CHANNELLING THE FORCES OF NATURE - HUMAN AND EARTH CONSCIOUS MATERIALS MAY CREATE NEW WAVES -

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His work has produced 63 patents and more than 150 scientific papers, and he is co-author of 11 books. He has received eleven society awards from the American Ceramic Soc., Mineralogical Society of Japan, Ceramic Society of Japan and others.

1. INTRODUCTION

The demand for tiles in Japan has dropped along with a decrease in the number of new house buildings (Figure 1). Development of innovative manufacturing technology is one of the possibilities for reinstating tile in its position, and one of its most significant examples is considered the correspondence with the global environment.

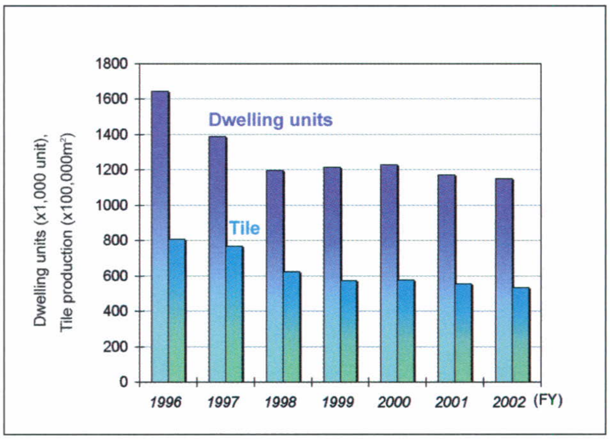


Figure 1. Variation of the Number of New House Buildings and Demand for Ceramic Tile in Japan with Time.

The 21st Century is taken to be the century of the environment and many attempts have been made to create a recirculation-based society, which is unavoidable. Unfortunately, perfect zero-emission or recycling will not exist. Nevertheless, the starting point in manufacturing depends upon how fabrication demonstrates its ability to minimally burden the earth, where goods are intended to maintain and improve necessary functions for people. Sharp criticism is therefore warranted of new creation that does not go beyond a purely conventional approach.

The ceramic tile industry is one of the industries that least burdens the global environment. Making use of this feature, applications can be envisaged for tile, used as a new material, to which further functions are added.

In this paper, as one of its approaches, two concrete examples are set out concerning the fundamental idea relating to man and the earth, with an explanation of the underlying ideas.

2. MAN AND EARTH CONSCIOUS MANUFACTURING

2.1. THE INEVITABILITY OF A RECIRCULATION-BASED SOCIETY

The global environment has now begun to have great effects on our lives. Environmental issues such as global warming, desertization, depletion of the ozone layer, acid rain, etc., which stem from two main problems - globalized expansion of the economic activities of industrially advanced nations and a population increase in the developing countries - compel us to consider radical reforms of the global social structure.

In their book "Beyond the Limits" published in February 1992, Meadows [1] and his co-authors warn that unless countermeasures are taken, the world economy will cease its growth in the near future, and the world social structure will have disintegrated completely by the year 2100. A number of similar reports supplementing these warnings have been published [2],[3], and were a great shock to us material scientists.

The United Nations Conference on Environment and Development (Earth Summit) held in Brazil in June of the same year issued the Rio Declaration on Environment and Development, adopting Agenda 21 as the action plan of the summit. Of all human activities, the ones that impose the largest load on the earth are the economic and industrial activities. These activities mean a flow of materials and energy. In order to avoid the danger of extinction of mankind and build a sustainable society, it is essential that we construct a "recirculation-based society". A "recirculation-based society" is a rejection of the consumption-based economic structure of the industrialized countries and means constructing a completely new type of society, hitherto unknown to mankind. What will the manufacture of goods be like in a recirculation-based society? Here, we need to re-define the basic concept of goods manufacturing.

2.2. MANUFACTURING OF GOODS WITH AWARENESS OF A RECIRCULATION-BASED SOCIETY

A recirculation-based society can be expressed by the simple schematic diagram shown in Figure 2. With the dawn of civilization, man fixed a border (system border) between the natural ecological system and the human life system (human ecological system).

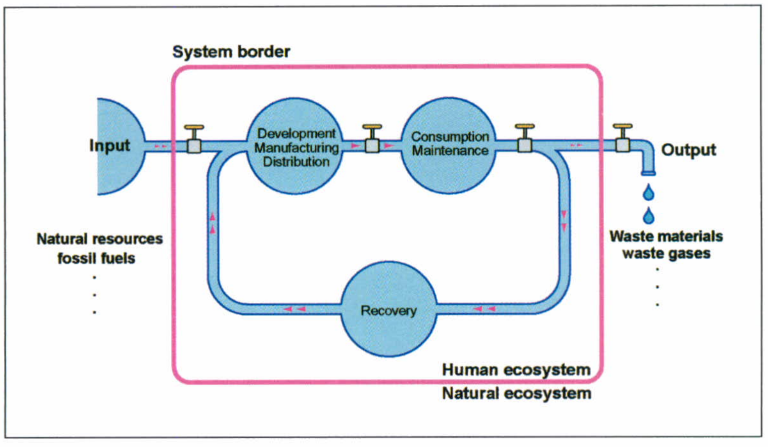


Figure 2. Recirculation-based Society.

Man cannot sustain his livelihood without exploiting nature. The amount of intake from nature and the resulting amount of release into nature have increased rapidly since the industrial revolution. These amounts now far exceed what nature can cope with by itself and are having serious effects on the preservation of mankind. A recirculation-based society is one that reduces its input from nature (fossil energy, raw materials), as well as its output (exhaust gases, exhaust heat, waste materials) into nature's ecosystem, as far as possible, and makes efforts to recirculate and regenerate the input from nature within the human ecosystem. In other words, when manufacturing goods in a recirculation-based society, it is very important to consider the total energy balance and material balance. In practice, it is necessary to reduce output by reducing the input, and in addition, synthesize new materials from materials and energy that have the possibility of producing fresh output. In other words, we must change our attitude from recycling to recirculation.

2.3. MANUFACTURING OF GOODS WITH CONSIDERATION FOR PEOPLE AND THE EARTH

Although the manufacturing of goods, in awareness of a recirculation-based society, is unavoidable, it is very doubtful whether the manufacture of goods based solely on such a concept would be accepted by the world. Let us consider an extreme example. An electric refrigerator not only consumes electricity, but also the refrigerating agent, Freon gas, which is a burden to the earth's environment. Therefore, in order to lower input and output, should we stop using electric refrigerators and return to the earlier era of ice-cooled refrigerators? The answer is probably NO. It is not easy for anyone to abandon a convenience that he or she has once experienced. Furthermore, denial of the existence of electric refrigerators also means denial of large-sized businesses such as department stores, markets and convenience stores. The invention of the electric refrigerator was responsible for great changes in the social system itself.

The authors term this an "Irreversible value of life". Human beings are the only species who may possess DNA which never renounces a desire of comfortable feeling and convenience once this has been experienced. As long as there is an irreversibility of life values, as seen in the above example, we cannot easily return to the "good old age". If we reach an ultimate state where there is no alternative but to return to a past age, such a reversal would probably be at the expense of unbelievable patience and great pain. Conversely, if it were easy to return to the past way of living, environmental problems would not occur and there would be no necessity to develop new materials. However, it is surely irreversible; therefore, great attention should be paid to environmental issues.

