VINETA SREBRENKOSKA[1],
EMILIJA FIDANCEVSKA[2]

Scientific paper
UDC:502.34/.35

Environmental issues in materials science and engineering

The industrial engineering consumes of materials and is dependent on a continuous supply of them. Increasing population and living standards cause the consumption rate to grow - something it cannot do forever. Finding ways to use materials more efficiently is a prerequisite for a sustainable future. Recent global attention to the issues and challenges of sustainable development is forcing industries to conduct self-assessments to identify where they stand within the framework for sustainability, and more importantly, to identify opportunities, strategies and technologies that support achieving this goal. Design for environmental sustainability is the long-term view: that of adaptation to a lifestyle that meets present needs without compromising the needs of future generations.

The composite material is a group of materials which they have not yet gained the same amount of utilisation as metallic materials. Since the composites consist of a mixture of several types of materials on macro level they cannot be regarded as homogenous as the steel materials. Both these circumstances complicate the possibilities to form a well-organised system for waste handling. The increased use of composites in industry will create continuously more waste to be handled in the future. Also for this type of materials several regulations put pressure on producers to consider the waste treatment. Examples are prohibition against landfill, producer responsibility for specific groups of products and eventually taxes on waste incineration. All these regulations are aiming for material recycling, due to decreased environmental impact. A common opinion is that recycling composite materials will be especially difficult or not even possible. The main alternative used today for handling composite waste is landfill but also waste incineration is an alternative. To respond to environmental awareness in society and to regulations, companies require new methods for waste disposal.

Key words: *environmental effects, eco-design, composites, waste.*

1. INTRODUCTION

Environmental and societal impacts of production are becoming significant engineering issues. In this regard, the material life cycle is an important consideration. This cycle consists of extraction, synthesis/ processing, product design/manufacture, application, and disposal stages. Materials, energy, and environmental interactions/exchanges are important factors in the efficient operation of the materials cycle. The earth is a closed system in that its materials resources are finite. Environmental issues involve ecological damage, pollution, and waste disposal. Recycling of used products and the utilization of green design obviate some of these environmental problems.

Composites are materials that comprise strong load carrying material (known as reinforcement) imbedded in weaker material (known as matrix). Reinforcement provides strength and rigidity, helping to support structural load. The matrix, or binder (organic or inorganic) maintains the position and orientation of the reinforcement. Significantly, constituents of the composites retain their individual, physical and chemical properties and together they produce a combination of qualities which individual constituents would be incapable of producing alone [1]. Composites can be grouped into categories based on the nature of the matrix each type possesses. Methods of fabrication also vary according to physical and chemical properties of the matrices and reinforcing fibers [2].

Polymer Matrix Composites (PMCs)

The most common advanced compositesare polymer matrix composites. These composites consist of a polymer thermoplastic or thermosetting reinforced by fiber (natural carbon or boron). These materials can be fashioned into avariety of shapes and sizes. They provide great strength and stiffness along with resistance tocorrosion. The reason for these being mostcommonis their low cost, high strength and simplemanufacturing principles.

Metal Matrix Composites (MMCs)

Metal matrix composites, as the name implies, have a metal matrix. Examples of matricesin such composites include aluminum, magnesium and titanium. The typical fiber includes carbon and silicon carbide. Metals are mainly reinforced to suit the needs of design. For example,the elastic stiffness and strength of metalscan be increased, while large coefficient ofthermal expansion, and thermal and electricalconductivities of metals can be reduced by theaddition of fibers such as silicon carbide.

Author's address: [1]Faculty of Technology, Goce Delčev University, “Krste Misirkov” b.b. P.O. Box 201, 2000 Štip, Republic of Macedonia, [2]Faculty of Technology and Metallurgy, Sts. Cyril & Methodius University, MK-1000 Skopje, Republic of Macedonia

Paper received: 10.12.2012.

Ceramic Matrix Composites (CMCs)

Ceramic matrix composites have ceramic matrix such as alumina, calcium, aluminosilicate reinforced by silicon carbide. The advantages of CMC include high strength, hardness,high service temperature limits for ceramics, chemical inertness and low density.

