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DESIGNER MATERIALS: AN INTRODUCTION TO THE APPLICATION OF MATERIALS SCIENCE AND TECHNOLOGY

У статті представлений короткий огляд загальних класифікацій конструкційних матеріалів, їхніх властивостей та використання на виробництві. Автор розглядає форми матеріалів, описує їхні властивості та вплив на навколишнє середовище. Він також виділяє наступні види технологій, такі як: телекомунікаційні, медичні, авіаційно-космічні, транспортні, технології спорту і відпочинку та описує їхні головні особливості. У статті здійснена систематизація видів конструкційних матеріалів за п'ятьма групами, а саме: природні полімери, синтетичні полімери, метали та їхні сплави, природні матеріали та суміші.

Ключові слова: *технологія, конструкційні матеріали, проектування, виробництво.*

В статье представлен краткий обзор основных классификаций конструкционных материалов, их свойств, использование на производстве. Автор рассматривает формы, особенности, влияние материалов на окружающую среду. Он также выделяет следующие виды технологий, такие как: телекоммуникационные, медицинские, авиационно-космические, транспортные, технологии спорта и отдыха и описывает их особенности. В статье осуществлена систематизация основных видов конструкционных материалов по пяти группам, а именно: природные полимеры, синтетические полимеры, металлы и их сплавы, природные материалы, смеси.

Ключевые слова: *технология, конструкционные материалы, проектирование, производство.*

The article is an overview of the common classifications and features of engineered materials and their use in the manufacturing. The author presents properties of materials, forms of materials, influence of materials. He also gives types of technology: telecommunication technology, medical technology, aerospace technology, recreation and sports technology, transportation technology and describes their main peculiarities. The article gives the systematization of five basic

kinds of engineering materials such as natural polymers, synthetic polymers, metals and metal alloys, earth materials, composites.
Key words: *technology, engineered materials, design, manufacturing.*

For the past six years, I have taught my students a unit of instruction titled «Designer Materials», an introductory study of materials and materials science containing many cross-curricular applications to the study of science. This article, and its accompanying activities, will provide you with an overview of the common classifications and properties of engineered materials, describing, too, how designers apply these materials.

Materials technology is an exciting world where every day new materials are designed. In the first unit that I teach on materials and their properties, students learn how to describe and classify earth, metal, wood, plastic, and composite materials and their basic properties. I also teach students how to measure and safely use basic tools.

To conclude and reinforce the content of this unit, I challenge my students to design and construct both a prototype and a final project that uses some – or all – of these engineering materials. Please note that since this is an introductory experience, this is the first time that many students have ever learned in a hands-on, minds-on environment!

The end result is an introductory experience in which sixth graders successfully learn about technology and apply materials science. For their final assignment, students design, construct, and evaluate a simple laboratory materials project.

The search for new materials has occurred since the stone age. Humans applied such materials as stone, bone, ivory, and wood to construct early tools.

These early tools helped humans develop an understanding of materials and tools. The search for new materials led to many of the developments we take for granted today.

Historically speaking, the study of technology may be described as the study of the knowledge and development of materials and their technical applications to satisfy human needs. The stone age; metal age; agricultural, industrial, space, and information ages exemplify how the history of technology can be described through materials and technology.

Properties of Materials. The study of both engineering and materials have led to a great variety of new and better products. New materials are investigated to learn about or improve their mechanical, chemical, electrical, magnetic, thermal, and optical properties.

Basic materials engineering investigates six types of property: mechanical, chemical, electrical, magnetic, thermal, and optical.

Mechanical properties may be thought of as a material's strength to resist various stresses.

Chemical properties describe a material's ability to resist either chemical degredation or corrosion.

Electrical properties determine a material's usefulness as either a conductor or insulator. Some materials' electrical properties allow them to act as semiconductors or even superconductors.

Magnetic properties tell how well a material can be magnetized or hold a magnetic field.

Thermal capabilities describe how materials react to heat.

Optical properties reveal how a material reacts with light.

Studying these materials has led to the applications that we use every day, from eyeglasses to aircraft, from computers to kitchen appliances. The applications of materials science and engineering surround us!

Forms of Materials. Materials are also described as either organic or inorganic.

Organic materials were once-living materials, such as trees.

Inorganic materials include nonliving ores, such as metals.

All materials exist in one of three physical states – as solids, liquids, or gases. Typically, the solid materials used in production are called *engineering materials*. Materials obtained in a liquid or gas state are called *non-engineering materials*.

A world of materials surrounds your students. Designers apply these materials to create products that meet human needs and wants.