Most importantly, manufacturers need to be made more conscious of the earth. At the same time, the materials developed need to be useful, convenient or possess new functions that yield a new type of satisfaction to people. Of course, as environmental problems become more and more serious, the balance between people and the earth will change, and without doubt, more and more emphasis will be placed on earth conscious materials and manufacturing. Even so, however, materials and goods produced without consideration of their value or usefulness to people certainly cannot exist. Looking at this from a different angle, it is clear that, whatever excuse one may give, the manufacturing of goods invariably involves the exploitation of something (input) from the earth and the discharge of something to the earth (output) in order to convert the input into goods with functions that have some sort of value to people. If this is so, we should be able to express the design and development of goods in the future, namely, the value of goods with due consideration for people and the earth, by the following equation. (Figure 3)

In general, if the value is less than one, there would be no merit in developing the material or goods. As much new value should be added as possible (high P) where the burden to the earth (to lower the I+O) is minimized. That is to say, development should aim to raise this value to five, ten or even hundreds. In order to realize this aim, new approaches, instead of extension of current concepts, become necessary. This will be the road that will lead toward the creative valuation of goods in the new century. Next, let us think specifically about materials development using the P/(I+O) valuation concept.

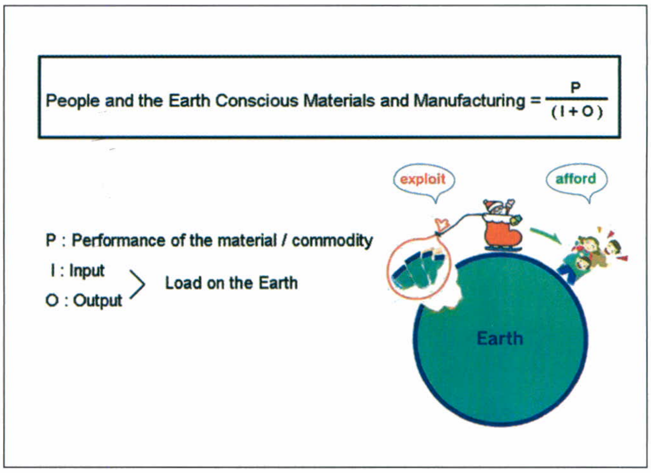


Figure 3. A New Value for Materials and Manufacturing.

People and Earth conscious Materials and Manufacturing = P/(I+O)

where P is the performance of the material, I+O are the input and output of the material when manufactured, used and scrapped.

3. ACTUAL APPLICATION OF HUMAN AND THE EARTH CONSCIOUS MANUFACTURING

3.1. NON FIRED CERAMICS - BREEZING MATERIALS –

3.1.1. Breezing Materials

One solution for maintaining a comfortable living space while reducing the burden on the earth's environment is the development of high heat insulation houses. But one cannot expect only this to be sufficient in the case of hot and humid regions such as those with monsoon climates. As one example, let us consider Japanese dwellings.

Japan, which is located in a monsoon area, has a relatively distinct climate compared to other developed nations. In this unique hot and humid climate, much damage is caused by the high humidity. Although the humidity itself is lower than that of London, Paris or San Francisco, Japan comes first with regard to humidity-related damage to houses (Figure 4).

This is due to the fact that fungi and bacilli that affect human health and cause damage to houses are able to breed rapidly under the warm and humid Japanese climate. To counter these adverse influences, elevated floor type houses were developed in Japan over the centuries. Elevated floors allowed good under-floor ventilation. The materials used for construction were paper, wood and soil.

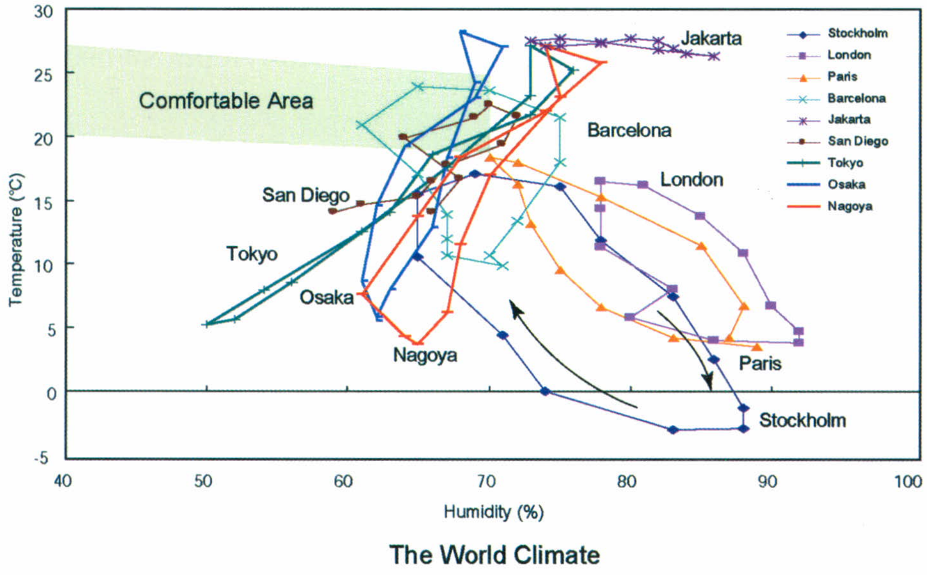


Figure 4. The World Climate.

About 50 years ago airtight houses were introduced into Japan as modern examples of buildings in Europe and America. Because of this, a new building culture, "apartment housing", took root in Japan. However, such airtight dwellings were unsuited for proper humidity control, making them uncomfortable for living. Search for comfort in such buildings led to the introduction of various indoor appliances - electric fans, followed by coolers and air conditioners. Also, the first oil shock in 1973, which demanded a significant reduction in energy consumption led to the spread of highly airtight and heat insulated housing as a national policy. Owing to the adoption of these houses, indoor temperature control technology for such dwellings has improved considerably. However, control of humidity has been proven to be difficult. As the volume of each room is small, the indoor environment in Japanese houses, contrary to expectations, tends to be inferior when compared to Europe and America [4],[5].

Because of the degraded interior environment, dwellings in Japan overflow with appliances such as humidifiers, dehumidifiers, air cleaners etc. In spite of these measures, the sick house syndrome and allergic diseases continue to increase. Compared to 1973, the industrial energy consumption in Japan is 104%. In contrast, this figure becomes 217% in the case of dwellings, showing that the energy consumption of dwellings has increased greatly [6]. And this rise has occurred in spite of the fact that much progress has been made in the development of low energy consumption type appliances. (Figure 5)

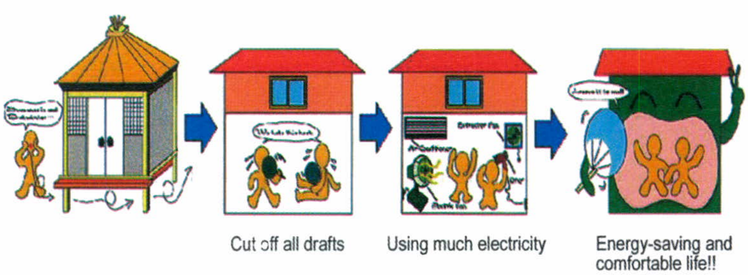


Figure 5. People and Earth Conscious Materials for the Living Environment.

The basic solution to these problems would be self-monitoring and self-regulation of the indoor climate (humidity, in particular) by the floor, walls and ceiling materials - i.e. a high P value. At the same time, it is necessary to examine methods of synthesizing these materials from the new perspective of reducing the use, as far as possible, of energy and natural resources for synthesis - i.e. a low (I+O) value. If such materials could be developed, indoor climate control should become effective even in highly airtight and heat insulated houses. Such materials would possess high value as materials with sufficient consideration for both people and the earth.

