Material Selection for Sustainable Products

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Why the Concern for Sustainable Products?

The development of complex product and services, with finite resources, has stressed our habitat which leads to an increasingly unsustainable life style. These are fundamentally caused by:

- Over-population
- Over-consumption
- Finite resources
- Pollution
- Lack of and/or limited restoration of habitat
- Limited understanding of impact on our habitat and planet by scientists and policymakers

A Case in Point
The Automotive Dilemma

In an effort to ease the task of recycling automobiles, automakers are trying to reduce the number of different types of plastics to just four or five. This will be a daunting engineering task.

Environmental Concerns Rationale for Sustainable Products

- Greenhouse gases
- Ozone layer depletion
- Summer smog
- Winter smog
- Acidification
- Eutrophication
- Toxins in air, water and soil
- Resource depletion
- Waste disposal
- Other problems
  - smell
  - noise
  - landscape degradation
  - radioactivity
  - ....

Sustainable Product
Raw Material Selection - The Challenge

There are a vast number of raw materials in use today for example take plastics.

- Plastics fifty eight families of plastics
- Over one thousand different grades of plastics many are tailored for specific applications.

Sustainable Product
Raw Materials – The Growing List

New types of raw material are being developed all the time as our understanding of molecular structure and our ability to manipulate these structures improves. Increasingly raw materials can be tailored to specific applications. Below is a list of some of the more recent raw material developments:

- metal matrix
- advanced composites
- nano-materials
- specialty polymers
- flexible ceramics and metal “memory metal”

What is Sustainable Product Development?

Sustainable product development is the design and development of products that have a minimal impact on the environment. This requires a holistic perspective that analyzes the total product development and life cycle of a product using analysis (LCA).

Origins of ISO 14001

Issued by the International Organization for Standardization (ISO) this standard was formally adopted in 1996. It is considered a “sister” standard to ISO 9001 the quality control standard. The purpose of ISO 14001 is the creation of an environmental management system (EMS) to systematically support improved environmental performance through pollution prevention.

ISO 14001 - EMS

This international standard encourages organizations to development an environmental management system (EMS) leading to certification. The EMS can provide both the culture and engineering context for sustainable product design and development. The proper procedure of this effort is through the use of life cycle analysis.

LCA Defined

Life cycle analysis is the process of performing an environmental evaluation of a product's development during each stage of its useful life:

- extraction of the raw materials
- refining of raw materials
- fabrication and packaging the final product
- proper reuse, recycling and disposal of the product at the end of its life cycle – product take back

Product take back supports the idea of "cradle to cradle."

Product Take Back

Product take back – is at times a highly contentious issue, particularly in the United States, it is the idea that the company that produces the product is responsible for its disposition at the end of its useful life cycle.

Pre-Market Phase
Design – First Thoughts

- Initial decisions are based on product aesthetic features, functionality, manufacturability, which in turn effect overall life cycle of product based on raw materials/process used for individual components
- Systematic design reviews supported by computer analysis, when necessary, can help evaluate the effects of various design decisions on manufacturing costs and the useful service life of individual components and ultimately the final product. Life cycle testing, number of cycles to failure, is critical to understand various modes of failure and improve overall design and materials selection.

Basic Environmental Considerations

Selection criteria – Design

- ❖ reduce the amount of raw materials
- ❖ reduce the number of components
- ❖ reduce the products energy requirements
- ❖ increase the useful life cycle
- ❖ maximize the use of renewable and recyclable materials
- ❖ assess and minimize the environmental impact over the entire life cycle of the product

Enabling Technologies

Selection criteria – Design

- reduce the amount of raw materials
- Finite element analysis (FEA)
- reduce the number of components
- Design for Manufacturing and Assembly (DFMA)
- Modeling via Rapid Prototyping
- reduce the products energy requirements
- Thermal Analysis
- increase the useful life cycle
- Life cycle testing (C/S curves)
- Mode of Failure Analysis
- maximize the use of renewable and recyclable materials
- assess and minimize the environmental impact over the entire life cycle of the product

