Materials Transactions, Vol. 55, No. 5 (2014) pp. 745 to 749

New Aspects of Ecomaterials from the Viewpoints of the Consumer and Regional Communities

Osamu Umezawa[1,*], Yoshikazu Shinohara[2] and Kohmei Halada[2]

[1]*Faculty of Engineering, Yokohama National University, Yokohama 245-8501, Japan*
[2]*National Institute for Materials Science, Tsukuba 305-0047, Japan*

The concept and new categorization of environmentally conscious materials, ecomaterials, is proposed. Advanced steps ranging from high eco-efficiency of products, to consumer-oriented and regional community adaptation are introduced. An additional new concept, the robust design of materials, is also proposed as part of a new range of activities in ecomaterials. [doi:10.2320/matertrans.MB201302]

(Received September 17, 2013; Accepted November 12, 2013; Published December 28, 2013)

Keywords: *ecomaterials, ecosphere, eco-efficiency, resource security, recycle, amenity, robust design, environmental information, communication, social system, sustainable development*

1. Introduction

Presently, materials security and production of environmentally conscious materials (ecomaterials)[1)] are of concern to the global community, which needs to recognize the challenges that both present. As a nation, Japan has focused on better management of natural resources and materials, and has developed a framework to advance a move towards a closed-loop economy through advancing and implementation of its knowledge of the 3Rs (reduce, reuse, recycle). Ecomaterials also make an important role in ecodesign. Ecodesign is an approach to design of a product with special consideration for the environmental impacts of the product during its whole lifecycle. Substantial progress has been made in ecodesign and high-performance fabrication for sectors such as living, automotive, electrical, machinery, building, etc., where a need to improve resource productivity and adopt ecomaterials are a key priority for progress.[2)]

The concept of ecomaterials, defined as an ecosphere with three basic paths (i.e., frontier, environmental protection, and amenity), was originally proposed in Japan in 1992 and became the preferred area of focus in materials engineering through the 1990s.[1)] In the beginning of the 21st century, Halada *et al.*[3)] attempted to classify ecomaterials into three categories as follows:

(1) Functional materials for environmental protection,
(2) Energy-saving materials and materials supporting low-emission systems, and
(3) Materials designed by means of life-cycle assessment or analysis (LCA), and selected based on a lower environmental impact.

This is why not only materials selection is important, but also novel process technologies for synthesizing high-performance materials with a low environmental burden. Both are also dependent on product design to achieve coexistence of societal economic health and reduced environmental burden. Therefore, general guidelines for ecomaterial selection and development were discussed and proposed,[2)] in which eco-efficiency was defined by an equation.[4)] We have developed and standardized the indices of this equation, and its framework for disclosing information on environmental impact of materials traded under international collaboration.[5)] The six environmental information indices are demonstrated in the eco-star system.[6)]

The specific challenges facing ecomaterials have played an important role in the global recognition of environmentally conscious concepts since 1993, and have served motivators for the development of an eco-friendly world. In fact, the ecomaterials concept has already been widely accepted in the fields of material production and product manufacturing, in addition to being accepted by the academia and various governments. This is especially true in Japan, where adoption of ecomaterials that are less hazardous, or have a higher resource productivity, has noticeably increased.

Despite all the importance attached to ecomaterials, its concept has now become outdated, and a new categorization of ecomaterials is therefore being sought. Through the declaration at Ishigakijima,[7)] and at the round table conference at ICEM9,[8)] we have discussed the breakdown and rebuilding of the ecomaterials concept for a sustainable society. The point at issue, and the direction of technological advancement of the world, has remained confused, and it is this that we seek to correct. Moving from high eco-efficiency of products to consumer orientation and regional community adaptation is focused upon as a part of the "amenity", one of three basic paths in achieving an ecosphere. A new concept, the robust design of materials, is also proposed as part of new range of activities focused on ecomaterials.

