lubricated bearing research in the U.S. The ceramic suppliers in particular see solid-lubricated elevated-temperature bearings as a major future application of ceramic materials.

Table 3. Comparison Between High Carbon Chromium Bearing Steel and Silicon Nitride (after Ref 2)

| Item                                            | Silicon Nitride                                     | High Carbon Chromium Bearing Steel         |
|-------------------------------------------------|-----------------------------------------------------|--------------------------------------------|
| Heat-resistant temperature, °C                  | 800                                                 | 120                                        |
| Corrosion resistance                            | Large                                               | Small                                      |
| Specific gravity                                | 3.2 or above<br>(small centrifugal force of roller) | 7.8<br>(large centrifugal force of roller) |
| Hardness Hv (room temperature)                  | 1,800 - 2,000                                       | 700 - 800                                  |
| Friction without lubrication                    | Small                                               | Large                                      |
| Magnetic property                               | Nonmagnetic                                         | Magnetic                                   |
| Rigidity (Young's modulus), kgf/mm <sup>2</sup> | 32,000                                              | 21,000                                     |

Table 4. Accuracy of Silicon Nitride Ball (after Ref 2)

| Item                                | Developed Material | Comparison Material |
|-------------------------------------|--------------------|---------------------|
| Sphericity, $\mu\text{m}$           | 0.3                | 0.5                 |
| Surface roughness Ra, $\mu\text{m}$ | 0.006-0.008        | 0.04-0.08           |

## CONCLUSIONS

- Bearing suppliers in Japan are strong world-wide corporations that are intent upon developing their business on an international basis.
- The aircraft and precision bearing facilities visited were clean and modern with primarily new and up-to-date machinery. However, no radical differences were seen in the basic approaches used in manufacturing as compared to U.S. companies.
- A strong philosophy that each worker was responsible for the precision and quality of his operation was in evidence. There didn't seem to be the split between production and quality control sometimes seen in U.S. companies.
- Great pride was taken in the use of quality circles and improving quality via input from the workers actually producing the parts.

Table 5. Characteristics of Ceramic Fatigue by Conventional Theory  
(after Ref 1)

| Item                 | Ceramic Fatigue                                                                    | Metal Fatigue                                                  |
|----------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Mechanism            | By mechanochemical reaction between stress and moisture                            | By accumulation of alternative microscopic plastic deformation |
| Dependence           | Time dependent                                                                     | Cycle dependent                                                |
| Stress Factor        | 1st: Tensile stress.<br>No effect: Stress amplitude; frequency; compressive stress | 1st: Stress amplitude.<br>2nd: Mean stress; frequency          |
| Material Factor      | Glass and alumina suffer; nonoxide ceramics hardly suffer                          | All metals suffer                                              |
| Environmental Factor | Moisture is indispensable                                                          | Corrosive environment can accelerate                           |

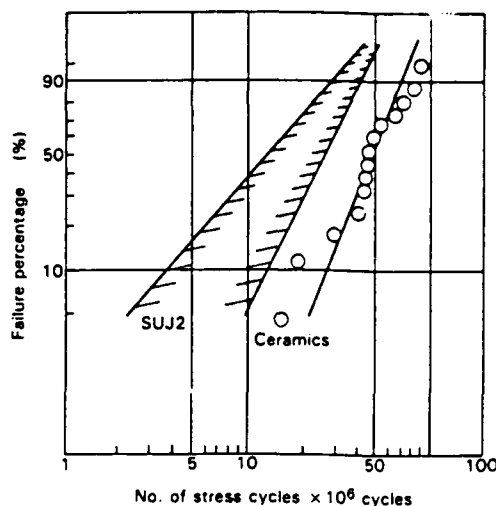


Figure 1. Rolling fatigue life of silicon nitride (from Ref 2).

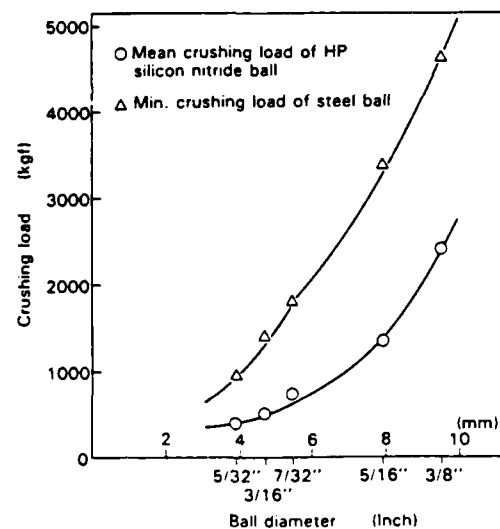


Figure 2. Crushing load comparison between silicon nitride ball and steel ball (from Ref 2).

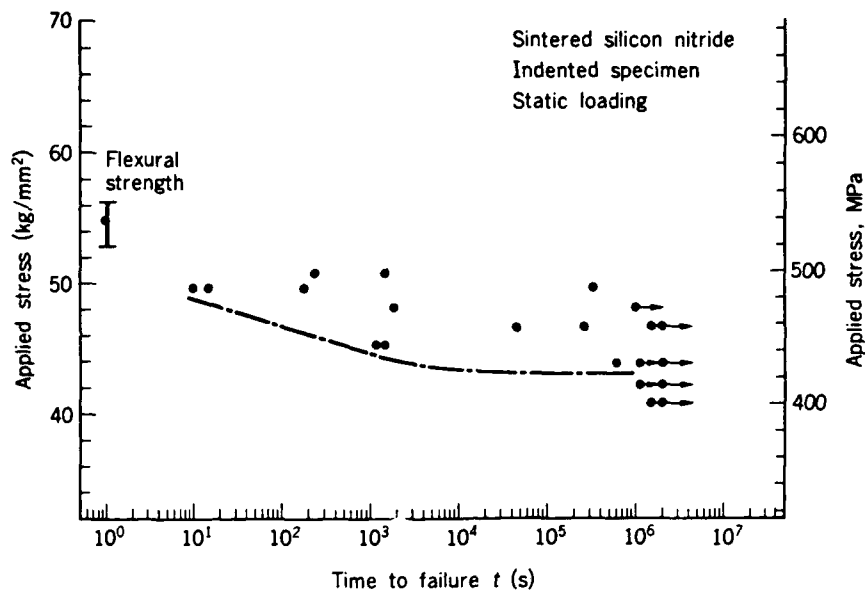


Figure 3. Static fatigue life of sintered silicon nitride (from Ref 1).