3.1.2. Indoor Climate Control by Porous Materials

The humidity range in which a person feels comfortable is said to be 40 to 70%. It has been reported that by maintaining the humidity within this range, the breeding of allergy sources such as mites, and wood eating bacteria, mould, etc., which cause degradation of wood in wooden houses, could be restricted [7]. Furthermore, this humidity range is also effective in curbing the breeding of viruses and accumulation of static electricity. Chemical methods and physical methods of humidity regulation are available, but here, let us think about a safe method, which is humidity regulation by porous bodies.

The target material would be one that does not absorb water vapour when the humidity is less than 40%, but, if the humidity becomes higher, it should be able to work towards lowering humidity by rapidly absorbing the water vapour from the atmosphere. In addition, when the humidity tends to fall, the material should be able to act and increase humidity rapidly to 40-70%. In other words, the water vapour absorption isotherm of the material should be steep in the 40 to 70% humidity range (Figure 6).

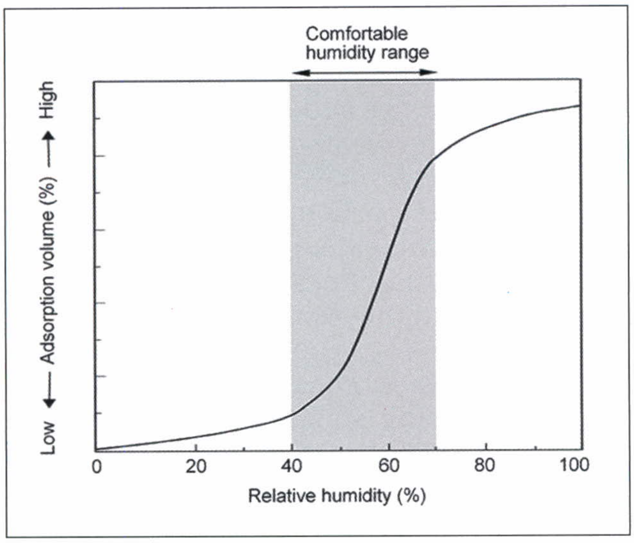


Figure 6. Property for Humidity Regulating Porous Materials.

Humidity regulating porous materials are those capable of making the water vapour in the atmosphere condense inside the capillary pores that exist on their surface when the humidity is high. And, when the humidity is low, they work by vaporizing the condensed water. The relation between the vapour pressure (P/P_0)

required for capillary condensation and pore size (curvature radii r_1, r_2) is expressed by the Kelvin equation of capillary condensation shown below:

$$ln(P/P_0) = -(\gamma V / \cos\theta / RT)(1/r_1 + 1/r_2)$$

where, r_1 and r_2 are the radius of curvature of the pores in two perpendicular directions, γ is the surface tension of the condensate, V is the molecular volume of the condensate and θ the contact angle of the condensate within the pore.

The calculations based on this equation, corrected for the pre-existence of a certain thickness of the adsorbed layer prior to capillary condensation [8], yield pore radii values of 3.2 nm for 40% relative humidity and 7.4 nm for 70% humidity. High humidity regulating performance can be expected from materials synthesized with their pore radii controlled within this range.

3.1.3. Using the Soil Wisely

There are many possibilities of synthesizing porous materials with humidity regulating properties. For example, using petroleum as the starting material, synthesis by chemical polymerization or biomimetic methods of synthesis can be selected. However, use of these methods makes it quite difficult to lower the input and output of the synthesized material. For this reason, we selected "soil", as the starting material. Natural soil is a material containing incipient micropores, which can be effective in imparting humidity regulating performance. Even after its use in the human ecosystem is over, soil will not inflict a large burden on the natural ecosystem.

Soil was born 400 million years ago. At that time, plenty of oxygen was supplied to the atmosphere, whose composition was almost the same as at present. The excess oxygen was decomposed in the stratosphere to form the ozone layer. The ozone layer prevented strong ultraviolet rays from pouring onto the surface of the earth, and allowed the movement of animals and plants from sea to land to begin. With the help of this organic matter, the land of stone and sand turned into a land of green, and soil was born for the first time from the weathering and decomposition of rock [9]. If not for soil, the perfect recirculation performance of the current natural ecosystem would not exist, and one cannot ignore the benefits obtained from it, when one recites the existence of mankind. Mankind is indebted to soil with respect to food of course, but not only that - it was through the aid of earthen dwellings that mankind was able to get over the glacial era without running out of seed.

Soil contains numerous pores, both large and small. These pores collect air, water and many nutrients, allowing soil to carry out its functions. For example, surveys of the virgin forests of the Shiga plateau (Japan) have shown that in a 1m x 1m x 15cm volume of soil, there are 360 animals such as centipedes or earthworms of a size around 2 cm, those about 2 mm in size, such as thread earthworms and beach fleas, amount to 2.3 million, while the number of protozoa, mould and bacteria is more than 10 trillion [10]. In other words, it can be said that there are many incipient pores in soil.

Figure 7 shows the pore size distribution of common earth (soil). It is clear that 10 nm (0.01 μm) pores that are suitable for humidity regulation are incipient in the material. It is also clear that the cohesive structure in the neighbourhood of 10 nm does not collapse easily even under pressure. However, when any kind of soil is lost for some reason or other, it takes an extremely long time to regenerate. Furthermore, because of its complex structure, soil is a material that has not been successfully synthesized artificially up to now.

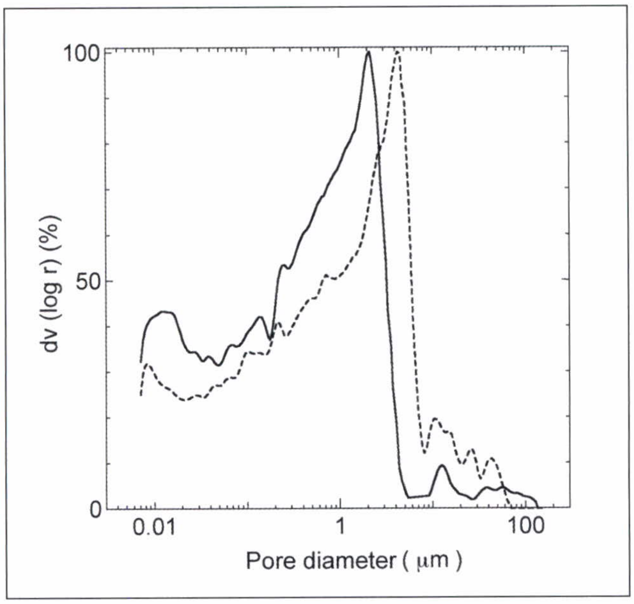


Figure 7. Examples of Pore Size Distribution of the General Soil after Dry Pressing at 30 MPa (solid line) and 20 MPa (broken line).

Mankind has utilized earth very cleverly as a construction material in many ways. In its natural state, it has been used for cave type dwellings and in pit type ones. It has been processed and used to obtain various types of construction materials such as sun-dried bricks. In Japan, it was used as "TATAKI" or earthen walls. The humidity regulation and thermal insulation properties arising from the innumerable pores in soil were utilized in Japan's Edo era to build earthen storehouses that protected stock from wind, fire and water. The technology of soil utilization was even raised to artistic levels, as can be seen from the "NURIKABE" walls of the Edo era.

Once they have served their purpose in the human ecosystem, these materials can be returned as original soil to the natural ecosystem. Therefore, it may be said that soil is an extremely rare material that can cross the system boundary zone freely. Unfortunately, earth can not usually be used as it is in current construction practice. If, for example, earth is used as it is for the floor of today's highly airtight and heat insulated dwellings, the house would become dusty and could even affect the health of the inhabitants adversely. In addition, there would be problems regarding strength, durability and workability.

