Article Review

Sustainable Development by Green Engineering Materials

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Abstract

As concerns about population growth, global warming, resource scarcity, globalization, and environmental degradation have increased, it has become apparent that engineering materials design must be engaged more effectively to advance the goal of sustainability. This will require a new develop materials that incorporates sustainability factors as explicit performance criteria. Sustainable development is integrity of multi discipline concept combining, environment, and ecological, social and economic aspects to construct a livable human living system. The sustainable development can be support through the development of green engineering materials. Green engineering materials offers a unique characteristic and properties including abundant in nature, less toxic, economically affordable and versatility in term of physical and chemical properties. Green engineering materials as metallic materials. Polymer materials, concert materials and etc, can be applied for a numerous field in science and technology applications including for energy, building, automotive, aircraft, urbanism, maritime industries, construction and infrastructures.

Keywords: Green Engineering Materials, Metallic Materials, Polymer Materials, Concert Materials.

1. Introduction

The world faces significant challenges as population and consumption continue to grow while nonrenewable fossil fuels and other raw materials are depleted at ever increasing rates. Green Engineering is a technical approach to address these issues using engineering design and analysis. The scope of green engineering depends upon one's perspective and discipline, but it is broadly defined as minimizing environmental impacts across all life cycle phases in the design and engineering of products, processes, and systems. It is important to realize that Green Engineering is only one possible approach to addressing the larger issue of sustainability which includes environmental, economic, and social aspects [1]. Green Engineering is necessarily interdisciplinary, and therefore, is best considered as a set of concepts which can be applied across engineering disciplines. That said, the discipline of Materials Science and Engineering is a focus area since the design of essentially everything one can imagine requires materials. As such, materials scientists and engineers have a responsibility to design using materials which not only meet design requirements, but also consider the environmental, health, and societal impacts across the life cycle. The life cycle of a product (you can typically interchange "product" with "process" or "system" throughout this discussion) is a key concept for green engineering materials considerations.

The life cycle consists of all the inputs and outputs required from extraction to manufacturing to use, and finally to disposal [1, 2]. For any given product, raw materials are extracted from the earth resulting in depletion of these materials as well as waste, ecosystem disruption, and energy use. Raw materials are then manufactured (refined, purified, mixed, formed, alloyed, chemically reacted, shaped, etc.) to transform them into materials which have desired properties and performance. In this step, energy and chemicals are the primary inputs with solid, liquid, and gaseous outputs to the ground, water, or atmosphere. The use of many products requires energy or fuel as well as additional chemicals or materials for maintenance. Finally, at the end of a product's useful life it is disposed typically by landfill burial or incineration. In some cases, products might be reused, composted, or recycled. Each of these disposal methods carries potential environmental impacts. Transportation also needs to be accounted for within and between life cycle phases [2]. Life Cycle Assessment (LCA) is a powerful analytical tool with many uses in Green Engineering. This formal discipline has specific methodologies and international standards (ISO 14040: 2006 and ISO 14044: 2006) to objectively quantify the environmental impacts of all inputs and outputs for a product. LCA can be used to compare environmental impacts of different products or different life cycle phases of a given product.

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It is important to understand that while the analysis of inputs and outputs as well as their environmental impacts can be quantified objectively using current scientific understand, decisions based on these results necessarily depend on the weighting of various environmental categories and are therefore subjective [1-3].

The benefits to society of implementing green engineering concepts specifically to materials science are significant and include health benefits, improved environmental quality, and cost reductions. Explicitly considering the environment as an initial design constraint along with economic and performance metrics is critical; many significant environmental impacts that would be difficult to remediate can be minimized if considered early.

Moreover, applying green engineering concepts early in the design stage provide benefits which compound throughout the life cycle.

For example, using less mass in a product due to better design will require less raw material extraction, less material manufacturing, less material transport, and less material disposal. In this example which is relevant to almost all products, a seemingly small reduction in material mass can have a significantly larger life cycle environmental benefit especially for high volume products [2-4].

Green engineering concepts for materials should also be applied outside of the design stage in any of the life cycle phases.

Examples of this include substituting materials with similar performance but lower embodied energy, larger natural reserves, less energy-or chemical-intensive extraction or manufacturing, lower toxicity, less maintenance, better recyclability, or longer durability.

Opportunities to incorporate such thinking are all around us using both current technology and innovative new thinking [5].