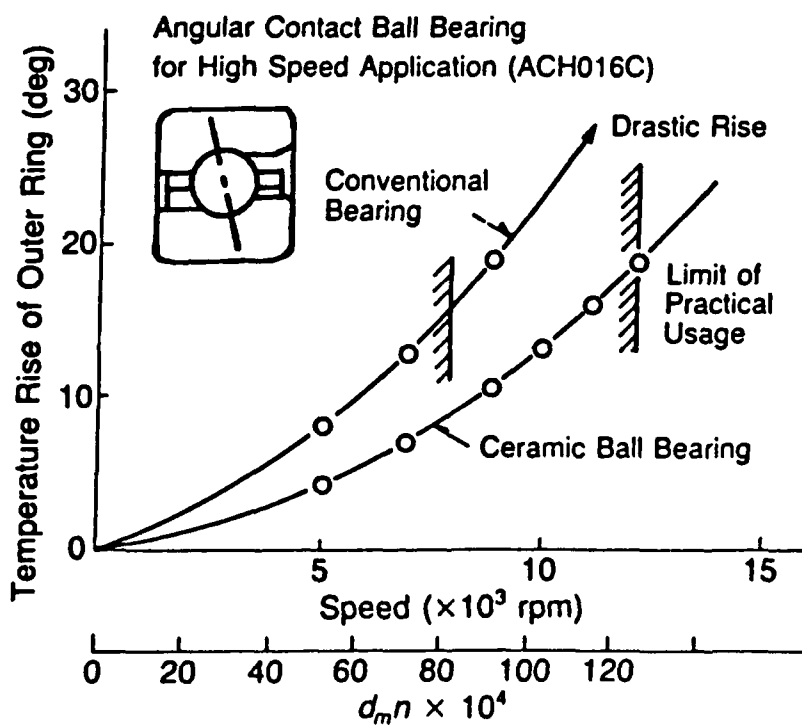


Figure 4. Test results under high speed rotation (courtesy of Koyo Seiko Co., Ltd.).

- The use of charts displayed at different places throughout the plant showing how each different department's efforts fit in the overall process was felt to give workers a better sense of the final product. Department production rates and reject rates were also posted to remind the workers of the goal of zero defects.
- Considerable high-quality research in rolling element bearing technology is in progress in Japan. Benefits could be realized by U.S. suppliers by following Japanese research as closely as possible.
- In terms of ceramic materials and ceramic bearing production for liquid- and grease-lubricated applications, the Japanese appear to be ahead of the United States. However, considerably less solid lubrication research was evident in Japan when compared to the United States.
- All of the Japanese companies visited were open about their capabilities and our visits were hosted by top level management. A genuine willingness to cooperate was felt in our visits.
- If Japanese suppliers could be shown that there is a U.S. market that justified the investment, they would consider developing aircraft or ceramic bearing facilities in the United States. Any such assessment would include both market potential and competition.
- In general-purpose bearings, third world and developing countries like Singapore and Korea are becoming strong competition for Japanese suppliers.

*James F. Dill received B.S. and M.S. degrees in physics from John Carroll University and a Ph.D. in physics/chemical engineering from Catholic University of America. Currently Dr. Dill is the manager of the Technology Development Branch at the R&D Division of Mechanical Technology Inc. He is responsible for the analytical and experimental programs in bearings, seals, gearing, rotordynamics, and basic tribology. He also acts as a consultant on bearing and lubricant technology. Dr. Dill's areas of interest are rolling element bearings, bearing materials, chemical physics of lubricants, rotordynamics, and experimental design and instrumentation. He is a member of the American Society of Lubrication Engineers, the American Society of Mechanical Engineers Research Committee on Tribology, and the North American Society of Adlerian Psychology.*

*Robert A. Harmon received B.S. and M.S. degrees in mechanical engineering from the Illinois Institute of Technology. Mr. Harmon has over 38 years of experience in applied research and program development at International Harvester, IITRI (formerly ARF), Williams International, General Electric Company, and Mechanical Technology, Inc. As an independent consultant since 1970, he has focused on gas turbines; diesel engines; and combined cycle power and cogeneration systems for industrial, marine, and vehicle applications. His emphasis has been on identification of the research and development needed to fill technology gaps and advance the state-of-the-art for critical components. Hence, he has recently focused on advanced materials such as ceramics and composites. Mr. Harmon has been active on numerous Society of Automotive Engineers and American Society*

*of Mechanical Engineers (ASME) technical committees, the International Organization for Standardization TC 70 Committee, and the American National Standards Institute B133 Committee. He was chairman of the ASME Gas Turbine Division in 1966.*

*Edward Mark Leno, on leave from the Army Materials and Mechanics Research Center, joined the*

*staff of ONRFE/AFOSRFE/AROFE in October 1985. Previously he managed the AMMRC Reliability Mechanics and Standardization Division, served as operating agent for the International Energy Agency implementing agreements on high temperature ceramics for heat engine applications, and also managed numerous major contracts. His studies for ARO will be devoted to structural ceramics.*

**Appendix A**  
**VISITING PERSONNEL**

**Mechanical Technology Inc. (MTI):**

**\*Dr. James F. Dill, Technical Director**  
**MTI Bearing Tech Mod Program**

**Robert A. Harmon, Consultant**

**Air Force:**

**Carl A. Lombard, Tech Mod Director**

**Cheryl A. Jones, Tech Mod Project Manager**

**Office of Naval Research, Liaison Office Far East:**

**\*\*Dr. Edward M. Lenoe, Liaison Scientist**

**Army Material Command, Science and Technology Center Far East:**

**\*\*Joey F. Crider, Materials Engineer**

**\*\*Junya Suda, Coordinator**

**\*\*Sadao Saito, Coordinator**

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**\*Team leader.**

**\*\*Did not attend all visits.**

**Appendix B**  
**COMPANY PERSONNEL**

**Nippon Seiko K.K. (NSK) at Fujisawa**

Dr. Seiho Yamamoto, Managing Director  
Bearing Technology

Minoru Akiyama, Director  
Bearing Technology

Dr. Kazuo Kakuta, Director  
General Manager, Research and Development  
Manager, Tribology Research and Development

Hiroshi (Harry) Mitsuhashi, Senior Manager  
Aerospace Group, Precision Bearing Technical Center

Keiji Takada, Senior Project Engineer  
Bearing Engineering Division

Dr. Satoru Aihara, Senior Researcher  
Manager, R&D Center

Katsuya Touma, Manager 2nd Department  
Tribology, Research and Development

Mr. Abe, Assistant General Manager  
Materials R&D

Y. Kosaka, No. 1 Plant Manager at Fujisawa

Mr. S. Saitoh, Manager  
Precision Bearing Section of No. 1 Plant at Fujisawa

Koichi Takano, Manager  
Marketing Department – America

**NSK, Otsu Plant**

Reijirou Hosokawa, Director Factory Manager  
Nippon Seiko Co., Ltd.

Kazuo Harashima, Product Engineering Manager  
Nippon Seiko Co., Ltd.

Nobutaro Nakagawa, Production Manager  
(Machining & Heat Treatment)  
Nippon Seiko Co., Ltd.