2. Ecomaterials with Social Systems

2.1 High eco-efficiency

Product manufacturers have been keen to promote the environmental-consciousness of their products, and have made some changes as part of their corporate social responsibility. Government has also played a part by promoting "green purchasing".[9)] These activities represent high eco-efficiency of products, where eco-efficiency is defined as performance divided by the environmental burden

*Corresponding author, E-mail: umezawa@ynu.ac.jp

Table 1 Resource productivity in urban mining and natural resources.

Resource	Grade and distribution	By-products	Environment
Urban ore (scrap)	High grade Complex or contaminated Dispersed in city	None (dust) (No sorting and refining)	Saving energy
Natural (crude) ore	Low grade Individual or simple Localized in source	Inevitable (Refining or purification)	Diffusion of hazardous element Damaging landscape

of a product over its life cycle.[4] Although numerous practices and considerations have been taken into account for developing new social systems and business models for design, production and dissemination, consumers have a limited understanding as to the life-cycle of products and services with high eco-efficiency. Interest is normally focused on a limited performance, but low price of products, with hidden information on materials and technologies in products usually ignored. A high eco-efficiency, however, represents a key means of achieving a sustainable society since the materials are utilized throughout the life cycle of the product. In the definition of eco-efficiency, the equation was divided into countable and uncountable factors for which factors responsible for any kind of environmental burden were clarified. Ecomaterials have subsequently been classified into six categories, "eco-star", from the viewpoint of fabricators as follows:[2]

(1) Materials for environmental purification
(2) Materials for higher performance and efficiency
(3) Materials without (minimizing) hazardous substance
(4) Materials of green environmental profile
(5) Materials of higher recyclability
(6) Materials of higher resource productivity

This classification is insufficient for further expansion of eco-efficiency, as it is not directly linked to how a product is used.

Consequently, we have clearly recognized that formation of an epistemic community concerned with environmental issues is a necessity. Specifically, ecomaterial activities should involve communication not only with fabricators, but also with both consumers and regional communities. Such activities are indispensable to achieving high eco-efficiency of materials, and ecomaterials should be developed to promote and support the environmental practices of consumers and communities.

2.2 Material systematized in product

While materials play an essential role in the development of human society, the negative aspects of the environmental burden posed through massive production, consumption, and disposal have been pronounced in recent years. This demand for materials has been increasingly expanding in order to satisfy growing human needs, and has caused a rapid increase in resource risk such as securing supply of minor metals. In the declaration at Ishigakijima 2007,[7] three principles and four practices in the area of resource use were appealed. Those are "We, who aim to utilize materials to construct a sustainable society, reconfirm the importance of three principles in the area of resource use as: (1) resource conservation, (2) environmental protection, and (3) regional and generational equity. Based on these principles, we ask consumers of materials to observe four practices in the area of resource use, i.e., (1) use the minimum quantity, (2) use completely, (3) circulate as many times as possible, and (4) use abundant resources". Recovery and reproduction processes to address these various needs are therefore required. We also pledge ourselves to the advancement of technologies that realize these four practices in material research. In the technological development for a sustainable society, it is rather important to provide high performance and/or service with low costs, low environmental burden, and good adaptability in secondary (recycled) materials".

To provide such flexibility in secondary materials, the concepts "material systematized in the product" and "secondary materials accepted for products" should be applied as follows:

(1) Development not only in refinement of secondary materials, but also in making secondary materials benign by removal of impurities in order to enable their wide utilization
(2) Development of advanced material separation, and new material substitution, for materials containing toxic substances.

Such concepts make possible the development of a totally managed industry for manufacturing and recycling, in order to minimize material flow. In addition, they may also provide for development of more profitable production systems in order to answer social requirements and to increase scrap production.

Although numerous studies and considerations have been conducted into recycling subjects such as waste plastic, many problems still exist.[10,11] The formation of a network has been realized for one of these problems, through utilization of wastes and by-products. Specifically, a type of chemical recycling system, based on the coke-oven chemical converting process used by some steelworks in Japan, has been used for material or chemical recycling of waste plastics from each municipality. Such recovery systems obviously depend on the distribution area of scrap, and the associated flow and variability.