For example, applications in which designers apply advanced engineered materials include sports, recreation, toys, packaging, business, industry, transportation, space exploration, telecommunications, and medicine. The selection and application of materials science affects nearly every aspect of our daily life.

Influence of Materials. Few of your students have probably ever considered that the application of materials relates to how the world around them is formed and how it will evolve. Materials science is used in the design of devices for biotechnology, communications, sporting goods, manufacturing, construction, and transportation.

Take the future of 2″ x 4″ framing as applied to residential construction as a simple example. As the quality and quantity of natural resources decline, wood may be surpassed as the material of choice in residential construction projects.

Such engineered materials as metal studs and /or composite studs made from recycled materials have many advantages over traditional stick construction. Engineered materials can be designed to be stronger, pest- and water-resistant, and so forth.

Furthermore, many engineered materials can be designed to resist cups, bows, and twists. So, applying engineered materials in residential construction framing may someday become cheaper than doing the same in natural wood. Future availability and cost of quality wood products may also affect the techniques and designs used to construct homes.

Recreation and Sports Technology. In such applications as recreation and sports equipment, designers employ engineered materials to enable users to achieve higher performance levels. A variety of sporting goods use such exotic materials as titanium, composites, metal alloys, and synthetic polymers.

Bicycles, golf clubs, skates, hockey sticks, skate boards, fishing rods, skis, tennis rackets, and athletic shoes – all common items – all feature the latest in materials technology. Consumers often select products to purchase based upon the materials used to make the item.

For example, while many golfers purchase titanium-alloyed clubs, the selection and purchase of exotic materials will never substitute for natural ability and practice! Another example that students identify with is bicycles.

At their local bike store students can purchase bikes with frames made of cromoly steel, titanium, carbon fiber, and aluminum. Because the advantages and disadvantages of these materials are not readily evident, you have to either research the pluses and minuses yourself or be able to rely on the opinions of a knowledgeable and honest sales associate who can direct you toward a bicycle that will fulfill your needs instead of his pocketbook.

For the privilege of enjoying a weight reduction of 1 or 2 kilograms, the difference between a bicycle that incorporates a frame made from titanium or carbon fiber versus cromoly may be nearly$3,500! For the majority of bikers – your students included – the difference in weight will not readily benefit their biking abilities or needs.

Telecommunication Technology. Fiber optics transmit data across oceans, continents, and space. Transmitting such information as audio, video, voice, graphics, and text at high speeds, lasers and light-emitting diodes communicatethrough the global telecommunications network at speeds approaching one billion pulses of light per second.

Semiconductive materials act as both conductors and insulators, and are used to produce transistors; therefore they permeate nearly all forms of electronic equipment. Advances in semiconductor research and applications all actively affect computers, consumer products, manufacturing, communications equipment, automobiles, and so forth. The application of silicon accounts for nearly every advance made in developing the information age.

Medical Technology. Advances in materials technology continually affect medical applications. Plastics used throughout the doctor’s office include syringes, bandages, tubing, and bags.

In biotechnology, such applications as artificial limbs, hips, and knees are almost common place. Research in synthetic polymers and semiconductors have even led to applications in such artificial organs as the artificial heart.

Materials with special properties are applied to the medical profession’s instrumentation. Medical instruments used in routine diagnosis of injuries include Magnetic Resonance Imaging (MRI) and X-ray radiography.

The MRI, commonly used to explore tissues without exploratory surgery, employs electromagnets and superconducting materials which surround a chamber, aiming radio wave pulses at patients who enter the chamber. The tissues under investigation resonate and emit measurable radio waves, resulting in an image of human tissues that physicians use in making diagnoses.

Transportation Technology. The application of materials integrally affects the world of transportation. Automobiles, ships, motorcycles, and aircraft all require materials designed to meet particular needs.

Designers pay careful attention to detail when selecting materials, their selection influenced by the balance of performance, safety, range, durability, fuel economy, and manufacturing cost.

The construction of many kinds of vehicles commonly requires such metals and alloys as cromoly, steel, and aluminum. Many vehicles also employ fiber composites, particle composites, and various synthetic polymers. Materials are engineered and selected for their properties for every part of every vehicle.

Aerospace Technology. To construct aircraft and spacecraft, aerospace designers use materials engineered to maximize durability and dependability. Furthermore, space craft designers must pay careful attention to both material weight and strength.

Each space shuttle mission costs $400 million, according to conservative estimates. Included in the cost of each launch are the costs of the cargo, experiments, satellites, and laboratories aboard each mission.