Setsuo Ueno, Quality Assurance Manager  
Nippon Seiko Co., Ltd.

**Koyo Seiko Co., Ltd., Kokubu Plant**

Ikuro Ito, Executive Director

Saburo Ueno, Managing Director  
Engineering Department

Kanji Ogura, Managing Director  
R&D Division

Toshio Miki, Director  
Engineering Department

Akira Nomura

Mr. H. Yasui, General Manager  
Research and Development Dept. 1

Mr. H. Kotani, Deputy General  
Manager, Research and Development Dept. 1

Mac Yokoyama, Senior Engineer  
Overseas Coordination Dept.

**NTN Toyo Bearing Co., Ltd., Kuwana Plant**

M. Takimoto, Manager  
Aerospace Bearing Operations Department

K. Yamashita, Manager  
Technical Department

Tomosaburo Ogiuchi, Manager  
Export Department International Trade  
Headquarters

Noriyuki Tsushima, Ph.D.  
Manager, Research Section  
Product Research Department  
Engineering Headquarters

M. (Mike) Tajiri  
Senior Design Engineer  
Design Section  
Technical Department  
Aerospace Bearing Headquarters

**Toshiba, New Materials Department, Yokohama**

Dr. Katsutoshi Komeya  
Senior Manager  
New Materials Department

Katsutoshi Nishida  
Senior Specialist  
New Materials Department

Koichi Inoue, Engineer  
New Materials

**Kyocera Corporation, Kyoto**

Y. Hamano, Dr. Engineering  
Senior Managing Director  
General Manager  
Corporate Planning Division

Dr. Kazunori Koga  
Materials Development Division

Mataro Miyazaki, Manager  
Automotive Components

**Ishikawajima-Harima Heavy Industries Co. (IHI)**

Chiaki Aoki, Vice President  
Aero-Engine & Space Operations

Dr. Shinobu Saito, Section Manager  
Machinery Department  
Research Institute

Y. Yamashita, Manager  
Precision Gears Engineering Group  
Aero-Engine & Space Operations

Seiji Kobayashi  
F-3 Engine Project Department  
Aero-Engine Division  
Aero-Engine & Space Operations

## Appendix C

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7. W. Wade et al., "A structural ceramic diesel engine - The critical elements," Society of Automotive Engineers, February 1987 (SAE paper no. 870651). Koyo Seiko participated with a roller bearing test rig simulating crankshaft main bearing loads and speeds to test silicon nitride roller bearings.

## THE INDIAN CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

Wayne V. Burt

*The Central Marine Fisheries Research Institute was established to conduct research to improve exploitation, management, and conservation of marine and brackish water fisheries resources. This article describes the institute's efforts to improve the culture of prawns; sea weed; pearls; mussels, oysters, and clams; fin fish, lobsters and crabs; and marine turtles.*

### PROLOGUE

India is chronically in need of increasing its supplies of food for its burgeoning population. Its present yield of marine fisheries products within the 0- to 50-meter depth zone is only 15 percent of an estimated potential yield of just over 2 million tons a year. There is an additional potential yield of over 2 million tons per year in the deeper waters running out to the edge of the 200-mile exclusive economic zone with even a smaller percentage of present yield. Of 135,000 fishing vessels in India, less than 20,000 are motorized. There is a good deal of need for research to increase fisheries technology and improve fisheries management in order to increase the sustained yield of marine fisheries products.

The history of freshwater aquaculture in India dates back to 300 B.C. On the other hand, mariculture, the culture of marine fish and other marine organisms, is of much more recent origin. India abounds in brackish lakes, estuaries, backwaters, and coastal mangrove and other swampy coastal areas. Recent estimates state that there are over 4 million acres near the coasts that are suitable for mariculture of one sort or another. However, only 74,000 acres, less than 2 percent, are now being used for mariculture.

The above facts indicate that there is a wide open field for marine fisheries and mariculture research.

### FISHERIES AND MARICULTURE RESEARCH

The Central Marine Fisheries Research Institute was established in February 1947 by the Government of India within the Ministry of Agriculture and Irrigation. It later came under the control of the Council of Agricultural Research.

The objectives of the institute are to conduct research related to the marine fisheries and mariculture in order to improve exploitation, management, and conservation of marine and brackish water fisheries resources and to support development and stability to all facets of the industry through transfer of technology and dissemination of information through education, training, and extension programs.

The headquarters and main laboratories of the institute are in a 1-year-old, five-story building with 91,000 ft<sup>2</sup> of floor space. The building is located on the waterfront of one of the channels of the main estuary in Cochin in the long, narrow State of Kerala on the southwest coast of India.

In addition to the headquarters, there are 12 other research centers belonging to the institute scattered around the coast of India and 29 field centers along the coasts of India that collect fisheries catch data and other relevant statistics. The institute has a staff of 300, including 60 scientists.

## PRAWN CULTURE

Many of the estuaries in southern India have numerous islands near their mouths with channels other than the main river channel between the islands. The areas between the islands are called backwaters. Most of the mariculture takes place in these backwaters. For centuries prawns have been cultured in these areas. During the postmonsoon season, the backwaters are brackish with a mixture of salt and fresh waters. Earthen or stone bunds or dikes separate many of the backwaters into paddies. During high water these paddies are flooded and prawns in various stages of growth are captured in the fields. The weirs separating the paddies from the tidal channels are screened to keep the shrimp from escaping but allowing the tides to bring in food organisms for the shrimp. The yields are poor and uncertain.

Before the monsoon season arrives the shrimp are harvested. When the monsoon rains begin the fields are flushed out with freshwater from the runoff. Then a crop of rice is grown during the monsoon season.

The institute has done a tremendous amount of work to improve the mariculture of shrimp. Hatcheries where prawn "seeds" are hatched and grown by the millions have been developed and improved. Methods to manipulate the female prawns so they will spawn on demand as well as methods of artificial insemination that have increased the hatching rate of prawn eggs in the hatchery from 3 to over 90 percent have been developed. This enables the prawn farmer to seed his paddy with young prawns that are all the same age and can be harvested all at the same time. One of the most important things that the hatcheries can do is select the best species of shrimp to grow in paddies. The ideal salinity range for this species ranges

from 10 to 35 ppt. If a farmer follows all of the procedures recommended by the institute, he can harvest a little over a quarter of a ton of shrimp per acre in just under 2 months and raise several crops each year. The shrimp that are cultured are strictly a cash crop. The shrimp bring such a good price that the farmers and their families cannot afford to eat them.

## SEA WEED CULTURE

Some species of sea weeds are a much needed raw material for obtaining agar-agar, algin, and pharmaceutical chemicals. The institute has developed a simple technology for culturing commercially important sea weeds. The method involves growing fragments of fresh seaweed on coir rope made from coconut husks. The growth increases the amount of sea weed by 400 or 500 percent. Three harvests or crops can be taken in a year.