Solidified ceramics such as bricks, blocks and tiles made their appearance in order to solve these problems. However, ceramics, which could be considered to have developed from the stone culture, are produced through high temperature reactions. For this reason, it is difficult to say that they maintain the inherent properties and performance of soil. In order to sustain the inherent properties and performance of soil (pore size distribution), the manufacturing temperature of earthen products should be less than 500°C at most. In the case of earth/organic material composites, an even lower temperature is desirable.

The new technology of solidifying soil by hydrothermal processing is a low temperature process developed to obtain a material with properties and performance halfway between those of soil and ceramics. (Figure 8)

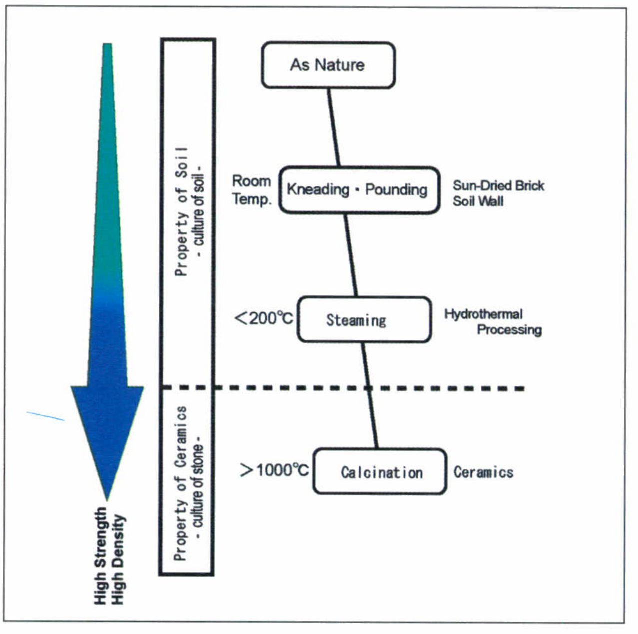


Figure 8. A Culture of Soil in Human History.

3.1.4. Solidifying the Soil by Hydrothermal Processing

The largest application of hydrothermal processing is in the field of building materials manufacture. It was developed in Europe and has over 100 years of history as represented by sand lime bricks [11],[12]. Usually, the process involves mixing quartz (SiO_2) with about 10% lime ($Ca(OH)_2$) and exposing the mixture to saturated steam at about 200°C. This results in the formation of acicular calcium silicate hydrates (Figure 9) [13]. It is believed that strength develops because these hydrates are entwined with each other in the solidified bodies. From the point of view of energy consumption, this method of synthesis is a high-efficiency process. Numerous studies have been made regarding the reactions involved during synthesis by hydrothermal treatment and regarding the behaviour of calcium silicate hydrate materials, mainly in the CaO-SiO_2-H_2O system [14],[15],[16]. Although many of the reports deal with the purity of the starting materials, it is usually accepted that it is desirable to use SiO_2 with high purity [12]. However, almost no studies seem to have been made with significantly altered SiO_2 compositions.

This is because in the CaO-SiO_2-H_2O system for example, when a lot of A_2O_3 is added, hydrogarnet (cubic structure $Ca_3A_{12}Si_3O_{12}$-$Ca_3A_{12}H_{12}O_{12}$) is formed.

That is, in the composition range over which hydrogarnet is the main phase formed, little study seems to have been carried out on the strength development of hydrothermally synthesized bodies. Investigations regarding the relationship between strength development and the microstructural changes that accompany the formation of hydrogarnet cannot be found either. This is probably because of the fact that it was thought that formation of hydrogarnet causes strength deterioration in calcium silicate materials [17]. Because of this belief, avoidance of hydrogarnet formation has been an important direction of research up to now.

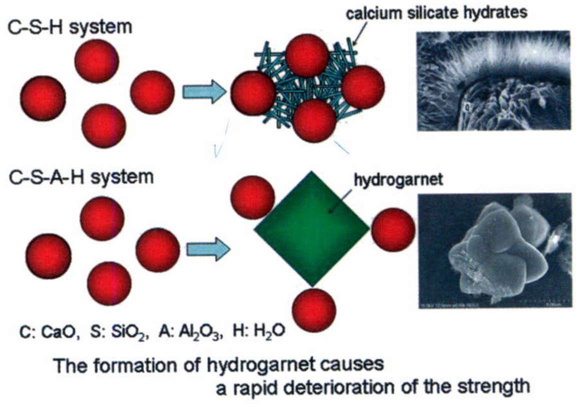


Figure 9. Hydrothermal Reactions in the System CaO-SiO_2-Al_2O_3-H_2O.

A completely different approach from current directions of research is required here. Soil, which usually consists of clay minerals such as quartz, feldspar and kaolinite ($Al_2(Si_2O_5)(OH)_4$), besides SiO_2 contains a considerable amount of Al_2O_3 (about 30%). For this reason, it is unsuitable as a raw material for calcium silicate hydrate formation. In order to produce solidified materials with soil as the starting material, sufficient strength development would be required in solidified bodies that contain hydrogarnet as the main phase.

The author et al. have clarified that hydrogarnet would work as a strength generation factor by more closely packing the particles of the starting materials and have succeeded in commercializing the hydrothermally solidified earth on a industrial basis [18],[19]. (Figure 10)

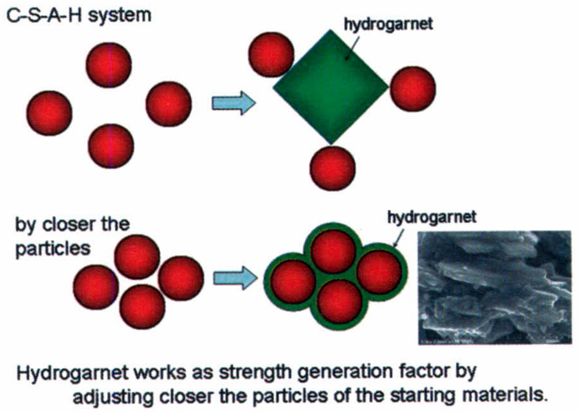


Figure 10. Hydrogarnet Works as the Strength Generation Factor by Closer Particle Packing of the Starting Materials.

An example of a solidification experiment using quartz, kaolinite and lime (CaO) is outlined here. In this experiment, the mass ratio of quartz, kaolinite and lime were varied, such that kaolinite/(quartz+kaolinite) (K/(Q+K)) = 0, 0.1, 0.5, 0.9, 1.0 and lime/(quartz+kaolinite) = 0.21 (Figure 11).

After weighing the materials, the lime was slaked and a further 10% of water was added and mixed to allow easy forming. Specimens were obtained by uniaxial press forming of this mixture at 30 MPa. The press-formed specimens were cured under saturated steam pressure at 200°C for 2 to 20 hours. (The compositional range of the specimens was Ca/(Si+Al) = 0.23 to 0.25, Al/(Si+Al) = 0.0 to 0.50.).

The variation in the phases formed with treatment time is shown in Figure 12 together with the strength development characteristics. It can be observed that in all specimens, hydrothermal treatment results in increased flexural strength. It is also clear that hydrothermal solidification is possible even in those specimens with K/(Q+K) = 0.5-1.0 where hydrogarnet is the main phase formed.