Naturally resistant to high temperature, ceramic materials have a tendency to becomebrittle and to fracture. Composites successfully made with ceramic matrices are reinforced with siliconcarbide fibers. These composites offer the same high temperature tolerance of super alloys but with out such a high density. The brittle nature of ceramics makes composite fabrication difficult. Usually most production procedures involve starting materials in powder form.

There are four classes of ceramics matrices: glass (easy to fabricate because of low softening temperatures, include borosilicate and aluminosilicates), conventional ceramics (silicon carbide, silicon nitride, aluminum oxide and zirconium oxide are fully crystalline), cement and concreted carbon components.

Carbon-carbon composites (CCMs)

CCMs use carbon fibers in a carbon matrix. Carbon-carbon composites are used in veryhigh temperature environments of up to 6000°F, and are twenty times stronger and thirty times lighter than graphite fibers.

In production industry the environmental questions are in the focus of attention. Several new strategies for incorporating these issues into design have been developed under designation eco-design or design for environment. The purpose of these strategies are to:

- minimise energy consumption,
- minimise use of material,
- exclude hazardous materials and substances,
- facilitate recycling.

Over the last decades, knowledge of complexity and extent of the environmental problems has increased. From being concentrated on local problems the focus has changed to global problems and resulted in a new viewpoint, sustainable development.The aim of this concept is to reach balance between resource use and environmental impact, so that the environment is able to withstand the burden within the ecological cycle. At the same time the resource distribution should be fair.

2. ENVIRONMENTAL CONTEXT

The extensive effect on the environment is connected to human activities and unrestrained exploitation of natural resources, which is illustrated in Figure 1.

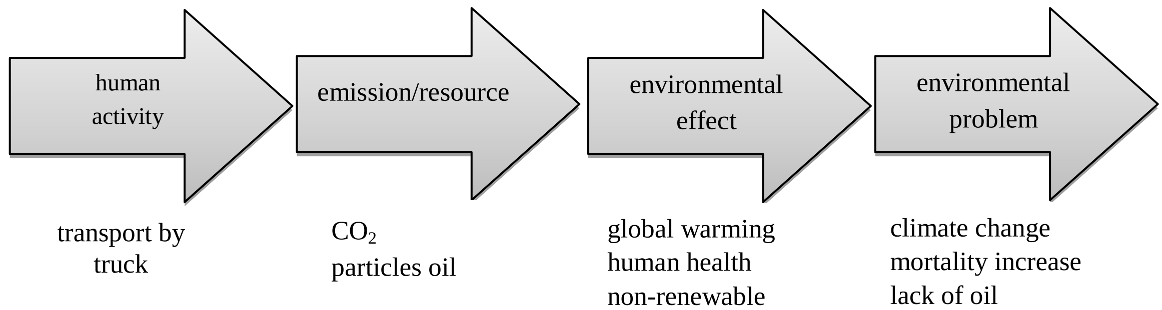

Figure 1 - The chain of events resulting in environmental problems

Examples of such activities can be found through the whole life cycle of a product from raw material extraction, product manufacturing, use of the product to the waste disposal. Examples of emissions generated in transportation by trucks are carbon dioxide, CO_2, and particles, resulting in global warming and deteriorating human health. Increasing use of resources as oil decreases non-renewable sources. The effects mentioned cause climate change and increased mortality. The increasing use of oil also may lead to shortage, due to insufficient supply.This exploitation has resulted in a high standard of living in the industrialised countries. With this high standard follows a high consumption of products leading to increased consumption of resources and energy[3].

Materials play a crucial role in technology-economy-environment scheme (Fig.1).A material that is utilized in some end product and then discarded passes throughseveral stages or phases.These stages sometimes are termed the “total materials cycle“ or just “materials cycle” and representsthe life circuit of a material. Raw materials are extracted from their natural earthly habitats bymining, drilling, harvesting, etc. These raw materials are then purified, refined, and converted into bulk forms such as metals, cements, petroleum, rubber, fibers, etc. Further synthesis and processing results in products that are what may be termed‘‘engineered materials’’and examples include metal alloys, ceramic powders, glass,plastics, composites, semiconductors, elastomers. Next, these engineered materialsare further shaped, treated, and assembled into products, devices, and appliancesthat are ready for the consumer - this constitutes the "product design, manufacture,assembly“ stage. The consumer purchases these products and uses them (the “applications” stage) until they wear out or become obsolete. At this time the product constituents may either be recycled/reused or disposed of as waste, normally being either incinerated or dumped as solid waste in municipal land-fills - as such, they return to the earth and complete the materials cycle [4].