Environmental Protocols Motorola

- ***Motorola Toxicity Index*** — identifies each chemical used in a product, weights each chemical by toxicity, develops simple aggregate measure of toxicity of a product
- ***Green Design Advisor*** — design tool for designing in recycle-ability and designing out toxicity
- ***W 18 Specifications*** — electronic list of banned substances and substances that can only be used below certain concentration levels

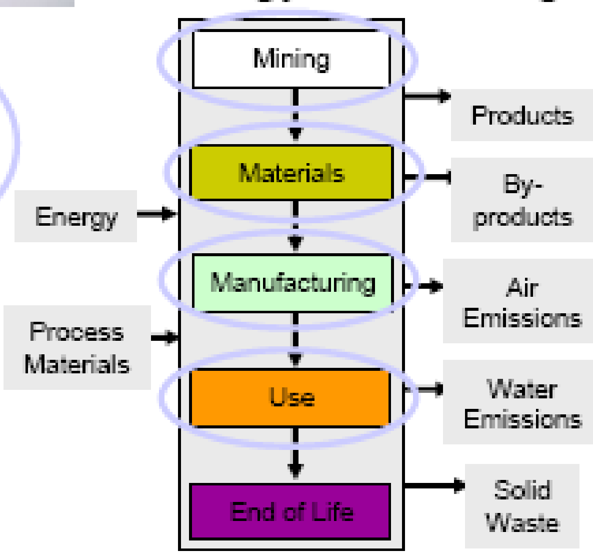
Case Study: Mobile Phone Project

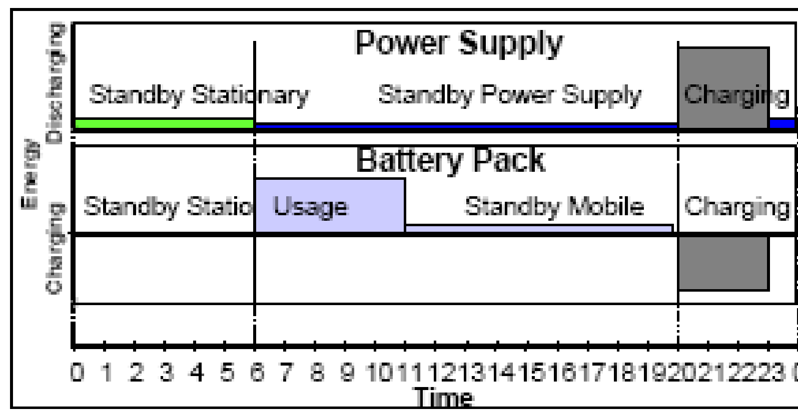
Focus of Environmental Assessment Study

Material Toxicity:
- Material inherent toxicity
- Assessed by the Motorola Toxicity Index

Energy Use:
- Energy used for materials
- Energy used for manufacturing of components and product
- Energy used during use phase (charging, standby charger)

Life cycle phases studied





Component Analysis

Exercise Number 4

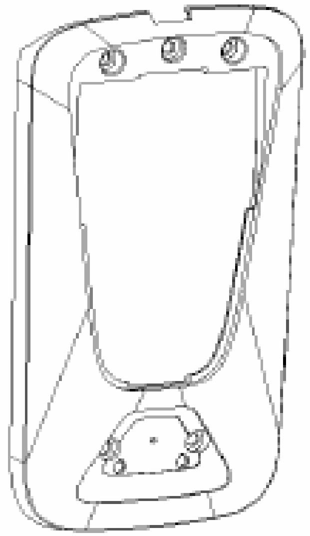
Complete a Compliance Connect W18 Disclosure for the Assembly below

Assembly Structure

Part	qty	Supplier part number	Part weight	Rev #	Rev date
0185000F01 - Bought assembly		xxxxx12	12.45	12	14-Jul-04
1585000F01 - painted housing	1	xxxxx13	10.7	6	14-Jul-04
0285000F01 - threaded insert	5	xxxxx14	0.35	1	14-Jul-02