## PEARL CULTURE

Hatchery techniques have been developed for breeding of pearl oysters and rearing their larvae to young pearl oysters suitable for transplanting to open sea farms. About 60 to 70 percent of the nucleus-implanted oysters produce pearls in from 3 to 24 months, depending on the size of the pearls.

## CULTURE OF MUSSELS, OYSTERS, AND CLAMS

The institute has developed viable technologies for open-sea farming of mussels, farming of edible oysters in the backwaters and creeks, and culturing of clams in open bays. All three are now bred in hatcheries and their larvae are reared in the hatcheries until they are old enough to be transported to the habitat where they will grow to adult size.

## FIN FISH CULTURE

The institute has shown that milk fish, mullets, whiting, and perches can be profitably grown in pens and cages and even in polyethylene-lined ponds in beaches with proper management techniques.

## LOBSTERS AND CRABS

Breakthroughs have been achieved in the rearing of lobsters and in the breeding and culturing of crabs. These crustaceans bring a good price and have good mariculture potential for the coastal waters of India.

## MARINE TURTLES

Predators, including man, take a heavy toll on the marine turtles that come ashore to lay their eggs in the sand of beaches. Every year the institute gathers several hundred turtle eggs and hatches them out and sees that the young are safely placed in the ocean. This helps to ensure that, while the turtles are an endangered species, they will not eventually become extinct.

## EDUCATION

A Center for Advanced Studies in Mariculture was established at the institute in 1979 under the sponsorship of the Indian Council of Agricultural Research, the United Nations Development Program, and the United Nations Food and Agricultural Organization.

Although the specific technologies for the culture of many commercially important marine organisms have become available, a prospective market for the produce is waiting, and financing is available, a sufficient number of trained people have not been available to guide and execute mariculture programs. This constraint was found to

seriously hamper the development and expansion of mariculture projects. To correct this program, a Master of Science program in mariculture was established at the institute. It is a 2-year program. Ten new students are accepted each year. In addition to course work, the students are required to gain practical experience through laboratory and field work and to know basic research techniques.

The Ph.D. degree is also offered to more advanced research-oriented students. It is a 3-year program and again 10 new students are admitted to the program each year.

Under the Lab-to-Land program the actual technologies are carried to the farmers' fields, where institute scientists help the farmers with their mariculture problems. Some 500 families have been helped in this way. Short courses, seminars, and radio programs are all used to give information to the farmers. Detailed manuals giving all the specifics have been written on hatchery production of prawn seed and on prawn farming in Kerala.

The institute renders consultancy services to small farmers, fish culturists, the industry, development agencies, and government departments on various aspects of capture fisheries, mariculture, and environmental problems.

The research and instructional programs in the institute are most impressive. All of the people that I interviewed spoke good English and the scientific papers given to me were all in English. I believe that it would be worthwhile to send a few American students to the institute for training in mariculture techniques.

The address of the institute is: Central Marine Fisheries Research Institute, Post Bag No. 2704, Kochin - 682 031.

# INTERNATIONAL MEETINGS IN THE FAR EAST

1988-1994

Compiled by Yuko Ushino

Yuko Ushino is a technical information specialist for ONR Far East. She received a B.S. degree from Brigham Young University at Provo, Utah.

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

## 1988

| Date                    | Title,<br>Attendance                                                                                      | Site                    | For information, contact                                                                                                       |
|-------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| January<br>28-31        | Royal Australian Chemical<br>Institute, Division of<br>Inorganic Chemistry, National<br>Meeting (COMO 13) | Melbourne,<br>Australia | Dr. P. Tregloan,<br>Department of Inorganic Chemistry,<br>University of Melbourne<br>Parkville, Victoria 3052                  |
| February<br>2-5         | The International Association<br>of the Institute of<br>Navigation (IAIN) Congress                        | Sydney,<br>Australia    | The Australian Institute of Navigation<br>Box 2250, G.P.O.,<br>Sydney, New South Wales,<br>Australia 2001                      |
| February<br>2-5         | A Congress of the<br>International Association<br>of Institutes of Navigation                             | Sydney,<br>Australia    | Professor Günther Zade,<br>World Maritime University<br>P.O. Box 500, S-20124 Malmö,<br>Sweden                                 |
| February<br>22-26       | Engineering Conference                                                                                    | Sydney,<br>Australia    | The Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600                    |
| February<br>(tentative) | The 10th Australian Electron<br>Microscopy Conference                                                     | (Undecided)             | Secretariat: Australian Academy of<br>Science<br>GPO Box 783, Canberra, ACT 2601                                               |
| March<br>1-3            | International Forum on Fine<br>Ceramics '88 Nagoya Japan<br>10-F100-J900                                  | Nagoya,<br>Japan        | Secretariat: International Forum on<br>Fine Ceramics<br>c/o Japan Fine Ceramics Center<br>2-4-1 Mutsuno, Atsuta-ku, Nagoya 456 |

\*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries  
F: No. of overseas participants  
J: No. of Japanese participants

| Date           | Title,<br>Attendance                                                                                                                       | Site               | For information, contact                                                                                                                                            |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| March<br>10-12 | International Biotechnology<br>Symposium '88 (tentative)<br><br>10-F100-J500                                                               | Nagoya,<br>Japan   | Organizing Committee of International<br>Biotechnology Symposium<br>c/o The Foundation of Chubu Science<br>and Technology Center<br>2-17 Sakae, Naka-ku, Nagoya 460 |
| March<br>14-16 | International Symposium<br>on Non-Equilibrium Solid<br>Phase of Metals and Alloys<br><br>F100-J200                                         | Kyoto,<br>Japan    | Department of Metal Science and<br>Technology, Faculty of Engineering,<br>Kyoto University<br>Yoshida-hommachi, Sakyo-ku, Kyoto 600                                 |
| March<br>14-17 | International Symposium on<br>Non-Equilibrium Solid Phases<br>of Metals and Alloys<br><br>N.A.-F100-J200                                   | Kyoto,<br>Japan    | Department of Metal Science and<br>Technology,<br>Faculty of Engineering, Kyoto University<br>Yoshida-Hommachi, Sakyo-ku, Kyoto 600                                 |
| March<br>22-25 | International Symposium on<br>Basic Technology for Future<br>Industries (New Materials)<br><br>6-F15-J700                                  | Kobe,<br>Japan     | c/o Agency of Industrial Science and<br>Technology<br>Ministry of International Trade and<br>Industry<br>2-1-3 Kasumigaseki, Chiyoda-ku,<br>Tokyo 100               |
| March<br>22-26 | International Conference on<br>Several Complex Variables,<br>Kyoto<br><br>7-F15-J26                                                        | Kyoto,<br>Japan    | Research Institute for Mathematical<br>Sciences,<br>Kyoto University<br>Oiwake-cho, Kita-Shirakawa,<br>Sakyo-ku, Kyoto 606                                          |
| April<br>4-12  | The 4th International<br>Conference on Aluminium<br>Association (JLWA)<br><br>32-F100-J150                                                 | Tokyo,<br>Japan    | Japan Light Metal Welding and<br>Construction Weldment<br>Yura Building, 3-37-23,<br>Kanda-Sakumacho,<br>Chiyoda-ku, Tokyo 101                                      |
| April<br>11-14 | ISFNT International<br>Symposium on Fusion<br>Nuclear Technology<br><br>20-F150-J50                                                        | Tokyo,<br>Japan    | Nuclear Engineering Research Laboratory,<br>Tokyo University<br>Tokai-mura, Naka-gun, Ibaraki 319-11                                                                |
| April<br>13-15 | The 21st JAIF Annual<br>Conference<br><br>25-F250-J1,000                                                                                   | Tokyo,<br>Japan    | Japan Atomic Industrial Forum, Inc.<br>Koshin Building, 1-1-13 Shimbashi,<br>Minato-ku, Tokyo 105                                                                   |
| April<br>19-23 | International Conference on<br>Nuclear Power Plant Water<br>Chemistry-Operation<br>Experience and Sophisti-<br>cated Management Technology | (to be<br>decided) | Japan Atomic Industrial Forum, Inc.<br>Toshin Building, 1-1-23 Shimbashi,<br>Minato-ku, Tokyo 105                                                                   |