Advanced materials are used to ensure the success of each mission, and specialized metal alloys are incorporated using specialized construction techniques.

Satellites typically have life spans engineered to last from 10 to 30 years. To prevent premature failures, spacecraft include redundant systems.

Since it is difficult or financially impossible to repair orbiting spacecraft, minimum use is made of components that could act as single points of failure. Advanced materials such as ceramics, metal alloys, composites, and polymers are used within spacecraft systems and subsystems, including power, control, guidance, thermal, payload, and propulsion components.

Spacecraft operate within a harsh and extreme environment. As a result, their design must withstand the earth's atmosphere and the rigors of space exploration.

The sun's rays subject spacecraft to drastic thermal changes. The resulting simple thermal expansion and contraction of materials can easily destroy a spacecraft.

Engineers create new materials to protect critical electronic control and guidance components. Radiation, such as ultraviolet light, can adversely affect materials in space, causing failure. Solar winds cause a kind of radiation in which electron and proton particles continually bombard a spacecraft, leading to potentially catastrophic problems, especially for on-board semiconductors.

NASA aerospace researchers and engineers also account for the effects of space debris and junk when selecting materials for a spacecraft. Moving at speeds of 17,500miles per hour or greater, meteors, comets, paint chips, cosmic dust, nuts, bolts, gloves, and even astray golf ball in orbit can spell the demise of a spacecraft.

NASA also carefully chooses all systems and subsystems aboard a spacecraft. Every year, NASA develops new materials specifically for the space program.

The reach of the space age can even be found in such consumer products as ceramics, metals, polymers, semiconductors, adhesives, lubricants, paints, and coatings. NASA's Office of Technology Transfer (**www.nasasolutions.com**) is a great place to investigate the connection between materials and the space program. Another great site to investigate the space program's spinoffs is **www.sti.nasa.gov/tto/spinoff.html**.

NASA's aerospace designers continue to investigate new materials applications in their pursuit of developing a fully reusable spacecraft. The current space shuttle, which has acted as NASA's workhorse since its debut in 1981, is not an entirely reusable vehicle.

Its side boosters, for instance, drop off after only two minutes of flight. They are recovered and rebuilt after each launch. The center fuel tank, however, is jettisoned eight minutes after launch and burns up upon reentry.

NASA aims to develop a new and completely reusable spacecraft, as do many independent aerospace industries. But a replacement for the space shuttle should be cheaper to operate; offer a one day, recovery-to-launch turnaround; have payload capabilities; and operate like an aircraft.

Work continues within the technology of propulsion and vehicle structure. Designs incorporating advanced ceramics, such composite materials as graphite epoxy, and such strong alloys as aluminum-lithium are being investigated for their feasibility in the design of the reusable spacecraft of tomorrow.

Currently, placing a payload into space costs roughly $10,000 per pound. NASA and private industry hope to develop a fully reusable launch platform that will reduce the cost to $1,000 per pound.

The Basic Materials. Various textbooks contain sections and chapters that study materials and material technology. The textbook I use with my students is *Experience Technology* by S. Soman and N. Swernofsky (1997), published by Glencoe/McGraw-Hill.

In my research, I have learned that there are ways to describe and catagorize the study of materials. Table I illustrates the basic organization that I follow and apply.

Polymers (natural and synthetic). A polymer is an organic material with a noncrystalline structure. Polymers are made up of many materials, including carbon and hydrogen, and are formed in long chains of molecules with a long carbon structure.

Natural polymers. Natural polymers include such materials as wood, silk, wool, and natural rubber. Wood, for instance, is a durable material of medium hardness and low conductivity that is easily shaped. For these reasons, wood continues to be a popular component of products.

Woods may be further classified as soft or hard. The classification, however, has less to do with the material's density than it does with the way a tree produces leaves.

Coniferous trees – softwoods – have needle-like leaves. Also called evergreens – including firs, pines, and spruces – coniferous lumber is *structural lumber*, which refers to the various applications of soft woods in framing posts, beams, and joists.

Hardwood-deciduous-trees produce broadleaves. Deciduous trees include oak, walnut, cherry, hickory, and maple, which are used in manufacturing furniture, cabinets, flooring, and trim.

Synthetic polymers. Plastics, typically classified as synthetic polymers, are engineered products belonging to a family of inorganic materials, such as natural gas and oil. The three basic kinds of plastics are *thermoplastics*, *thermosetting plastics*, and *elastomers*.