The transition of standard engineering practices and education to include concepts of green engineering for materials science and engineering will not happen overnight.

Given the potential benefits, however, it is important for materials professionals to start this transition now rather than later.

The process starts by asking some basic questions whenever materials are considered for a product [5-8]:

a) From where and how is the material physically extracted from the environment?
b) What are the energy and chemicals requirements to manufacture the material?
c) What are the inputs/outputs for the use/maintenance of the material over its life cycle?
d) What is the ultimate fate of the material when the product is disposed?

The answers to these basic questions are generally not simple and should lead one to carefully consider the environmental impacts of materials choices.

2. Green and Sustainable Metallic Materials

The growing importance of the consideration and use of sustainable materials depends on the relationship between the renewability of the natural resources and the material products that are generated from them. Renewable resources are considered to belong to the natural environment and are replaced by the natural processes that occur in that environment as part of an ecosystem. Non-renewable resources are natural resources that occur only in a fixed amount or are used up faster than nature can create and replenish them over geological time spans. The risk of depleting a natural resource can make their use less desirable when other, more sustainable, alternatives exist [9].

Metals originate from the naturally occurring solid material, ore. Ore, specifically bauxite is extracted from the Earth's crust through mining. Bauxite is an amorphous clay-like rock that is the primary commercial ore that makes up aluminum. It consists largely of hydrated alumina with varying proportions of iron oxides. From here, the bauxite is processed into alumina/aluminum. The fact that the ores are mined contributes to the misconception that it is a depletion of natural resources. However, metals such as aluminum (Al) and Iron (Fe) are elements and therefore cannot be destroyed or depleted. The Earth's overall resource deposits of metallic elements have not decreased but simply change locations and present themselves in different forms [9, 10]. Aluminum and steel have many product applications, and once these product applications cease to function in their useful existence, not material lifespan in the case of metals, the aluminum and steel can be recycled and reused in the creation of another product. This cycle allows the aluminum and steel to remain a permanently accessible material through recycling. Consequently, each time the aluminum or steel product is recycled into a new product, the properties of the metals are retained. As a result, this cycle can take place an infinite amount of time with little to no change to the inherent properties of the metal [11].

Metal also offers a lightweight, fire resistant, and durable alternative to wood and plastic material applications. Unlike wood, metal is not susceptible to rot, termites, or mold. A metal roof for instance, will last several times longer than a traditional asphalt roof. The roof on the Chrysler Building in New York is nearly 100 years old and has been cleaned only once. It should perform well for at least another century. Zinc roofs in Paris have held up since the Napoleonic era [1, 11]. Constructing with metal comes with the advantage that the majority of fabrication and assembly has to be done off-site thus reducing on-site labor, cycle time, and construction waste. If the construction of a 2,000 square foot residence is framed in steel there will be less than 2% leftover material, all of which can be recycled.

Compared to a house of the same square footage framed in wood, the waste generated would be close to 20%, and all of it would go to a landfill. As far as building materials go, steel is one of the most sustainable. It is not only environmentally conscious but economically strategic in its inherent longevity and durability. Steel is the most recycled material in the world.

More steel is recycled each year than aluminum, paper, glass and plastic combined. Steel is unlike wood and plastic because it is only used and never consumed.

The process that takes place to create steel is arguably worth the energy required, because once the material is produced, it is reused infinitely, thus making it one of the only truly cradle to cradle materials[2,10].

Aluminum is also considered one of the most efficient and sustainable materials. The process of melting Aluminum down to its molten form does not change any properties of the metal.

Therefore, like steel, aluminum can be recycled infinitely. Aluminum is one of the most widely recycled materials and through the recycling process it saves 95% of the energy that it would cost to produce new aluminum [11].Like aluminum and steel, copper is 100% recyclable and there is no diminution in the integrity of the metal regardless of its state either as raw material or a manufactured product. By volume, copper is the third most recycled metal following steel and aluminum [12].

3. Green Polymer Materials Directional Solidification

Go green, go natural! When it comes to polymers, green and natural are not the same. As their name implies, natural polymers (or biopolymers) are polymers that occur naturally or are produced by living organisms (such as cellulose, silk, chitin, protein, DNA). By a wider definition, natural polymers can be man-made out of raw materials that are found in nature [13].