Thus, this materials cycle (Figure 2) is really a system that involves interaction sand exchanges among materials, energy, and the environment.

One approach that is being implemented by industry to improve the environmental performance of products is termed *life cycle analysis/assessment.* With this approach to product design, consideration is given to the environmental assessment of the product, from material extraction to product manufacture to product use, and, finally, to recycling and disposal. Some times this approach isalso labeled as “green design“. One important phase of this approach is to quantifythe various inputs (e.g., materials and energy) and outputs (e.g., wastes) for eachphase of the life cycle. In addition, an assessment is conducted relative to the impact on both global and local environments in terms of the effects on the ecology, human health, and resource reserves [5].

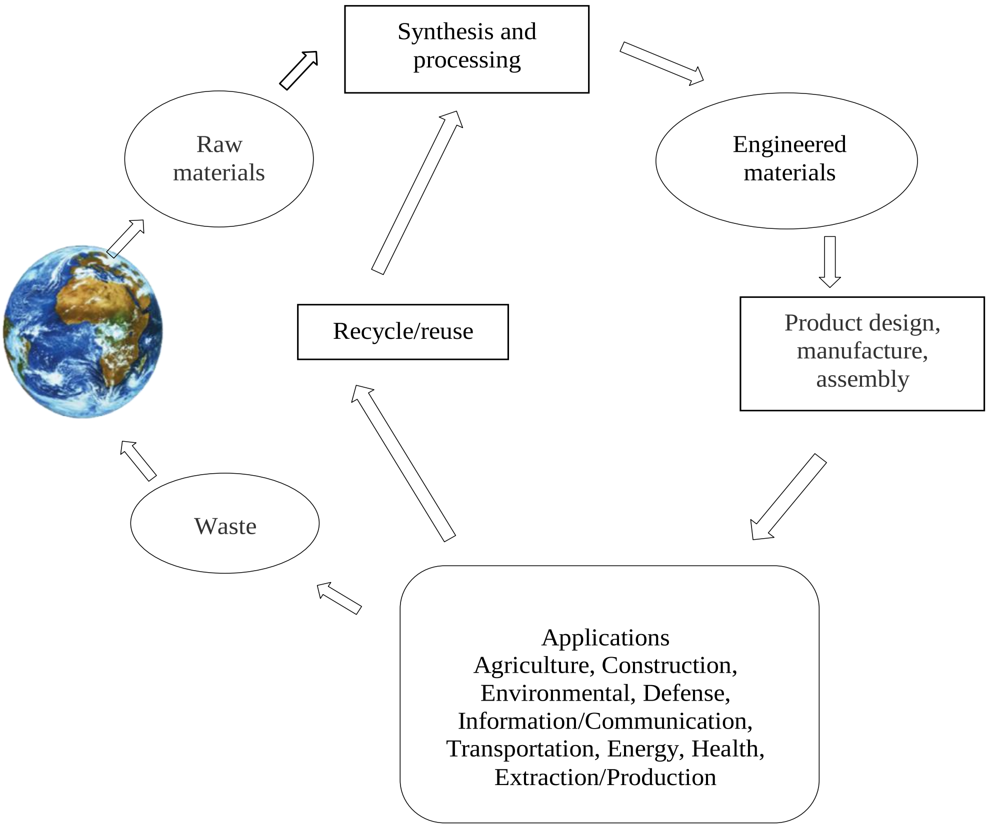

Figure 2 - Schematic representation of the total materials cycle

3. SELECTING MATERIALS FOR ECO-DESIGN

For selection of materials in environmentally responsible design we must first ask: which phase of the life cycle of the product under consideration makes the largest impact on the environment? If material production consumes more energy than the other phases of life, it becomes the first target. The energy required to shape a material is usually much less than that to create it in the first place. Certainly it is important to save energy in production. But high priority often attaches to the local impact of emissions and toxic waste during manufacture and this depends crucially on local circumstances. Clean manufacture is the answer here. The eco-impact of the use phase of energy - using products depends on mechanical, thermal and electrical efficiencies; it is minimized by maximizing these [6].