In advanced countries, the formation of a recycle loop and building of urban mines are needed to develop a civic system for a sustainable society. Nanjo[12] considered the manufactured products accumulated on the ground to be a resource, and named the accumulated places "urban mine". Resource productivity in urban mining (scrap recycling) is different from that of the use of natural ore, as listed in Table 1. The broad definition of urban mining is the reclaiming of compounds and elements from products, buildings and waste, in which valuable minerals and/or organics are extracted. Questions and prospects on the urban mining resources, urban mining stock and recycling sequence have been discussed.[13] By optimizing the recycling system with each step of the process as recovery, separation, sorting and processing, urban mining can reach its potential. The instability of quantity and quality of output is a particular problem in scrap use, where material recycling depends on conditions in the local area.[10)] It is more cost-effective to reuse scrap in the area in which it was produced, than to have it transported to far-away areas. This concept was applied to start with zero emissions from factories. At the same time, in order to respond flexibly to emerging market needs and various resource types, without increasing environmental load, demands on materials for simple recycling and scrapping should also move towards advanced utilization of scrap, low costs, and smaller and more profitable production. Some directions for technological development were proposed in order to answer the requirements for sustainable materials.[10)] Further, a materials circulation system named "material leasing system" has been proposed in order to promote social resource productivity.[11)] In this system, the responsibility to manage end-of-life material lies with the material's producer, and provides the producer an economic motivation. In any case, initiatives using urban mining as well as building one are critical to a sustainable society through material systematization in products.

3. Ecomaterials in Symbiotic with Nature and Life

3.1 New aspects of ecomaterials from fabricators to consumers

Based on the discussion at ICEM9,[8)] we proposed a new categorization of ecomaterials from the viewpoints of the fabricator and the consumer, whose use can be extended into the future, as illustrated in Fig. 1. This target view shows a road map of ecomaterials from the 1990s' to 2050 in Japan. This road map is divided into three phases as follows:

Phase 1: Achieving high eco-efficiency of products

Materials equipped with some of the eco-star characteristics listed in section of 2.1, from the viewpoint of the fabricator.

Phase 2: Raising environmental consciousness, and promoting environmental practices, of consumers

Increasing familiarity with materials that are oriented towards energy-saving, resource saving, renewable energy, recycling and recovery, biomass, and so on, from the viewpoint of consumers (e.g., solar panels, wood-ceramics).

Phase 3: Building new life-styles suitable for regional communities

Materials are related to local production for local consumption, slow living, for the future (e.g., electric bicycles, natural products).

This categorization meets the original concept of ecomaterials. The ecomaterials developed under three phases take a holistic view of the ecosphere, and progress along three basic paths as shown in Fig. 2. The basic paths are defined as follows:

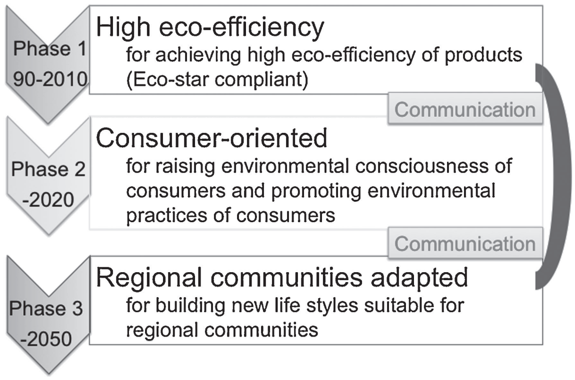

Fig. 1 Road map of ecomaterials and eco-products in Japan.