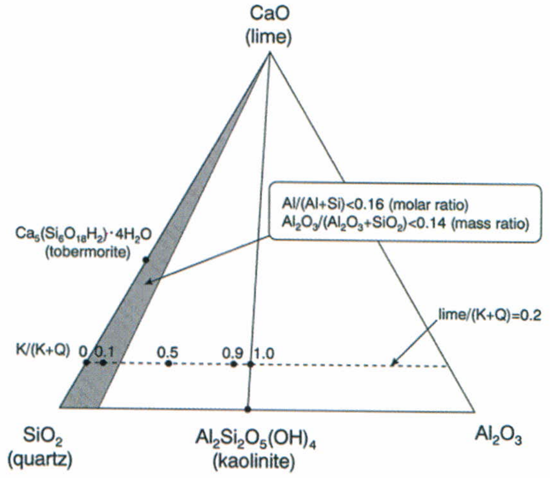


Figure 11. Experimental Compositions (mass ratio) in the CaO-SiO_2-Al_2O_3 System. Hatched area was mainly discussed in the past.

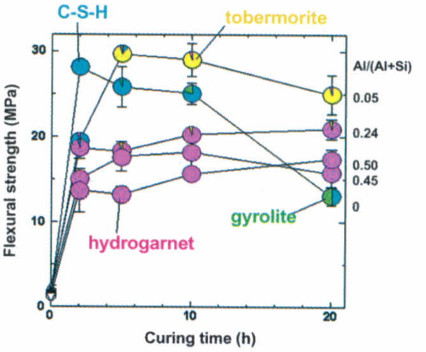


Figure 12. Generation of Flexural Strength and Phases along with Hydrothermal Processing.

In kaolinite-rich specimens with K/(Q+K) = 0.5-1.0, flexural strength reaches approximately 15 to 20 MPa in 2 hours along with the formation of hydrogarnet. Longer treatment times lead to only slight strength increases. The flexural strength maximizes for specimens with K/(Q+K) = 0.1, and becomes lower for larger K/(Q+K) values. However, the rate of decrease in strength becomes small with increasing value of K/(Q+K). In the specimens with K/(Q+K) = 0.5-1.0, the decrease in maximum flexural strength with increase in Al content is clearly smaller than in that with K/(Q+K) < 0.5.

These results are extremely significant. Namely:

1) By making hydrogarnet the major phase, sufficient strength is obtained, allowing the synthesized bodies to be utilized as building materials, although the strength may be somewhat lower than that of conventional calcium silicate hydrate materials.

2) Although strength decreases with increasing amounts of kaolinite, it is possible to limit the strength decrease to acceptable levels by making hydrogarnet the main phase. As a result, in actual practice, variations in the composition of natural soil will not significantly affect the final physical properties of the synthesized material. In other words, this means that a wise range of starting materials can be used.

It is envisaged that ultrafine hydrogarnet particles grow densely and in situ from the surface of kaolinite particles towards their interior (forming 0.04 μm pores). Through this solidification mechanism, bonding of the kaolinite particles occurs with almost no alteration to the pore sizes existing at the time of press forming. Although the detailed mechanism of strength development by the hydrothermal treatment of soil needs further investigations, it is believed that strength development is attained through ultrafine particles becoming uniformly dispersed within the densified body, i.e. a mechanism similar to the mechanism of strength development in DSP (Densified System containing homogeneously arranged ultrafine Particles). [20],[21][22]

As described above, sufficient strength development is obtained through hydro-thermal treatment of bodies that have been press formed from a mixture of lime and the starting material, kaolinite. The strength is believed to be attained not by the filling up of the pores in the material but by the formation and dispersion of ultrafine hydrogarnet particles within the press formed, dense body. This solidification mechanism allows strength to be attained without destroying the agglomerated micropore structure. This is important from the point of view of the humidity regulation performance of the solidified bodies.

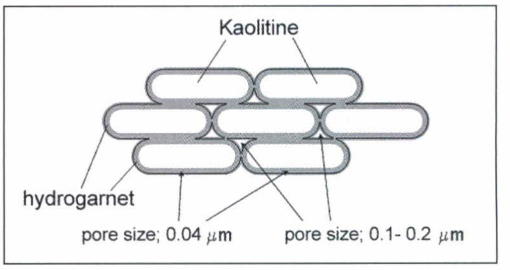


Figure 13. Estimated Schematic Figure for the Formation of Hydrogarnet under Higher Al/(Al+Si).

3.1.5. Performance of the Hydrothermally Solidified Soil Bodies (Earth Ceramics)

The industrial method of synthesizing hydrothermally solidified soil bodies is illustrated in Figure 14. A little lime and water are added to the soil and mixed well. Since the treatment temperature is low, straw or other organic additives can be added if necessary in order to obtain higher strength or to enhance the finish. The mixture is then dry-pressed into tiles and subsequently cured for a few hours at about 150°C in saturated steam pressure to obtain solidified bodies.

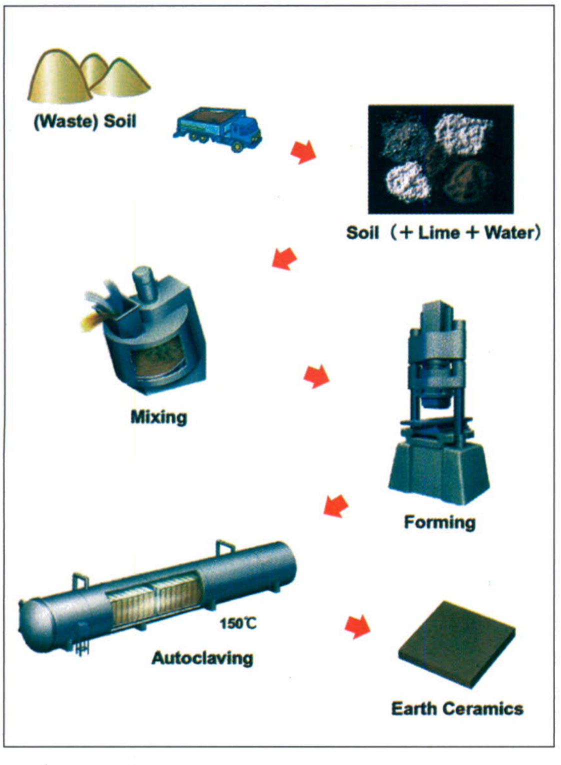


Figure 14. Actual Processing of Earth Ceramics Manufacturing.

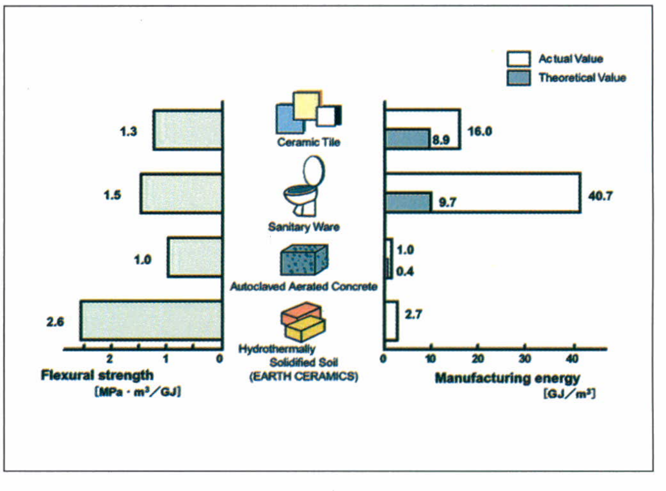


Figure 15. Energy Consumption of Materials on Processing.