Threaded Insert Material
300 Series Stainless Steel

Plastic Housing Material
ABS - Black
Paint - Acrylic Polyester



MOTOROLA

intelligence everywhere

Exercise Number 4

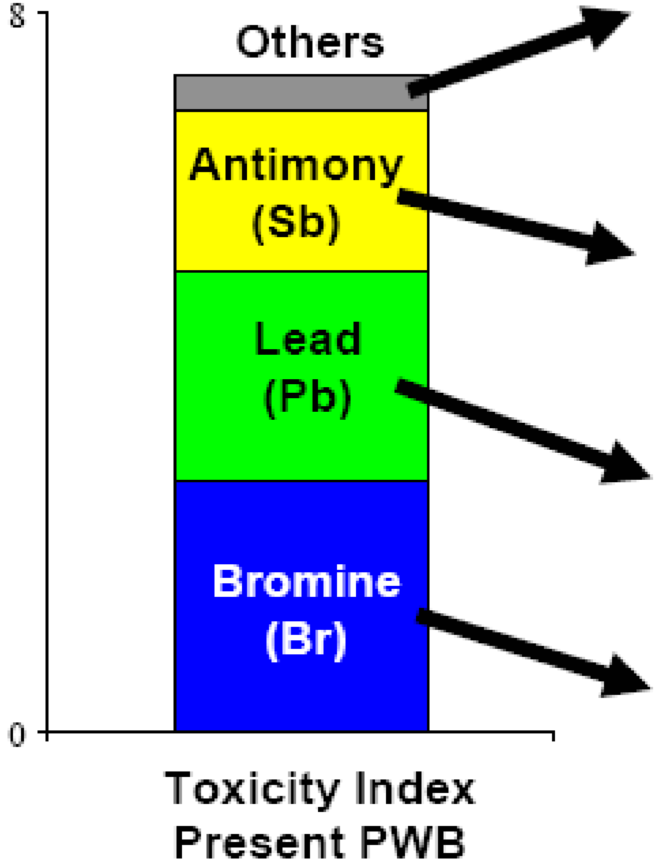
INSERT Material

Manufacturer	Material	Grams	Substances	CAS Number	% in Material	
Penn Engineering and Manufacturing	300 Series Stainless Steel	0.35	Iron		58.25	
			Chromium	7440-47-3	24.75	
			Molybdenum	7439-98-7	2.50	
			Nickel		12.50	
			Manganese	7439-96-5	2.00	100.00
	Finished part weight	0.35	grams			

HOUSING Material

GE	Material	Grams	Substances	CAS Number	% in Material	
	ABS - BLACK	10.7	ABS	9003-56-9	100.00	
						100.00
Nexium	Metalic Paint	0.15	1-mothoxy-2-propyl Acetate	108-65-6	25.000	
			2-Butoxyethyl Acetate	112-07-2	4.000	
			N-Butyl Acetate	123-86-4	55.400	
			Xylenes	1330-20-7	10.100	
			Carbon Black	1333-86-4	2.600	
			Aluminum Powder	7429-90-5	2.900	100.000
	Finished sub-part weight	10.85	grams			

Results: Material Toxicity (PWB)