The environmental consequences of the final phase of product life have many aspects or requirements which are summarized in the following guidelines:

- Toxicity - it means that avoiding toxic materials such as heavy metals and organometallic compounds is good because they in landfill, cause long term contamination of soil and groundwater.
- Potential of recycling - it means examination the using of materials that cannot be recycled, since recycling can save both material and energy and to minimize recycling of materials for which this is possible.
- Controlled combustion - when recycling is impractical the best way is to recover energy by controlled combustion.
- Biodegradability - it means the using of materials that are biodegradable or photo - degradable, although these are ineffectual in landfill because the anaerobic conditions within them inhibit rather than promote degradation.

Rational selection of materials to meet environmental objectives starts by identifying the phase of product life that causes greatest concern: the material production, the product manufacture, the product use or the product disposal. Dealing with all of these requires data not only for the obvious eco-attributes (energy, CO_2 and other emissions, toxicity, ability to be recycled, and the like) but also data for mechanical, thermal, electrical and chemical properties. Thus, if material production is the phase of concern, selection is based on minimizing the embodied energy or the associated emissions (CO_2 production, for example). But if it is the use phase that is of concern, selection is based on other constraints on stiffness, strength, cost, etc.

4. METHODS OF END OF LIFE TREATMENT: STATE OF THE ART

The methods are divided into the following groups: 1. reuse; 2. mechanical material recycling; 3. energy recovery; 4. material recycling and energy or chemical recovery.

Important stages in the materials cycle where materials science and engineeringplays a significant role are recycling and disposal. The issues of recyclability and disposability are important when new materials are being designed and synthesized. Further more, during the materials selection process, the ultimate disposition of the materials employed should be an important criterion. From an environmental perspective, the ideal material should be either totally recyclable or completely biodegradable. Recyclable means that a material, after having completed its life cycle in one component, could be reprocessed, could reenter the materials cycle, and could be reused in another component - a process that could be repeated an indefinite number of times. By completely biodegradable, we mean that, by interactions with the environment (natural chemicals, microorganisms, oxygen, heat, sunlight, etc.), the material deteriorates and returns to virtually the same state in which it existed prior to the initial processing. Engineering materialsexhibit varying degrees of recyclability and biodegradability.

Preparing for the future end of life treatment is important for product manufacturers, due to the increased environmental demands (based on legislation) and common awareness. This is especially important for products containing composite materials since these materials commonly are thought not to be recyclable because they are multiphase in nature. The two or more phases/materials that constitute the composite are normally intermixed on a very fine scale and consequently, complete phase/material separation is virtually impossible, and recycling procedures that require material separation are impractical [7].

The model presented in Figure 3 starts with the composite waste.

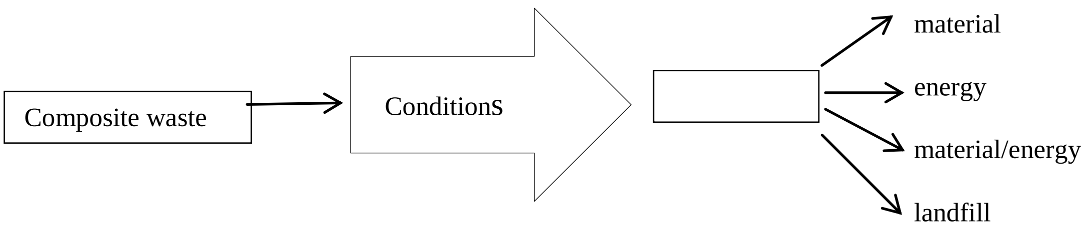

Figure 3 - A model for treatment of composite waste

Dependent on the disposal options chosen a number of processes are used to obtain material, energy, material/energy or to decide on landfill. These processes are identified by their process properties. The treatment conditions are set by the required processes through their process properties, which are coupled to information about the waste, the waste properties.

For example, process properties, which we need to know in order to accomplish a cutting process, are capacity, size of end of life product, cutting edge material/hardness etc. These properties need to be correlated to the waste properties including information on type of material, size and metallic inserts etc. [8].