Although natural polymers still amount to less than 1% of the 300 million tons of plastics produced per year, their production is steadily rising. In the U.S., demand for natural polymers has been predicted to expand 6.9 percent annually and rise from $3.3 billion in 2012 to $4.6 billion in 2016.

The natural polymers market is driven by a growing demand for natural polymers with pharmaceutical and medical applications.

Natural polymers also are used in construction and adhesives, food, the food packaging and beverage industries, and cosmetics and toiletries, as well as the paint and inks industries. The market is led by cellulose ethers and also includes starch and fermentation polymers, exudates and vegetable gums, protein-based polymers, and marine polymers [13, 14].

Green polymers, on the other hand, are those produced using green (or sustainable) chemistry, a term that appeared in the 1990s. According to the International Union of Pure and Applied Chemistry (IUPAC) definition, green chemistry relates to the "design of chemical products and processes that reduce or eliminate the use or generation of substances hazardous to humans, animals, plants, and the environment." Thus, green chemistry seeks to reduce and prevent pollution at its source. Natural polymers are usually green [14].

At the beginning of the 21st century, we are experiencing a renaissance of renewable polymers and a major thrust towards the development of bio-based macromolecular materials. There are several reasons for this paradigm shift and for the envisioned transition from petrochemistry to bioeconomy. From the economic point of view, the dwindling oil supply is likely to further boost the oil price, especially in view of the expected surge in worldwide energy demand.

This could drastically impact the cost-effectiveness and competiveness of plastics. Shifting chemical raw material production to renewable resources or coal could safeguard plastics production against this expected new future oil crisis.

Hence, another even more important reason is the growing concerns of consumers regarding global warming, resulting in a surging demand for sustainable and 'green' products.

In addition, a tsunami of environmental legislation and regulations is propelling the development of environmentally friendly products with a low carbon footprint [14, 15].

In the production of polymers, green principles include [13-15]:

- A high content of raw material in the product
- A clean (no-waste) production process
- No use of additional substances such as organic solvents
- High energy efficiency in manufacturing
- Use of renewable resources and renewable energy
- Absence of health and environmental hazards
- High safety standards
- Low carbon footprint
- Controlled product lifecycles with effective waste recycling

In addition, the use of renewable resources for green polymer production should not compete with food production, should not promote intensified farming or deforestation, and should not use transgenic plants or genetically modified bacteria; biodegradable polymers should not produce inhalable spores or nanoparticles.

There are three basic strategies to produce renewable plastics [15, 16]:

a) Using biomass and/or carbon dioxide to produce 'renewable oil' and green monomers for highly resource- and energy-effective polymer manufacturing processes.

b) Through living cells, which are converted into solar-powered chemical reactors, using genetic engineering and biotechnology routes to produce biopolymers and bio-based polymers.
c) By activation and polymerization of carbon dioxide.
Green polymers, renewable polymers, and bioplastics already are more common than you might think. We all know about bioethanol as an emerging biofuel, produced by fermentation of sugar obtained from sugar cane or cellulose. Bioethanol also is a versatile raw biomaterial for producing olefin and diolefin monomers, including ethylene, propylene, and butadiene. In 2010, Braskem in Brazil inaugurated a 200 kiloton/year plant producing green ethylene from sugar cane bioethanol for the production of Green Polyethylene, which is 100% recyclable[13,15].
Using processes that are even more energy-efficient, biomass can be directly converted into renewable coal and oil. Agricultural and forestry wastes already are used to produce renewable monomers. Processes have been developed to convert carbon dioxide into carbon monoxide, methanol, formic acid, and formaldehyde. Vegetable oils can be used to produce biodiesel and glycerol as a byproduct, which can be used to make a variety of monomers such as propane diol, acrylic acid, and even epichlorohydrin for the production of epoxy resins [15, 16]. Carbohydrates, terpenes, proteins, and polyesters are chemically modified and used in polymer processing and applications. Natural fibers provide excellent fiber reinforcement for thermosets and thermoplastics. Microfibrillated cellulose has been used in polymer nanocomposites, including applications in medical implants. Lignin serves as renewable energy source in paper manufacturing, as a filler for cement, and in various polymers and rubbers. Thermoplastic lignin mixed with natural fibers (Arboform) combines the advantages of wood and synthetic thermoplastics. Biohybrids has been using starch as a blend component with polyolefins and compostable polyesters (Ecoflex). Chitosan and polylactic acid have numerous medical applications. Casein is used as a binder and as an adhesive [14-16]. Renewable monomers are already substituting for "oil-made" monomers. The ever-present plastic bottles are just one example. In 2011, Coca-Cola Co. announced a goal to make plastic bottles from 100% bio-based materials. Recyclable PET "PlantBottles," which use up to 30% bio-based monomers, were introduced in 2009, and can still be recycled [16].