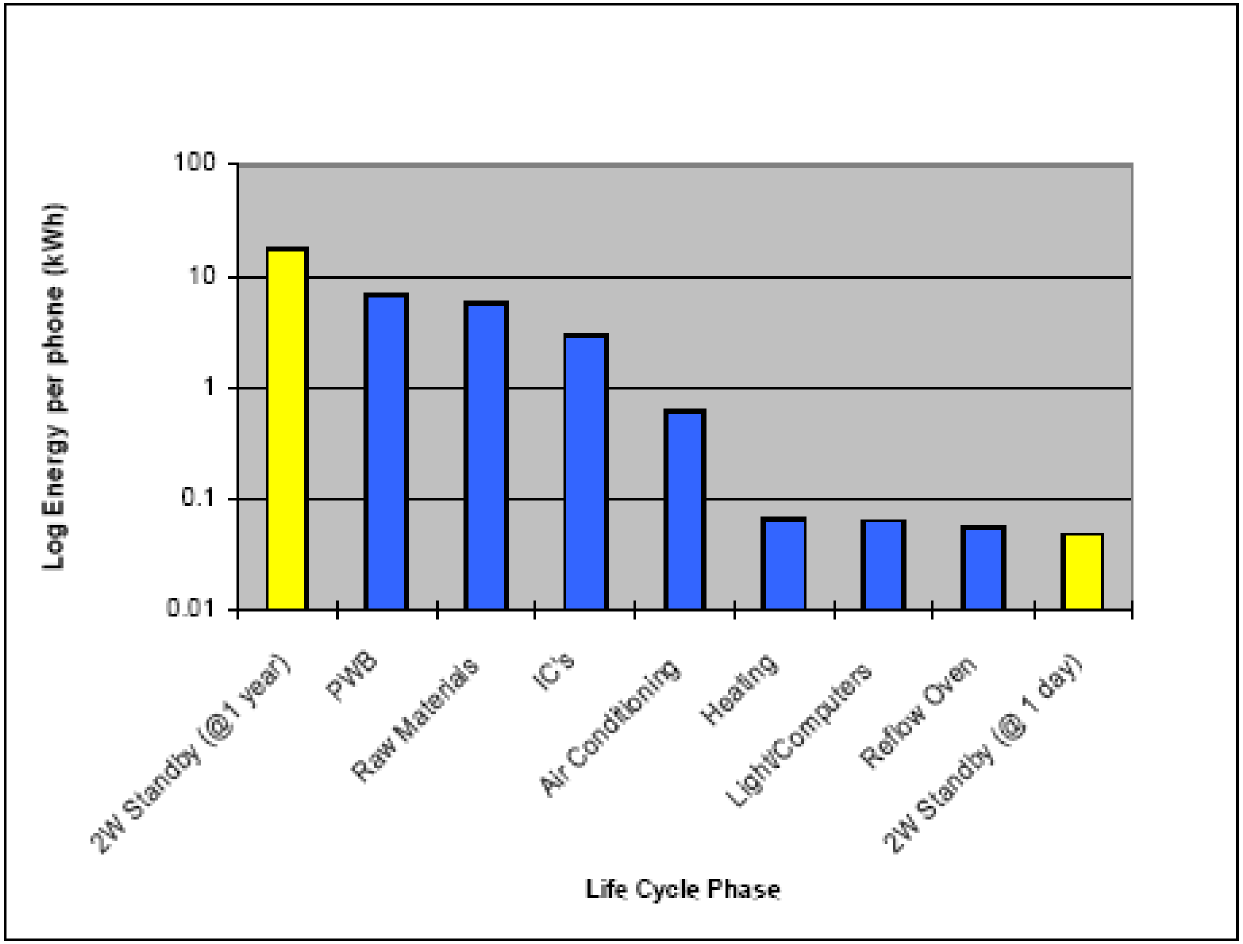
Others: e.g. Beryllium, trace materials

Antimony: Flame retardant synergist in PWB and components

Lead: Part of the solder and component finish

Bromine: Flame retardant in PWBs and components

Results: Energy in Life Cycle



- High energy use for raw materials
- High energy use for purchased components
- Use phase dominates due to:
  - Standby of the charger
  - Losses of the charger

Environmentally Improved Mobile Phone

Motorola's Personal Communications Sector and Swisscom showcased the world's first ecologically improved mobile phone prototype at Orbit/Comdex show in Switzerland.