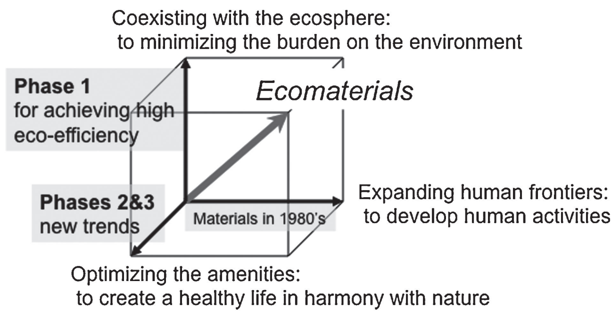

Fig. 2 Ecomaterial development taking into consideration a holistic view of the ecosphere as per Ref. 1).

Frontier path: expanding human frontiers

Materials are developed to increase human activities. This is consistent with the traditional development of materials, in which physical, chemical, thermal or functional properties are improved in order for the materials to be better utilized.

Environmental protection path: coexisting with the ecosphere

Materials are to minimize any harmful influence upon the environment. From the viewpoint of sustainable development, one should reduce the consumption of materials and energy, and the emission of wastes associated with materials processing.

Amenity path: optimizing amenities

Materials are to create a healthy life in harmony with nature. Materials should be friendly not only to nature, but also to humans.

In phase 1, ecomaterial development has mostly followed the paths of frontier and environmental protection to achieve higher eco-efficiency. Recently, we have faced unusual weather and global warming for which an increase in greenhouse gas (GHG) emission has been identified as the main cause. Most consumers, however, are unable to recognize the environmental impact they cause or to take responsibility for reducing their own GHG emissions. Moving from high eco-efficiency of products to consumer orientation needs a communication between fabricators and consumers. In future, we should seek a new paradigm building new life-styles with low environmental burden, where the styles depend on each regional community in the

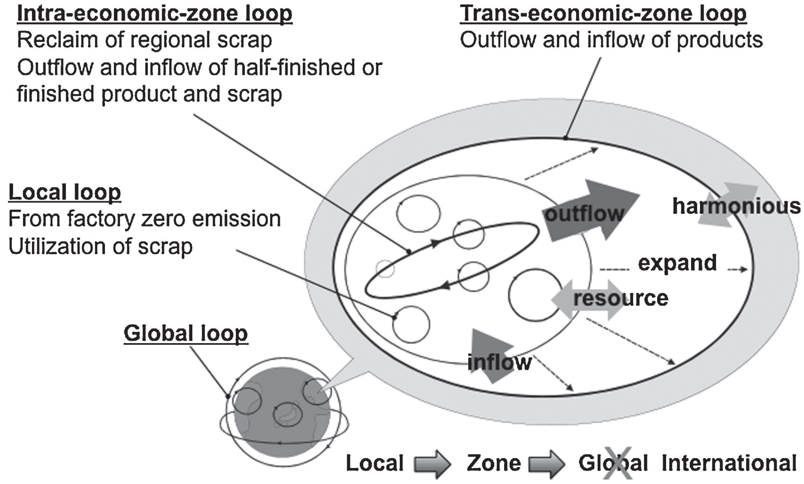

Fig. 3 A material flow concept based on Ref. 10).

world. Thus ecomaterials suitable for regional communities may have varieties to optimize their amenities with nature and humans. Therefore, ecomaterials should be considered for promoting and supporting the environmental practices of consumers and communities, by communication among fabricators, consumers, and regional communities as illustrated in Fig. 1. Such new trends of ecomaterials appear in phases 2 and 3, where the amenity path attracts considerable attention.

3.2 Towards post-global and post-modern

As mentioned above, high eco-efficiency of products is a global imperative for harmony in the development of a sustainable society, and the development of ecomaterials has been commonly recognized as part of the solution for the high eco-efficiency of products (phase 1). Thus, savings in energy and reduction of emissions are still the most important issues for ecomaterials, where meta-balance of the three basic paths of expanding human frontiers, coexisting with the ecosphere, and optimizing the amenities is concerned. The innovation for trade-off balance among material performances, and changing the relationship between product cost and performance, are the issues still confronting us.