| Date                     | Title,<br>Attendance                                                                                         | Site              | For information, contact                                                                                                                                                            |
|--------------------------|--------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| April<br>26-<br>May<br>3 | The 3rd World Biomaterials<br>Conference<br><br>15-F500-J500                                                 | Kyoto,<br>Japan   | Japan Society for Biomaterials<br>c/o Institute for Medical and Dental<br>Engineering,<br>Tokyo Medical and Dental University,<br>2-3-10 Kanda-Surugadai, Chiyoda-ku,<br>Tokyo 101  |
| May<br>13-15             | International Symposium on<br>Advanced Thermal Spraying<br>Technology and Allied Coatings<br><br>13-F50-J150 | Osaka,<br>Japan   | High Temperature Society of Japan<br>c/o Welding Research Institute of<br>Osaka University<br>11-1 Mihogaoka, Ibaraki-shi, Osaka 567                                                |
| May<br>16-20             | The 4th International<br>Conference on Metalorganic<br>Vapor Phase Epitaxy                                   | Hakone,<br>Japan  | Professor T. Katoda,<br>Secretary, ICMOVPE IV<br>c/o International Congress Service,<br>Inc.,<br>Kasho Building 2F,<br>2-14-9 Nihombashi Chuo-ku, Tokyo 103                         |
| May<br>22-27             | The 16th International<br>Symposium on Space<br>Technology and Science                                       | Sapporo,<br>Japan | The 16th International Symposium on<br>Space Technology and Science,<br>Sapporo Organizing Committee<br>4-6-1 Komaba, Meguro-ku, Tokyo 151                                          |
| May<br>25-27             | The 5th International<br>Microelectronics Conference<br>(IMC 1988)                                           | Tokyo,<br>Japan   | Dr. H. Hirabayashi,<br>ISHM Japan Chapter<br>6-20-4 Hanakoganei,<br>Kodaira-city, Tokyo 187                                                                                         |
| May<br>29-<br>June<br>2  | The 5th International<br>Symposium on Halide Glasses                                                         | Susono,<br>Japan  | Professor Masayuki Yamane,<br>Inorganic Materials,<br>Faculty of Engineering,<br>Tokyo Institute of Technology<br>2-12-1 Ookayama, Meguro-ku, Tokyo 152                             |
| May<br>30-<br>June<br>3  | MRS International Meeting on<br>Advanced Materials<br><br>20-F600-J1,500                                     | Tokyo,<br>Japan   | Organizing Committee for MRS<br>International Meeting on Advanced<br>Materials<br>c/o Nikkan Kogyo Shimbun Ltd.,<br>Planning Bureau,<br>1-8-10 Kudan-kita, Chiyoda-ku,<br>Tokyo 102 |
| May<br>30-<br>June<br>3  | International Conference on<br>Nuclear Data for Science and<br>Technology<br><br>10-F100-J200                | Mito,<br>Japan    | Japan Atomic Energy Research Institute<br>Tokai-mura, Naka-gun, Ibaraki 319-11                                                                                                      |

| Date          | Title,<br>Attendance                                                                                                                   | Site              | For information, contact                                                                                                                                                                  |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| June<br>5-6   | The 7th International<br>Conference on Ion Implan-<br>tation Technology (IIT'88) -<br>Technical School                                 | Kyoto,<br>Japan   | Professor Isao Yamada,<br>Ion Beam Engineering Experimental<br>Laboratory, Kyoto University<br>Sakyo, Kyoto 606                                                                           |
| June<br>5-10  | The 6th International<br>Conference on Surface and<br>Colloid Science                                                                  | Hakone,<br>Japan  | Division of Colloid and Surface<br>Chemistry,<br>The Chemical Society of Japan<br>1-5 Kanda-Surugadai, Chiyoda-ku,<br>Tokyo 101                                                           |
| June<br>6-10  | International Conference on<br>Physical Metallurgy of<br>Thermomechanical Processing<br>of Steels and Other Metals<br><br>20-F100-J100 | Tokyo,<br>Japan   | Nippon Tekko Kyokai<br>3rd Floor, Keidanren Kaikan,<br>1-9-4 Otemachi, Chiyoda-ku, Tokyo 100                                                                                              |
| June<br>7-10  | International Conference on<br>Precision Electro-magnetic<br>Measurements (CPEM'88)                                                    | Tsukuba,<br>Japan | The Society of Instrument and<br>Control Engineers<br>1-35-28-303 Hongo,<br>Bunkyo-ku, Tokyo 113                                                                                          |
| June<br>7-10  | The 7th International<br>Conference on Ion<br>Implantation Technology<br>(IIT'88)                                                      | Kyoto,<br>Japan   | Professor Isao Yamada,<br>Ion Beam Engineering Experimental<br>Laboratory, Kyoto University<br>Sakyo, Kyoto 606                                                                           |
| June<br>12-17 | The International Conference<br>on Ion Beam Modification of<br>Materials (IBMM'88)                                                     | Tokyo,<br>Japan   | Professor Susumu Nanba,<br>Faculty of Engineering Science,<br>Osaka University<br>1-1 Machikaneyama-cho,<br>Toyonaka-city, Osaka 560                                                      |
| June<br>13-15 | JSAP-MRS (Japan Society of<br>Applied Physics-Material<br>Research Society) Inter-<br>national Conference on<br>Electronic Materials   | Tokyo,<br>Japan   | Professor Takeshi Kamiya,<br>Faculty of Engineering,<br>Tokyo University<br>7-3-1 Hongo, Bunkyo-ku, Tokyo 113                                                                             |
| June<br>23-24 | The 3rd Asia Pacific<br>Physics Conference                                                                                             | Hong Kong         | K. Young, Secretary,<br>Local Organizing Committee,<br>The 3rd Asia Pacific Physics Conference<br>c/o Department of Physics,<br>The Chinese University of Hong Kong,<br>Shatin, Hong Kong |
| July<br>1-12  | The 16th International<br>Congress of Photogrammetry<br>and Remote Sensing<br><br>48-F2,000-J2,600                                     | Kyoto,<br>Japan   | Japan Society of Photogrammetry<br>601 Daiichi Honan Building,<br>2-8-17 Minami-Ikebukuro,<br>Toshima-ku, Tokyo 171                                                                       |