The prototype, a Motorola V.2288, has the following features:

- WAP-enabled
- integrated FM radio
- lead-free solder
- bromine-free printed wiring board
- housing of recycled plastic
- energy-efficient charger

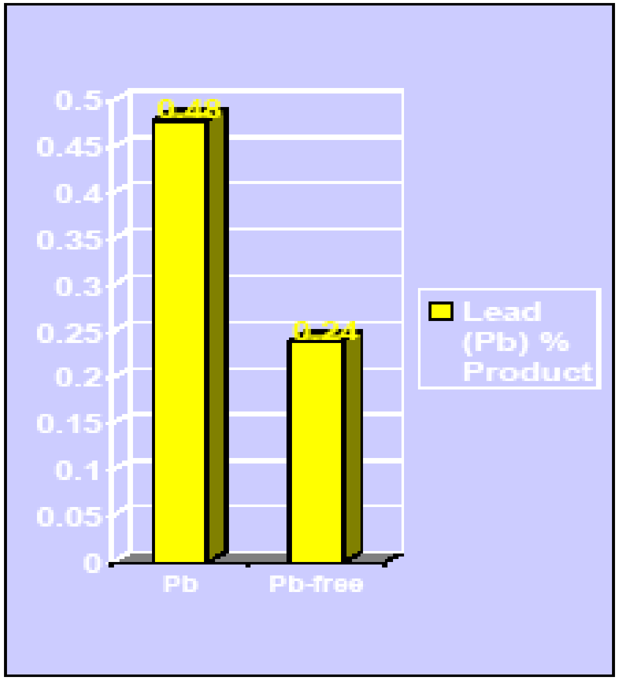
This innovative prototype was developed by Motorola implementing findings from ecological research conducted by Swisscom and demonstrates Motorola's superior technological capabilities.

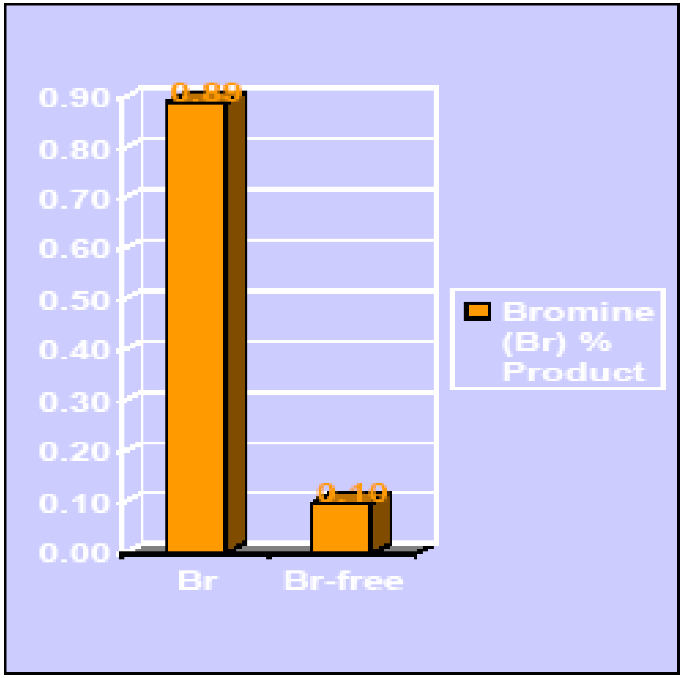
Lead (Pb) and Bromine (Br) Reduction

- Lead-Free solder was used on the PWB
- No attempt was made to obtain lead free components
- ↓ The Lead content of the <u>entire product</u> was reduced by 51%