Among those industrial ceramics that utilize smaller amounts of energy [23] for their manufacture, ceramic tiles are considered to consume relatively little energy. The energy required for synthesizing Earth Ceramics is even lower, being about 2.7 GJ/m^3 [24], which is only 1/6th that of the energy needed for ceramic tiles (Figure 15).

Since there is little limitation with regard to the starting materials and the energy required for synthesis is small, it can be concluded from the point of view of nature's ecosystem that Earth Ceramics are materials with very small input and output.

Pore sizes in Earth Ceramics are concentrated in two regions: 1) at around 0.05 μm corresponding to the initial pores at the time of press forming, and 2) at around 0.01 μm (10 nm) reflecting the agglomerated structure of soil. This is about 1/10000 of the pore diameters usually found in concrete and ceramics (Figure 16). The amount of water vapour absorbed at equilibrium when the relative humidity is varied from 40% to 80% at 25°C is shown in Figure 17. Although the response in the case of Earth Ceramics is somewhat slower, it can be seen that they exhibit humidity absorbency properties as good as, or better than, those of wood because of the existence of micropores in the starting material (soil).

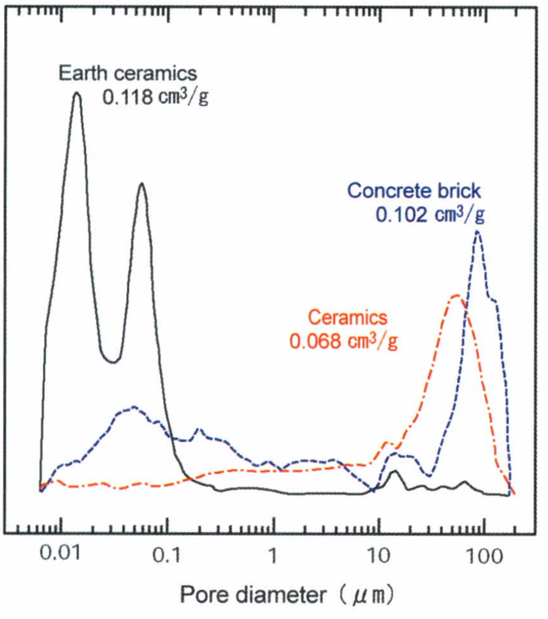


Figure 16. Pore Size Distribution of Earth Ceramics.

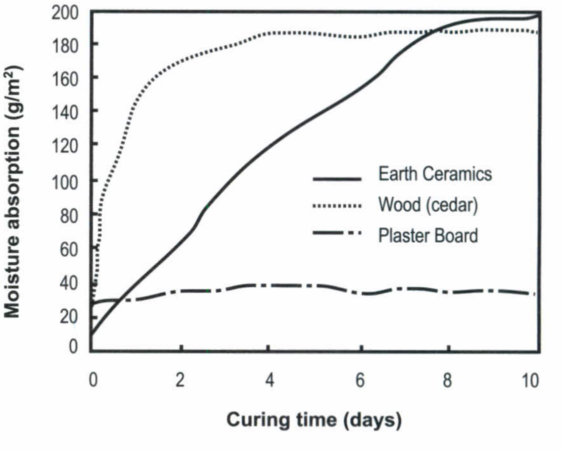


Figure 17. Variation of Moisture Absorption Capacity with Time at 25°C when Specimens (Earth Ceramics, Wood and Plasterboard) were kept under Relative Humidity from 40% of the Equilibrium Condition to 80%.

3.1.6. Living in a House of Soil

Earth Ceramic tiles (Size: 200x200 mm) were used as the flooring material for the living room of a highly airtight and heat insulated apartment (Figure 18), and the changes in temperature and humidity were measured. An apartment in the same apartment complex with acrylic carpet flooring was used for comparison (reference apartment), the floor plan and family make-up being the same for both apartments. As one of the results, the variations of temperature and humidity measured at 6 a.m., 12 noon and at 8 p.m. during one winter month are shown in Figure 19. The temperature and humidity in the Earth Ceramic floor apartment were within the range 15 to 18°C and 40 to 50%, respectively. This shows that extremely stable and comfortable living environment can be obtained by the use of Earth Ceramics.

Figure 18. Photo for the Actual Application of Earth Ceramics inside the Room.

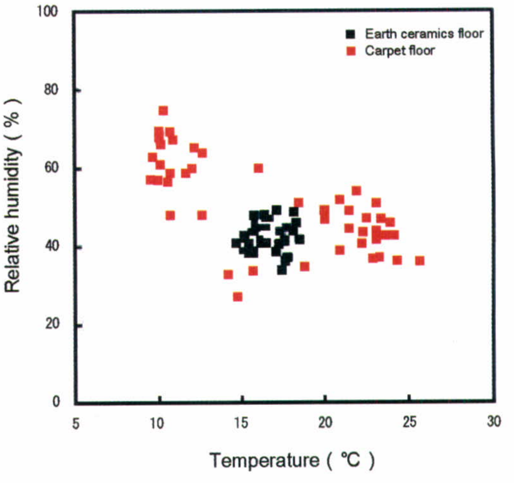


Figure 19. Variations of Temperature and Relative Humidity during one Winter Month when Earth Ceramics or Carpeting were used on the Floor.

The measurements are being continued for one year. It has been found that compared to the reference apartment, the variation of temperature and humidity is small throughout the year in the Earth Ceramic floor apartment. In particular, the humidity is within the 40 to 70% RH range which is the normal range of comfort for humans. Because of this, the use of humidifiers or dehumidifiers was unnecessary, and the period of air-conditioner operation became short. This means lower use of fossil energy. The amount of energy utilized for living (electricity, gas, water) in the apartment before and after the use of Earth Ceramic floor, converted into an equivalent amount of CO_2, is shown in Figure 20. After remodelling, the amount of electricity expected to have been used for air-conditioning dropped sharply and the seasonal fluctuation of energy consumption was controlled. On average, there was a 17% reduction of energy consumption per year. The foregoing energy consumption refers to the entire quantity required for living in the apartment (floor area = 72 m^2). The energy consumption reduction effect with respect to the living room (floor area = 32 m^2) where the Earth Ceramics were laid as flooring is considered to be greater.

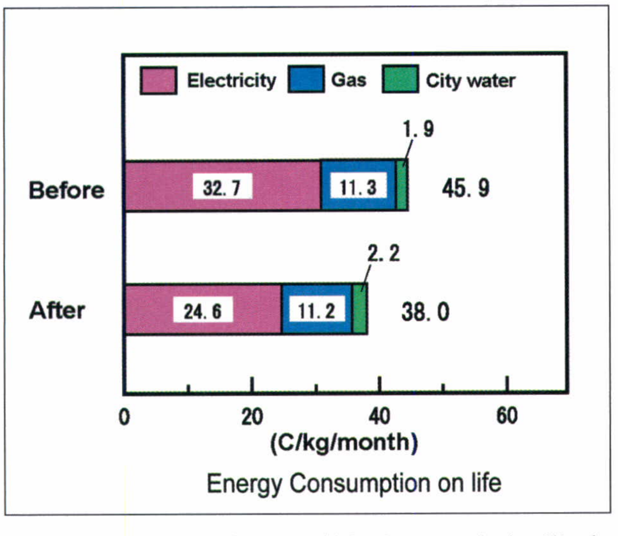


Figure 20. Amount of Energy (CO_2 Consumption) utilized for Living (Electricity, Gas and Water) before (Carpeting) and after the use of Earth Ceramics floor.