| Date            | Title,<br>Attendance                                                                                       | Site                 | For information, contact                                                                                                                                                                        |
|-----------------|------------------------------------------------------------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| July<br>12-15   | The 6th International<br>Conference on Ultrafast<br>Phenomena<br><br>20-F200-J200                          | Shiga,<br>Japan      | The 6th International Conference on<br>Ultrafast Phenomena Organization<br>Committee<br>c/o OPTO Marketing Service Ltd.,<br>Maenochi Heights 5-206,<br>6-10 Maenochi, Itabashi-ku,<br>Tokyo 174 |
| July<br>17-23   | International Congress of<br>Endocrinology<br><br>48-F2,000-J2,600                                         | Kyoto,<br>Japan      | Japan Endocrine Society<br>c/o Seirenkaikan,<br>Kyoto Furitsu Medical University,<br>Nishizume Konjinbashi, Kamigyo-ku,<br>Kyoto 602                                                            |
| July<br>18-22   | International Symposium on<br>Scale Modeling                                                               | Tokyo,<br>Japan      | Secretariat:<br>c/o The Japan Society of<br>Mechanical Engineers,<br>Sanshin Hokusei Building,<br>2-4-9 Yoyogi, Shibuya-ku, Tokyo 151                                                           |
| July<br>18-22   | 1988 XVI International<br>Conference on Quantum<br>Electronics<br><br>30-F300-J700                         | Tokyo,<br>Japan      | Optoelectronic Industry and Technology<br>Development Association<br>No. 20 Mori Building,<br>2-74 Nishi-shimbashi, Minato-ku,<br>Tokyo 105                                                     |
| July<br>25-30   | International Conference on<br>Clustering Aspects in Nuclear<br>and Subnuclear Systems<br><br>31-F150-J150 | Kyoto,<br>Japan      | Dr. K. Tanaka,<br>Faculty of Science,<br>Hokkaido University<br>5-chome, Kita 10-jo, Kita-ku,<br>Sapporo 060                                                                                    |
| August<br>1-5   | The 10th Congress of the<br>International Ergonomics<br>Association                                        | Sydney,<br>Australia | Secretariat IEA88<br>IEA88<br>PO Box 380<br>Spit Junction, NSW 2088, Australia                                                                                                                  |
| August<br>1-6   | The IUPAC 32nd International<br>Symposium on Macromolecules<br><br>50-F600-J1,200                          | Kyoto,<br>Japan      | The Society of Polymer Science, Japan<br>5-12-8 Ginza, Chuo-ku, Tokyo 104                                                                                                                       |
| August<br>2-6   | The 9th World Conference on<br>Earthquake Engineering<br><br>59-F800-J2,000                                | Tokyo,<br>Japan      | Secretariat: The 9th SCEE Steering<br>Committee<br>c/o Association for Earthquake<br>Disaster Prevention<br>5-26-20 Shiba, Minato-ku, Tokyo 108                                                 |
| August<br>14-19 | The 10th International<br>Congress on Rheology                                                             | Sydney,<br>Australia | R. I. Tanner,<br>Department of Mechanical Engineering,<br>University of Sydney<br>NSW 2006                                                                                                      |

1988

| Date                            | Title,<br>Attendance                                                                              | Site                    | For information, contact                                                                                                                                                                 |
|---------------------------------|---------------------------------------------------------------------------------------------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| August<br>15-17                 | International Federation of<br>Automatic Control Symposium                                        | Melbourne,<br>Australia | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600                                                                                  |
| August<br>15-17                 | Electrical IFAC Conference                                                                        | Melbourne,<br>Australia | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600                                                                                  |
| August<br>15-19                 | The 3rd International Phyco-<br>logical Congress                                                  | Melbourne,<br>Australia | Dr. M. N. Clayton,<br>Botany Department,<br>Monash University<br>Clayton, Victoria 3168                                                                                                  |
| August<br>16-19                 | The 7th International IUPAC<br>Symposium on Mycotoxins and<br>Phycotoxins<br><br>38-F100-J200     | Tokyo,<br>Japan         | Japan Association of Mycotoxicology,<br>Science University of Tokyo<br>c/o Science University of Tokyo,<br>12 Fungagawara-machi, Ichigaya,<br>Shinjuku-ku, Tokyo 160                     |
| August<br>21-26                 | International Geographical<br>Congress                                                            | Sydney,<br>Australia    | Secretariat: Australian<br>Academy of Science<br>GPO Box 783, Canberra, ACT 2601                                                                                                         |
| August<br>22-26                 | The 5th Australia-New Zealand<br>Conference on Geomechanics                                       | Sydney,<br>Australia    | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit Barton, ACT 2600                                                                                   |
| August<br>29-<br>September<br>2 | The 3rd International<br>Conference on Synchrotron<br>Radiation Instrumentation<br>(SRI-88)       | Tsukuba,<br>Japan       | Katsuki Kobayashi,<br>Photon Factory Synchrotron<br>Radiation Research Facility,<br>National Laboratory for High Energy<br>Physics<br>1-1 Uehara, Oho-machi, Tsukuga-gun,<br>Ibaraki 305 |
| August<br>30-<br>September<br>2 | The 5th International<br>Conference on Molecular<br>Beam Epitaxy<br><br>15-F150-J400              | Sapporo,<br>Japan       | Japan Society of Applied Physics<br>c/o Department of Physical<br>Electronics, Tokyo Institute of<br>Technology<br>2-12-1, Oh-okayama, Meguro-ku,<br>Tokyo 152                           |
| September<br>5-8                | The 1st International<br>Conference on Computational<br>Methods in Flow Analysis<br><br>F250-J300 | Okayama,<br>Japan       | Okayama University of Science<br>1-1 Ridaicho, Okayama 700                                                                                                                               |