4. Green Concrete Materials

Concrete which is made from concrete wastes that are eco-friendly are called as "Green concrete Materials". Green Concrete is a term given to a concrete that has had extra steps taken in the mix design and placement to insure a sustainable structure and a long life cycle with a low maintenance surface. e. g. Energy saving, CO2 emissions, wastewater. "Green concrete" is a revolutionary topic in the history of concrete industry. This was first invented in Denmark in the year 1998 by Dr.WG [2, 17].
Concrete wastes like slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand. The goal of the Centre for Green Concrete is to reduce the environmental impact of concrete. To enable this, new technology is developed. The technology considers all phases of a concrete construction's life cycle, i.e. structural design, specification, manufacturing and maintenance, and it includes all aspects of performance, i.e [17-19].:
- Mechanical properties (strength, shrinkage, creep, static behaviour etc.
- Fire resistance (spalling, heat transfer etc.)
- Workmanship (workability, strength development, curing etc.)
- Durability (corrosion protection, frost, new deterioration mechanisms etc.)
- Thermodynamic properties (input to the other properties)
- Environmental aspects (CO2-emission, energy, recycling etc.)

There are a number of alternative environmental requirements with which green concrete structures must comply [17-19].:
a. CO_2 emissions shall be reduced by at least 30 %.
b. At least 20 % of the concrete shall be residual products used as aggregate.
c. Use of concrete industries own residual products.
d. Use of new types of residual products, previously land filled or disposed of in other ways.
e. CO_2-neutral, waste-derived fuels shall substitute fossil fuels in the cement production by at least 10 %.

In addition to the environmental goals there are a number of environmental intentions. Most important are [18-20]. :
a. To avoid the use of materials which contain substances on the Environmental Protection Agency's list of unwanted materials, not to reduce the recycling ability of green concrete compared with conventional concrete and not to increase the content of hazardous substances in the wastewater from concrete production compared with wastewater from production of existing concrete types.
b. Different concrete types are tested for workability, changes in workability after 30 min., air-content, compressive strength development, E-modulus, heat development, homogeneity, water separation, setting time, density and pumpability. Furthermore, frost testing, chloride penetration and an air void analysis are carried out for the concretes in the aggressive environmental class.

c. The water/cement ratio, water/binder ratio and the chloride content are calculated from the mixing report of the precise mixture proportions and from the chloride content in the different raw materials.
The advantages of green concrete are as below [19,20].:
a. Reduction of the concrete industry's CO2-emmision by 30 %.
b. Increased concrete industry's use of waste products by 20%.
c. NO environmental pollution and sustainable development.
d. Green concrete requires less maintenance and repairs.
e. Green concrete having better workability than conventional concrete.
f. Good thermal resistant and fire resistant.
g. Compressive strength behavior of concrete with water cement ratio is similar to conventional concrete.
h. Flexural strength of green concrete is almost equal to that of conventional concrete.

The limitations of green concrete are as below [19,20].:
a. By using stainless steel, cost of reinforcement increases.
b. Structures constructed with green concrete have comparatively less life than structures with conventional concrete.
c. Split tension of green concrete is less than that of conventional concrete.

5. Conclusions

With increased strain on fossil fuels and petroleum resources and growing markets in the world, the importance of fiscally and environmentally responsible materials has never been higher.
The green engineering materials such as green metallic materials, green polymer materials,… the utilization of principles to reduce or eliminate hazardous substances in the design, manufacture and application of products. Life cycle assessment of the process will be introduced alongside the societal perspective on the use of sustainable engineering materials.
The green engineering materials concepts for materials should also be applied outside of the design stage in any of the life cycle phases. Examples of this include substituting materials with similar performance but lower embodied energy, larger natural reserves, less energy- or chemical-intensive extraction or manufacturing, lower toxicity, less maintenance, better recyclability, or longer durability. It has become apparent that engineering materials design must be engaged more effectively to advance the goal of sustainability.
The sustainable development can be support through the development of green engineering materials.

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