A Bromine (Br) and Antimony (Sb) free PWB was used

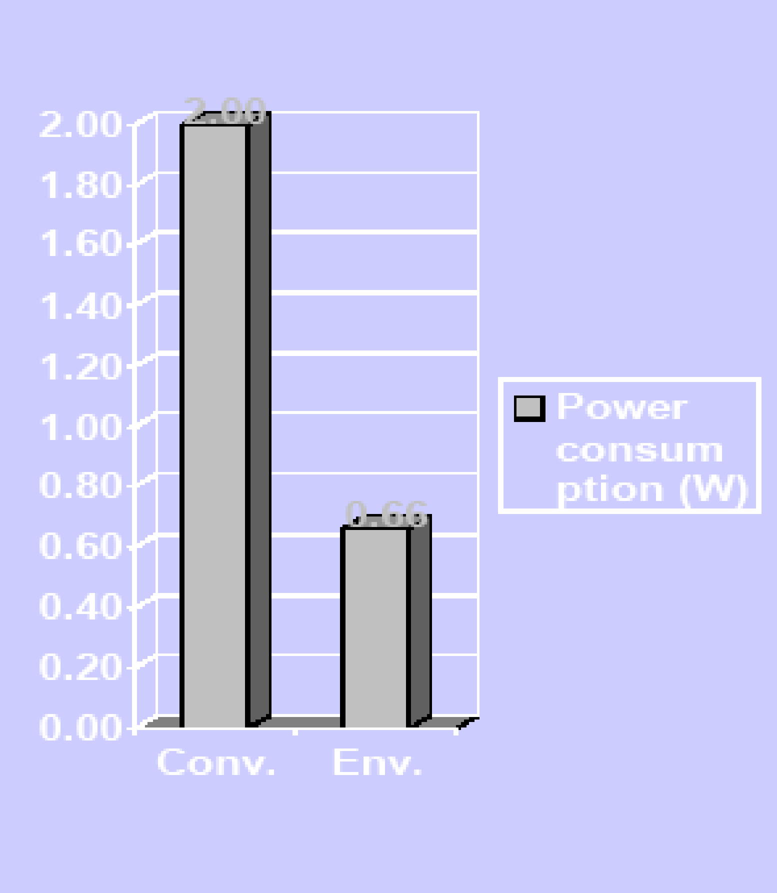
↓ The Bromine content of the <u>entire product</u> was reduced by 89%





Energy Efficient Charger

- New energy efficient charger reduces no-load energy loss (stand-by)
- Charger meets EU voluntary agreement of 2002
- The no-load energy loss was reduced from 2 W to 0.66 W => 66% reduction



Recycled Plastic Housing

Post Production Waste

Post Industrial Waste

Post Consumer Waste

Waste stream convergence

Processing plastic waste into specified regrind

Processing of specified regrind into quality assured base recyclate

Production of **quality assured recyclate** (pellets) consisting of base recyclate and virgin material = **“Recycled“ grades**

Recycled Content Housing

- PC+ABS recyclate blend
- comparable to lower grade virgin resin properties
- slightly lower toughness for comparable heat resistance

Implementation in Volume

Motorola iDEN i85s

- Halogen Reduced, Bromine Free, PWB Technology
- Lead Free Solder Assembly Technology

- More than 1.3 million units shipped with Bromine-free PWB to date
- More than 100'000 units shipped with lead-free solder paste to date.

- Energy efficient charger is part of standard package for certain Motorola mobile phones

Motorola Mid-Rate Travel Charger

Motorola's Website WEEE Statement

- **E-waste and product take-back**
- A new law in most European Union countries in 2005, the Waste Electrical and Electronic Equipment (WEEE) directive, affects end-of-life recycling for electrical and electronic equipment.
- ***Motorola implemented a waste take-back system according to the directive requirements, launching programs in many countries that already surpass minimum compliance regulations in several European Union member states.***
- http://www.motorola.com/content.jsp?globalObjectId=1686-3288-5399

First Environmentally Preferred Product

- **EcoMoto: Environmentally Preferred Mobile Phone**
  Motorola's C350 EPP is the first in a series of environment-friendly mobile phones.
- Copper is substituted for lead in the solder paste, and the circuit board is bromine free.
- The phone also uses recycled resins and water-based paint vs. metallic.
- These steps increase the recyclability of the phone from 50 to 71 percent.

Material Selection Criteria

Traditional Considerations:
Market and end-user demands which drives:

- Design
- Product Function
- Structural Requirements
- Thermal Requirements
- Environmental Durability Requirement
- Aesthetics
- Individual Component Cost
- Production Method
- Cycle Time
- Final Product Cost

Material Selection Criteria

Sustainability Considerations:

- Useful life cycle
- Overall Energy footprint
- Module Design
- Design for Reusability
- Design for Disassembly
- Separation Techniques
- Ease of reuse and or recycling at the component or sub-assembly level.