Materials are however imbalanced between production and waste or recycle, due to economic conditions. The material flow considers the global body, which involves both the local and intra-/trans-economic zone loops as shown in Fig. 3.[10] Although it is reasonable to minimize total environmental loads and resource consumption, we should also pay attention to the fact that it is not global standards, but international communication, which enables local characteristics to be taken into account in business activities, and allows marketing to be conducted more efficiently. This is why a value judgment on products depends on the life-style of people, where the advanced steps from high eco-efficiency of products (phase 1), to consumer-oriented and regional community adaptation (phases 2 and 3), as proposed in the section 3.1, may be closely related. In post-global and post-modern developments in particular, the appeal of originality and a sense of corporate branding results in the perception of added value of products. These conditions necessitate a modification to the material flow concept as shown in Fig. 3.

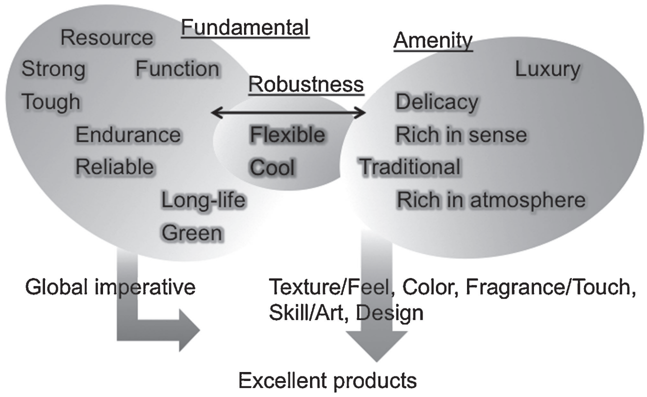

Fig. 4 Factors for the robust design of materials.

The trans-economic zone loop should maintain harmonious flexibility with each intra-economic zone loop, in order to answer the local requirements such that both international and regional communications are essential to ecomaterials.

3.3 Robust design of materials

As the appeal of the originality of materials in harmony with nature and life depends on local culture, sense of beauty, and so on, the amenity path is worthy of much attention rather than before. Optimizing the amenities in phases 2 and 3 means that materials should be friendly not only to nature but also to humans, as defined in the basic paths above. Materials optimized for amenity are categorized to be adopted in superior products involving three factors, as illustrated in Fig. 4. First are the fundamental properties of ecomaterials in phase 1, i.e., security, high performance, reliability, safety, quality control, long-life, green etc. Second are the characteristics such as it being a delicacy, a richness in sense and atmosphere, traditionality of the product, and sense of luxury. These are not always progressive, but comfortable and relaxing in feel, texture, color, fragrance, touch, art, design, etc. Consumers also need to continue to love their choice in product forever. Since these two factors are basically independent of each other, a third factor needs to be installed to connect them. Here, robustness is adopted as the third factor to provide communication between the consumer and the fabricator. In order to promote communication between consumers and fabricators when choosing improved products and materials, scientific and/or technological education is necessary for us to deepen our understanding. The robustness represents a consideration to consumer such as cool, flexible, etc. Then these three factors are totally managed so as to result in excellent products and materials. A new concept, robust design of materials, therefore, is proposed as a part of new activities in ecomaterials, where they contribute not only to maintaining social safety and stability, but also to providing tough, comfortable and robust products. As "mottainai" represents valuable or treasured items, we have to recognize that interaction between technology and humans is in balance with supply, including its cost and risk. Mottainai is a Japanese term conveying a sense of regret concerning waste. Wangari Maathai introduced the word "mottainai" as a slogan for environmental protection. In doing so, the paradigm "Enough is as good as a feast" also appears to represent the robust design of materials.

4. Conclusions

Materials security and high eco-efficiency of products are a global imperative. Advancements toward consumer-oriented materials and regional community adaptation of ecomaterials are introduced. The robust design of materials is proposed as a part of a range of new activities to address ecomaterials.

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