In addition to the above beneficial effects, earth ceramics proved to be effective in controlling chronic allergic disease suffered by the persons living in the house. Breeding tests with ticks, which are one of the sources of allergy, showed that at 25°C, 90% RH, 200 ticks multiply in number to 990, 1470 and 1895 in Earth Ceramics, vinyl cloth and acrylic carpet, respectively. This clearly demonstrates the advantage of Earth Ceramics over other materials with respect to restricting the breeding of allergy sources. Whether the low breeding rate in Earth Ceramics is due to the good humidity regulation characteristics of the material, or whether it is the result of changes in the pH of the surface by humidity absorption, remains unclarified at present.

It is clear from the above that laying Earth Ceramics in a house is effective in regulating the indoor climate without needing to use new energy.

3.1.7. New Functional Materials

It is believed that hydrothermally solidified soil materials attain strength through ultrafine hydrogarnet particles becoming uniformly dispersed within the densified press formed body, similar to DSP materials. This type of material synthesis holds many possibilities as the process for producing new functional materials. Such possibilities need to be investigated concretely from now on. For example, new functions might be imparted to the material by replacing the ultrafine dispersed particles by another functional material.

From the point of view of humidity regulation, we have only investigated the process of hydrothermal synthesis here. However, there are many other promising possibilities of using low energy processes for producing new materials. One is the use of natural porous materials. Sepiolite ($Mg_5Si_8O_{20}(OH)_2 \bullet 8H_2O$) contains micro-pores of about 1 nm and mesopores that are a few nm in size. Allophane ($1\text{-}2SiO_2 \bullet Al_2O_3 \bullet nH_2O$) is an amorphous alumino-silicate substance formed during the weathering of volcanic glass which is the major constituent of volcanic ash. It is widely distributed in nature in the form of hollow spheres of 3-5 nm in diameter [25],[26]. As shown in the water vapour absorption/desorption isotherms of Figure 21, both sepiolite and allophane exhibit high humidity absorption/desorption ability. Even at relative humidities less than 40%, they show a high ability, which is thought to result from the disordered surface structure and micropores smaller than 1 nm formed by the adsorbates. By adding a small quantity of binder to allophane-rich soil (e.g. Kanuma-soil/Japan), dry forming the material to shape and firing at about 900°C, it is possible to obtain a solidified material that has high humidity regulation ability (trade name: Ecocarat). The humidity absorption/desorption characteristics of Ecocarat at 40 to 80% RH is shown in Figure 22.

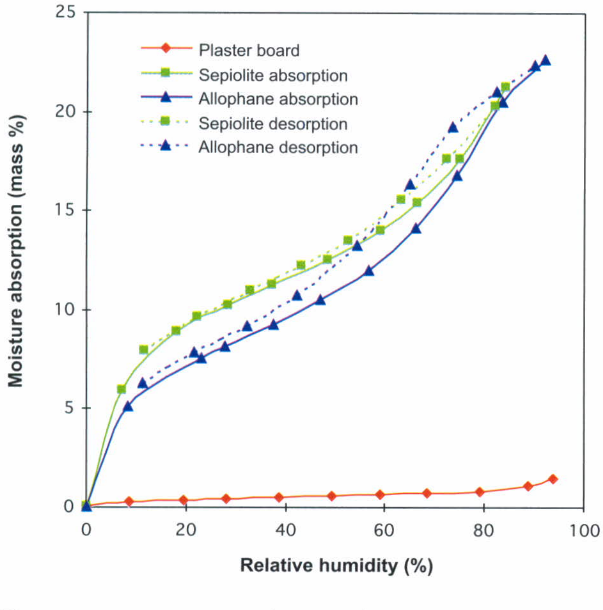


Figure 21. Water Vapour Absorption/Desorption Isotherms of Sepiolite, Allophane and Plasterboard.

Although there is a limitation in the choice of material, the

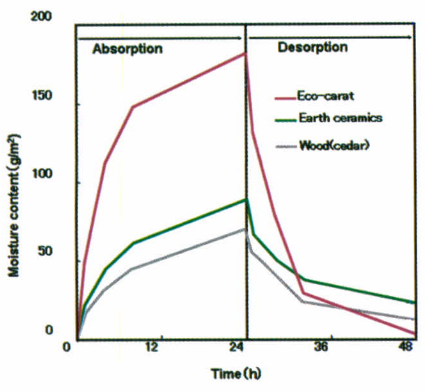


Figure 22. Humidity Absorption/Desorption Characteristics of Eco-carat at 40-80% RH.

micropore volume of Eco-carat is around 3 times that of Earth Ceramics, and it shows extremely high humidity regulation performance. Because of its high performance, the thickness can be considered as 1/3 (5 mm) of the Earth Ceramics to demonstrate its full ability, and a special under finishing of the wall is not required as lightweight wall material (9.0 kg/m^2). Besides humidity, it has been found that Eco-carat shows high performance in the absorption of gaseous substances such as VOC and odour (Figure 23), making it highly evaluated in the market as an earth conscious material. In addition, other materials for DIY which are combined with Eco-carat and a new tiling method, are also being developed.

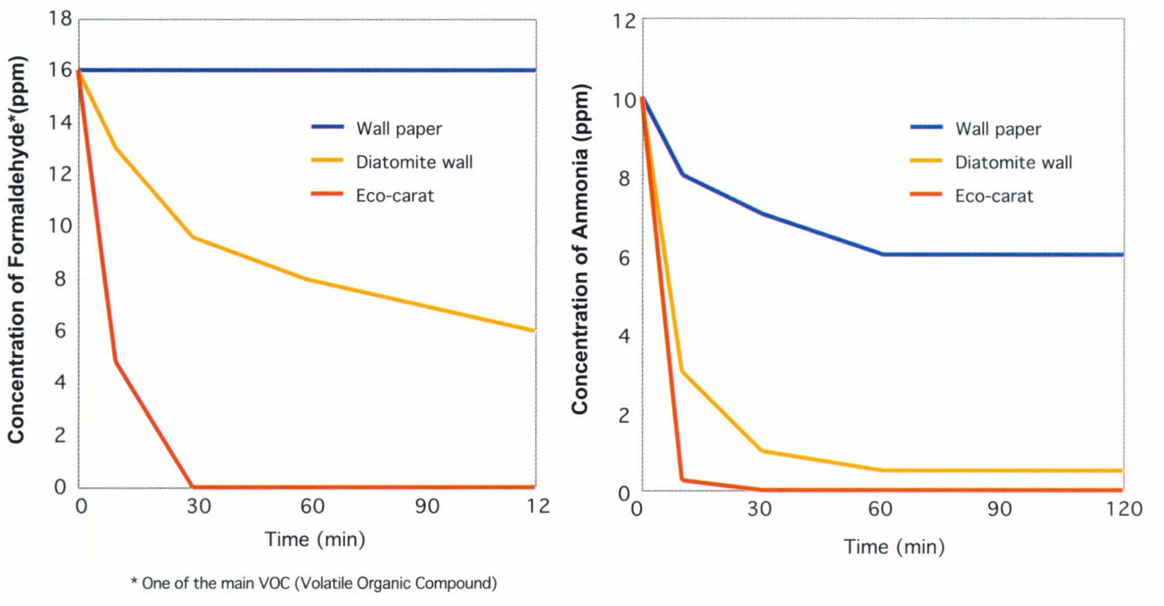


Figure 23. Some Properties of Eco-carat regarding VOCs and Odour.