## 1988

| Date               | Title,<br>Attendance                                                                                                                             | Site                                          | For information, contact                                                                                                                                                                                                           |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| September<br>19-22 | The 29th International<br>Conference on the<br>Biochemistry of Lipids<br><br>39-F100-J200                                                        | Tokyo,<br>Japan                               | Secretariat: The 29th International<br>Conference on the Biochemistry of Lipids<br>c/o Department of Psychological<br>Chemistry and Nutrition,<br>Faculty of Medicine,<br>University of Tokyo<br>7-3-1 Hongo, Bunkyo-ku, Tokyo 113 |
| September<br>20-22 | The 4th Japanese-German<br>Joint Seminar on Non-<br>destructive Evaluation<br>and Structural Strength of<br>Nuclear Power Plant<br><br>1-F30-J70 | Kanazawa,<br>Japan                            | Japan Atomic Energy Research Institute<br>Tokai Establishment<br>Tokai-mura, Naka-gun, Ibaraki 319-11                                                                                                                              |
| October<br>11-14   | The 4th International<br>Workshop on Electro-<br>luminescence                                                                                    | Tottori,<br>Japan                             | Dr. Hiroshi Kobayashi,<br>Department of Electronics,<br>Faculty of Engineering,<br>Tottori University<br>Koyama, Tottori 680                                                                                                       |
| October<br>17-20   | The 9th International<br>Conference on Pattern<br>Recognition                                                                                    | Beijing,<br>People's<br>Republic of<br>China  | 9 ICPR Secretariat:<br>Chinese Association of Automation<br>P.O. Box 2728,<br>Beijing                                                                                                                                              |
| October<br>24-26   | The 1st International<br>Conference New Diamond<br>Forum                                                                                         | Tokyo,<br>Japan                               | Secretariat: International Congress<br>Service, Inc.<br>Kasho Building 2F,<br>2-14-9 Nihonbashi, Chuo-ku, Tokyo 103                                                                                                                |
| October<br>24-28   | The 3rd International<br>Conference on Surface<br>Engineering                                                                                    | Tokyo,<br>Japan                               | Cotec Corporation<br>Sankocho Building<br>5-17-14 Shinjuku, Shinjuku-ku,<br>Tokyo 160                                                                                                                                              |
| October<br>25-28   | International Conference on<br>Materials and Process<br>Characterization for<br>VLSI (ICMP'88)                                                   | Shanghai,<br>People's<br>Republic<br>of China | Zhu Ye,<br>Institute of Materials Science,<br>Fudan University, Shanghai                                                                                                                                                           |
| November<br>2-5    | International High-<br>Performance Vehicle<br>Conference                                                                                         | Shanghai,<br>People's<br>Republic of<br>China | Ship Design Committee CSNAME<br>P.O. Box 3053,<br>Shanghai                                                                                                                                                                         |
| November<br>8-12   | The 2nd International<br>Conference on Formulation<br>of Semiconductor Interface<br>(ICFSI-88)                                                   | Takarazuka,<br>Japan                          | Tsunemasa Taguchi,<br>Faculty of Engineering,<br>Osaka University<br>2-1 Yamadaoka, Fukita-shi,<br>Osaka 565                                                                                                                       |

## 1988

| Date              | Title,<br>Attendance                                                                                    | Site                 | For information, contact                                                                                                     |
|-------------------|---------------------------------------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------|
| November<br>14-17 | The 3rd International<br>Topical Meeting on Nuclear<br>Power Plant Thermal<br>Hydraulics and Operations | Seoul,<br>Korea      | Dr. Jong Hee Cha,<br>P.O. Box 7 Daeduk-Danji,<br>Choong-Nam, Korea 300-31                                                    |
| November<br>14-18 | 1988 Annual Meeting of the<br>International Society for<br>Interferon Research<br><br>35-F300-J500      | Kyoto,<br>Japan      | The 5th ISIR Organizing Committee<br>c/o Inter Group Corporation<br>Shohaku Building,<br>6-23 Chayamachi, Kita-ku, Osaka 530 |
| November<br>19-26 | The 13th International<br>Diabetes Federation Congress<br><br>20-F80-J120                               | Sydney,<br>Australia | Professor J. R. Turtle, Professor of<br>Medicine<br>Department of Endocrinology,<br>University of Sydney<br>NSW 2006         |

## 1989

| Date           | Title,<br>Attendance                                                             | Site                                          | For information, contact                                                                                                                                                           |
|----------------|----------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| April<br>3-5   | International Symposium for<br>Electromachining<br><br>16-F100-J300              | Nagoya,<br>Japan                              | Institute of Industrial Science,<br>University of Tokyo<br>7-22-1 Roppongi, Minato-ku, Tokyo 106                                                                                   |
| April<br>10-13 | The International Symposium<br>for Electromachining<br><br>15-F100-J300          | Undecided                                     | The Institute of Electrical Engineers<br>of Japan<br>Gakkai Center Building,<br>2-4-16 Yayoi, Bunkyo-ku, Tokyo 113                                                                 |
| April<br>11-14 | International Symposium<br>on Ship Resistance and<br>Powering Performance (ISRP) | Shanghai,<br>People's<br>Republic<br>of China | International Symposium on Ship<br>Resistance and Powering Performance<br>Department of Naval Architecture<br>and Ocean Engineering,<br>Shanghai Jiao Tong University,<br>Shanghai |
| April<br>18-21 | The 2nd Asian Fisheries<br>Forum<br><br>30-F150-J150                             | Tokyo,<br>Japan                               | Secretariat: The 2nd Asian Fisheries<br>Forum<br>c/o Faculty of Agriculture,<br>Tokyo University<br>1-1-1 Yayoi, Bunkyo-ku, Tokyo 113                                              |
| July<br>2-7    | XXVII International<br>Conference on Coordination<br>Chemistry                   | Brisbane,<br>Australia                        | Professor Clifford J. Hawkins,<br>Department of Chemistry,<br>University of Queensland<br>Saint Lucia, Brisbane,<br>Queensland 4067                                                |