Raw Material Types

- Metals
- Ceramics
- Synthetic Polymers
- Elastomers
- Natural Organic Materials e.g. wood
- Composites

Metal Characteristics

Metals – steel, aluminum, titanium

Advantages:

- durable and strong
- can be plastics formed
- inexpensive
- high cost of machining
- mature understanding of design and performance issues

Disadvantages:

- low strength to weight ratio
- easily corrodes
- limited material innovations

Sustainability:

- mature reclamation infrastructure
- separation technology is mature
- easily re-melting

Ceramics Characteristics

Ceramics – Porcelain (clay), mineral glass, metallic oxides

Advantages:

- non-toxic
- hard and durable
- corrosive resistant
- high temperature
- mature understanding of design and performance issues

Disadvantages:

- brittle
- difficult to machine
- limited material innovations

Sustainability:

- limited reclamation infrastructure
- separation technology is not mature
- pulverizing
- low toxicity

Polymer Thermoplastic Characteristics

Polymers (thermoplastic) – acrylic, polypropylene,

Advantages:

- light
- tough
- easily molded, formed, shaped, machined
- inexpensive
- mature understanding of design and performance issues
- highly corrosive resistant

Disadvantages:

- low strength to weight ratio
- constant material innovations
- limited useful temperature range

Sustainability:

- maturing reclamation infrastructure
- separation technology is maturing
- easily re-melting

Polymer Thermoset Characteristics

Polymers (thermoset) – epoxy, polyurethane,

Advantages:

- light
- very tough
- easily molded, formed, shaped, machined
- inexpensive
- mature understanding of design and performance issues
- highly corrosive resistant and high temperature use
- high level of innovation

Disadvantages:

- low strength to weight ratio
- toxic when burnt

Sustainability:

- poor reclamation infrastructure
- separation technology is not mature
- difficult to recycle – pulverize or burn

Elatomer Characteristics

Elastomer – isoprene, neoprene, styrene butadiene rubber

Advantages:

- light
- extremely tough – impact resistance
- easily molded, formed, shaped
- inexpensive
- mature understanding of design and performance issues
- highly corrosive resistant
- constant material innovations

Disadvantages:

- low strength to weight ratio
- limited useful temperature range

Sustainability:

- limited reclamation infrastructure
- separation technology is not maturing
- usually cannot be re-melting for reuse e.g. tires

Natural Organic Characteristics

Metals – wood, bamboo, cotton

Advantages:

- renewable
- light
- durable and strong
- can be machined or woven
- inexpensive
- mature understanding of design and performance issues

Disadvantages:

- low to high strength to weight ratio
- increased material innovations

Sustainability:

- decomposes easily
- can be burnt

Composites Characteristics

Composites: graphite-epoxy, polyester-fiberglass

Advantages:

- extremely high strength to weight ratio
- highly corrosive resistant
- constant material innovations
- maturing understanding of design and performance issues

Disadvantages:

- difficult to predict final properties during processing
- expensive to produce

Sustainability:

- no reclamation infrastructure
- separation technology is not mature
- separation is extremely difficult – thermoset resins

Materials Selection Tools

- Okala Ecodesign (Ecology considerations)
- Cambridge Materials Selector Software

Closing Remarks

There is a vast array of raw materials to choose from and this list keep growing. Materials selection will always be a compromise of competing considerations. Therefore it important to remember some key points:

- all materials are recyclable some are more difficult than others to recycle
- reuse and recycling of raw materials minimizes energy consumption, pollution, and human injury
- design for disassembly must be an integral design consideration
- material selection must include a complex set of considerations
- proper eco-labeling is helpful e.g. recycling codes

Conclusion

There is a vast array of raw materials to choose from and the list keep growing. Regardless, it is important that designers and the public begin to understand that material selection must, beyond functional consideration, be done to minimize the impact on the environment. Please visit the MatEd website at: www.materialseducation.org/

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