3.2. SCIENCE OF THE SNAIL – STAIN FREE MATERIALS

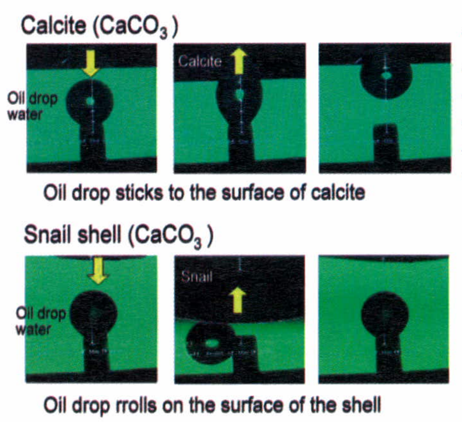
One of the biggest sufferings at home is cleaning around the kitchen area where water is used. Much energy and resources are consumed in removing dirt or stains in homes as well as buildings. For this removal, measures such as high quality detergents have been applied. However, from the environment burden cutting standpoint, P becomes high where there is no stain. And if stain-free material could be produced either by conventional level or even lower amounts of resources and energy, I+O could also be small.

Snails will not become dirty and their shells shine when rain stops. Snails demonstrate a stain-free property without producing an internal secretion. If the stain-free mechanism (hardly stained and easily cleaned) is reflected on a material, it would be a great benefit.

The snail shell has scale-shaped aragonite which is surrounded by protein and it possesses fine unevenness irrespective of a big change of the accretion line. (Figure 24)

Figure 24. Snails will not Become Dirty and their Shells shine when the Rain Stops.

Figure 25 shows how using a calcite with the same chemical composition ($CaCO_3$) as the shell, the contact angle of the oil drops in water is measured. In air, water as well as oil adheres to both shell and calcite, and the contact angle can be measured, but in the case of the snail shell, the contact angle of the oil drops in water can not be measured. Although details require further discussion, this is related with the fact that the apparent surface energy of the shell is about 60 mJ/m^2.



Specimen	Contact angle (degree)
Snail shell	N.D.
Egg shell	N.D.
Calcite	122
Ceramic tile	100

Figure 25. Measurement of the Contact (Oil) Angle in the Water.

That is to say, in air, it is possible to adhere water (72 mJ/m^2) and oil (cooking oil 35 mJ/m^2) to the shell but in water, the difference in surface energy between the shell and water is smaller than that of the one between the shell and oil; the shell shows more affinity to water, therefore, oil can not adhere. (Mechanism which can wash the oil stain) (Figure 26)

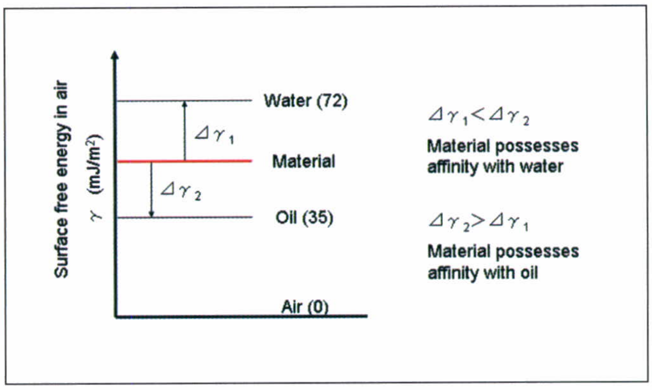


Figure 26. Surface Free Energy of the Material.

In the actual application, when a kind of stain is known, and a material having a certain surface energy to cope with is used, it should be possible to produce a stain-free surface as well as the surface which can be cleaned easily. Control of surface energy depends on a fine surface shape of the material and which kind of reaction group can be synthesized on the surface of the material. In addition, it is also possible to control the surface energy by changing the composition and the modification ions of the glassy phase of a ceramic surface.

Figure 27 shows some applications. If a ceramic-coated sink (54 mJ/m^2) whose surface energy is higher than that of the stainless steel sink (30 mJ/m^2) is used in the kitchen, it is possible to clean a stain (oil) by water.

			specimen	Water contact angle (degree)	Oil contact angle (degree.)	Surface free energy (mJ/m²)
A	Ceramic tile	1	Processed	<5	<5	72
		2	Original	33	18	60
B	SUS304 (kitchen sink)	1	Processed	37	16	60
		2	Original	85	23	30
			FRP	84	11	39
C	Sanitary ware	1	Processed	107	71	19
		2	Original	38	15	57

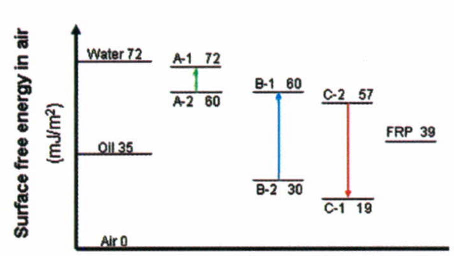


Figure 27. Some Applications of Controlling the Materials Surface Energy.

Regarding ceramic exterior wall tiles for buildings, it became obvious that the surface treated tiles (72 mJ/m^2) have high stain-free characteristics against a dissolution of silicon shielding, which is one of the typical stains of buildings, compared with the non-surface-treated ones (60 mJ/m^2) as well as the ones treated by TiO_2. (Figure 28) These materials (Micro Guard) are at present widely accepted in the market as new surface treated materials.

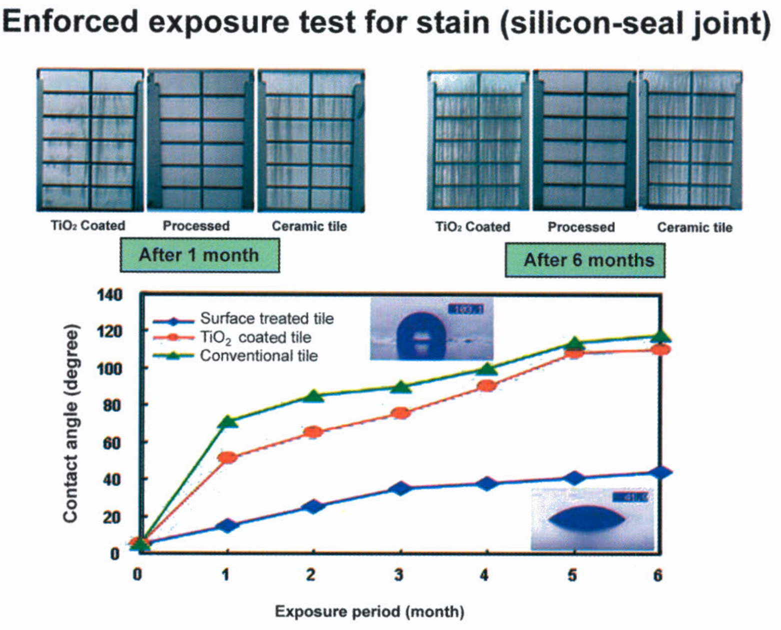


Figure 28. Enforced Exposure Test of tiles for Stain (Silicon-seal joint).

5. CONCLUSION

The present age is one in which the global environment has a serious meaning for mankind. While maintaining, as far as possible, the inherent highly advanced properties and abilities of nature, it is important that we develop technologies that convert, using the least possible amount of energy, these gifts of nature into forms that can be utilized in the human ecosystem.

In this paper, the fundamental way of thinking of human and the earth conscious manufacturing and two examples of its application are discussed. This is considered as a result of the hint from a natural environment and a scientific approach. We believe that the 21st century is not the time for us to challenge nature but to learn about the environment from the earth, where the entropy is lowest, and adopt a new direction for which thorough scientific research needs to be performed.

We need to create new values of life and living by changing today's synthetic materials into smarter ones that minimize the load on Mother Earth: the creation of such a technology and culture should be considered to be our greatest responsibility towards the next generation.

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