| Date                            | Title,<br>Attendance                                                                                                | Site                 | For information, contact                                                                                                                                                                                                               |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| July<br>24-25                   | The 2nd Microoptics<br>Conference/The 9th<br>Topical Meeting on<br>Gradient-Index Imaging<br>Systems (MOC/GRIN '89) | Tokyo,<br>Japan      |                                                                                                                                                                                                                                        |
| July                            | The 4th International<br>Organization of Plant<br>Biosystematists (IOPB)<br>Symposium<br>20-F,J250                  | Kyoto,<br>Japan      | IOPB Symposium<br>c/o Department of Botany,<br>Faculty of Science, Kyoto University<br>Kitashirakawa Oiwake-cho, Sakyo-ku,<br>Kyoto 606                                                                                                |
| August<br>13-18                 | Solar Energy Congress<br>Tokyo 1989<br>40-F600-J400                                                                 | Tokyo,<br>Japan      | Japanese Section of International Solar<br>Energy Society<br>322 San Patio, 3-1-5 Takada-no-baba,<br>Shinjuku-ku, Tokyo 160                                                                                                            |
| August<br>27-<br>September<br>1 | The 5th International<br>Symposium on Microbial<br>Ecology (5th ISME)<br>73-F600-J600                               | Kyoto,<br>Japan      | Japanese Society of Microbial Ecology<br>c/o Inter Group Corporation<br>8-5-32 Akasaka, Minato-ku, Tokyo 107                                                                                                                           |
| September<br>5-8                | Solar World Congress 1989<br>60-F600-J400                                                                           | Kobe,<br>Japan       | Japanese Section of International<br>Solar Energy Society,<br>Japan Solar Energy Society<br>322 San Patio, 3-1-5 Takada-no-baba,<br>Shinjuku-ku, Tokyo 160                                                                             |
| September<br>8-10               | 1989 International Symposium<br>on Electromagnetic<br>Compatibility<br>20-F150-J350                                 | Nagoya,<br>Japan     | Secretariat: International Symposium on<br>Electromagnetic Compatibility<br>c/o Department of Information and<br>Computer Sciences,<br>Toyohashi University of Technology<br>1-1 Tenpaku-cho, Aza-Hibarigaoka,<br>Toyohashi, Aichi 440 |
| September<br>24-28              | The 6th International<br>Symposium on Passivity -<br>Passivation of Metals and<br>Semiconductors                    | Sapporo,<br>Japan    | Dr. Norio Satoh,<br>Faculty of Engineering,<br>Hokkaido University<br>Nishi 8-chome, Kita 13-jo,<br>Sapporo-shi 060                                                                                                                    |
| October<br>3-5                  | The 10th Meeting of World<br>Society for Stereotactic<br>and Functional Neurosurgery<br>20-F200-J300                | Maebashi,<br>Japan   | Department of Neurosurgery,<br>Gumma University, School of Medicine<br>3-39 Showa-machi, Maebashi 371                                                                                                                                  |
| October<br>(tentative)          | Specialty Electric<br>Conference                                                                                    | Sydney,<br>Australia | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600                                                                                                                                |

## 1989

| Date                | Title,<br>Attendance                                                                                                                                                                   | Site                 | For information, contact                                                                                                                                    |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1989<br>(tentative) | International Conference<br>Evaluation of Materials<br>Performance in Severe<br>Environments-Evaluation and<br>Development of Materials in<br>Civil and Marine Uses<br><br>20-F80-J120 | Japan<br>(undecided) | International Conference Secretariat,<br>Conference and Editorial Department,<br>Iron and Steel Institute of Japan<br>1-9-4 Otemachi, Chiyoda-ku, Tokyo 100 |
| 1989<br>(tentative) | International Conference on<br>Zinc and Zinc Alloy Coated<br>Sheet Steels<br><br>20-F50-J150                                                                                           | Japan<br>(undecided) | International Conference Secretariat,<br>Conference and Editorial Department,<br>Iron and Steel Institute of Japan<br>1-9-4 Otemachi, Chiyoda-ku, Tokyo 100 |

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| Date                     | Title,<br>Attendance                                                                                          | Site                 | For information, contact                                                                                                                                                 |
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| May<br>19-26             | The 27th International<br>Navigation Congress<br><br>60-F500-J500                                             | Japan<br>(undecided) | Japan Organizing Committee for<br>27th International Navigation Congress<br>2-8-24 Chikko, Minato-ku, Osaka 552                                                          |
| July<br>(tentative)      | The 10th International<br>Congress of Nephrology<br><br>10-F1,000-J4,000                                      | Osaka,<br>Japan      | Japanese Society of Nephrology<br>c/o 2nd Department of Internal<br>Medicine,<br>School of Medicine,<br>Tokyo 173                                                        |
| August<br>21-29          | International Congress of<br>Mathematicians                                                                   | Kyoto,<br>Japan      | Research for Mathematical Sciences,<br>Kyoto University<br>Kitashirakawa Oiwake-cho,<br>Sakyo-ku, Kyoto 606                                                              |
| September<br>(tentative) | The 15th International<br>Congress on Microbiology<br><br>57-F2,500-J2,500                                    | Osaka,<br>Japan      | Preliminary Committee of<br>International Congress of Microbiology<br>c/o JTB Creative Inc.,<br>Daiko Building, 3-2-14 Umeda,<br>Kita-ku, Osaka 530                      |
| 1990<br>(tentative)      | The 6th International<br>Conference on the Science<br>and Technology of Iron and<br>Steel<br><br>50-F300-J500 | Japan<br>(undecided) | International Conference Secretariat<br>and Editorial Department,<br>Iron and Steel Institute of Japan<br>3F, Keidanren Kaikan, 1-9-4 Otemachi,<br>Chiyoda-ku, Tokyo 100 |
| 1990<br>(tentative)      | Chemeca 1990 Applied<br>Thermodynamics                                                                        | New Zealand          | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600                                                                  |

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|-----------------------|---------------------------------------------------------------------------------------------------|-----------------|-------------------------------------------------------------------------------------------|
| August<br>(tentative) | The 16th International<br>Conference on Medical and<br>Biological Engineering<br><br>45-F600-J900 | Kyoto,<br>Japan | ME Division, Kawasaki Medical School<br>577 Matsushima, Kurashiki City,<br>Okayama 701-01 |
| August<br>(tentative) | International Congress on<br>Medical Physics<br><br>45-F600-J900                                  | Kyoto,<br>Japan | National Institute of<br>Radiological Science<br>4-9-1 Anagawa, Chiba 260                 |

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## 1993

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|---------------------|-----------------------------------------------------------|----------------------|---------------------------------------------------------------------------------------------------------|
| 1993<br>(tentative) | International Federation of<br>Automatic Control Congress | Sydney,<br>Australia | Conference Manager,<br>The Institution of Engineers, Australia<br>11 National Circuit, Barton, ACT 2600 |

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| Date      | Title,<br>Attendance                                      | Site            | For information, contact                                                                                                                                            |
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| Tentative | XXX International Conference<br>on Coordination Chemistry | Kyoto,<br>Japan | Professor Hitoshi Ohtaki,<br>Department of Electronic Chemistry,<br>Tokyo Institute of Technology at<br>Nagatsuta<br>4259 Nagatsuta-cho, Midori-ku,<br>Yokohama 227 |

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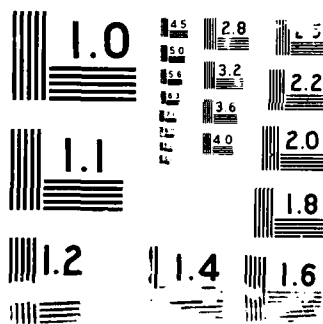
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