5. CONCLUSION

Because of increasing environmental demands, especially on dealing with products end of life phase, product manufacturers and designers must consider the future disposal of their products. For conventional materials like steel and aluminium well-functioning recycling methods exists. This is not the case for structures of composites, which are used more extensively. The composites consist of a mixture of several types of materials on macro level and they cannot be regarded as homogenous as the steel materials. These circumstances complicate the possibilities to form a well-organized system for waste handling. Several techniques do exist but they are not yet commercially available. The current disposal methods of composites are landfill and incineration. Many investigations have pointed out recycling of composite materials as the best alternative considering environmental effects. Since recycling composites is a complicated process, especially recycling polymer composite it is important to acquire comprehensive information about the constituents of these materials.

REFERENCES

[1] Henshaw, J. M., Han, W., Owens, A. D. (1996) “An Overview of Recycling Issues for Composite Materials”, Journal of Thermoplastic Composite Materials, Vol. 9, pp. 5-20.

[2] Heusing, D. (ed) (2005)”Environmental assessment and waste management”, Special issue, Journal of Cleaner Production, Vol 13, No 3.

[3] Keolean, G.A., Kar, K.(2003)”Elucidating complex design and management tradeoffs through life cycle design: air intake manifold demonstration project”, Journal of Cleaner Production 11, pp. 61-77.

[4] Callister, W.D (2001) “Fundamentals of Materials Science and Engineering”, John Wiley & Sons, New York, pp. 368-376.

[5] Marsh, G. (2001) “Facing up to the recycling challenge”, Reinforced plastics, Vol. 45, no. 6, pp.22-26.

[6] Mayes, J. S. (2005) “Recycling of fibre-reinforced plastics”, JEC – Composites, no 17.

[7] Baldwin J.S. , Allen P. M., Winder B., Ridgway K. (2005)“ Modelling manufacturing evolution: thoughts on sustainable industrial development”, Journal of Cleaner Production, vol. 13, pp. 887-902.

[8] AllenbyB.(2004)“Clean production in context: an information infrastructure perspective”, Journal of Cleaner Production, Vol. 12, pp. 833-839.

ИЗВОД

ПИТАЊА ЗАШТИТЕ ЖИВОТНЕ СРЕДИНЕ У МАТЕРИЈАЛИМА НАУКА И ИНЖЕЊЕРСТВО

Индустријски инжењеринг троши материјале и зависи од сталног снабдевања. Повећање броја становника и животног стандарда проузрокује да потрошња расте - нешто што се не може заувек уради. Проналажење начина да се користе материјали ефикасније је предуслов за одрживу будућност. Недавна глобална пажња о питањима и изазовима одрживог развоја присиљава индустрије да спроведе самопроцене и да идентификују где они стоје у оквиру одрживости, и што је још важније, да се идентификују могућности, стратегије и технологије које подржавају постизање овог циља. Дизајн за одрживост животне средине је дугорочан и окренут на поглед адаптације на живот који задовољава садашње потребе без угрожавања потреба будућих генерација.

Композитни материјал је група материјала који још нису стекли исту количину коришћења као метални материјали. Пошто се композити састоје од мешавине неколико врста материјала на макро нивоу, они се не могу сматрати хомогеним као челични материјали. Обе ове околности компликују могућности да формирају добро организован систем за отпадом. Повећано коришћење композита у индустрији ће створити континуирано више отпада који ће се руковати у будућности.

Такође, за ову врсту материјала, неколико прописа врше притисак на произвођаче да размотре третман отпада. Примери су забрана бацања на депоније, одговорности произвођача за специфичне групе производа и напослетку порези на спаљивање отпада. Сви ови прописи имају за циљ материјалну рециклажу, због смањеног утицаја на животну средину. Заједничко мишљење је да ће рециклажа композитних материјала бити посебно тешка или чак и не могућа. Главна алтернатива данас за руковање отпадом композитних материјала је депонија, али и спаљивање отпада је алтернатива. Да би се одговорило на еколошке свести у друштву и прописима, компаније захтевају нове методе за одлагање отпада.

***Кључне речи**: еколошки ефекти, еко-дизајн, композити, отпада.*

Рад примљен: 10.12.2012.

Оригинални научни рад