Synthetic polymers come from over 25 families of organic chains known as *monomers*. The application of monomers produces many of the different products that we call plastics. These materials are commonly used because they fulfill needs that woods and metals may be unable to fulfill or unable to fulfill as easily.

Thermoplastics easily heat and form into products and easily reheat and reshape into new products. This advantage makes thermoplastics ideal for manufacturing products to be recycled.

Thermosetting plastics do not easily reheat and reshape, but they do make products of greater durability than thermoplastics. Commonly used in the manufacture of products that must contain and control heat, thermosetting plastics make for ideal applications within the automotive and consumer electronics industries.

Elastomers, which come in both thermosetting and thermoplastic forms, can be stretched to nearly twice their normal length then returned to their original size and shape.

Overall, both natural and synthetic polymers offer the ability to create durable goods of medium to high-hardness. Furthermore, they also act as insulators. Plastics that can replace metals, glass, wood, and ceramics have been developed, and some products are made of no materials other than plastics.

Metals and metal alloys. Metals are popular materials used in manufacturing due to their desirable characteristics. Generally taken from the earth as ore-earth or rock that can be refined into useful products–few metals exist in a pure state, as are organic grains and nuggets. Metals are inorganic materials of crystalline internal structure, and are classified as either *ferrous* or *nonferrous*.

Ferrous metals include iron as their underlying ingredient. Nearly all ferrous metals are *alloyed*, meaning they contain both iron and carbon, along with other combinations of metals.

The amount of iron and carbon within steel determines its particular physical and mechanical properties. Steel is basically a combination of metals that include iron, carbon, and some other metal to meet a product's specific mechanical or physical need.

Ferrous metals, commonly used throughout the heavy machinery and automobile industries, can be alloyed to meet an application's particular needs. Ferrous metals typically have a high hardness, high durability, and a strong resistance to chemical degradation. Furthermore, ferrous metals are harder and more durable than nonferrous metals.

Nonferrous metals contain little or no iron–such as aluminum, copper, silver, gold, and lead-and are nonmagnetic and malleable. Nonferrous metals lend themselves easily to applications where durability and plyability are concerns. They are easier to form, machine, stamp, and punch into usable, everyday products.

When discussing metals, note that they are generally durable; have a high hardness, thermal conductivity, and melting point; and can be engineered by applying alloying techniques to meet particular product needs. It is also interesting to note that metals are used to classify ages of technology, such as the iron age, copper age, and bronze age.

Earth materials. Ceramics comprise a family of inorganic earth materials that–along with wood, stone, bone, and leather – are likely the oldest forms of materials used by humans. Clay objects have been found that are at least 27,000 years old.

The family of ceramics includes such materials as clay, glass, gypsum, and stone. Ceramics, hard materials that are generally poor conductors, usually consist of a crystalline internal structure. Yet, at extremely low temperatures, some ceramics lose their electrical resistance and become superconductors.

Other properties of ceramics include an extreme resistance to chemical degradation, salts, water, and high temperatures.

Commonly used in the construction of electrical and electronic equipment, buildings, windows, glass, dinnerware, abrasives, concrete, and enamels, ceramics are used even in applications that require high thermal stability, such as spacecraft.

Composites. These engineered materials combine materials designed to meet particular product needs by maximizing the benefits each material contributes to the application. Common composites include fiberglass, carbon fiber, concrete, and plywood.

Interestingly, wood itself is both a natural polymer and a natural composite. Composites are generally classified as *fiber composites*, *laminate composites*, or *particle composites*.

Fiber composites include fibers and a bonding agent. Fiberglass is a glass fiber matrix bonded together with plastic resin. Together, the glass fiber and plastic resin act to produce a lightweight material with high flexure resistance. Fiberglass is commonly used in the construction of race cars, recreational vehicles, boats, and so forth.

Laminate composites also produce high strength-to-weight ratios. Produced by layering materials, plywood, for instance, is constructed of thin veneers of material set in opposite grain directions.

The matrix that forms is then glued together with an adhesive and high pressure, resulting in a material commonly used in applications that receive high traffic or exposure to the elements, such as floor decking and roofs.

Particle composites are formed through a matrix of various particles and an adhesive. Concrete, for instance, forms in the mixture of sand, gravel, and cement. The cement acts as a bonding agent that holds the matrix in its final form until it cures.

Concrete is one of the oldest composites known to have been used by humans. The ancient Romans even constructed various civil projects, such as the aquaducts, using concrete.

This unit of instruction fits naturally with the age and interests of my sixth grade students. Furthermore, it is a good starting place for a general study of technology.

This unit may be easily enhanced with internet research, small group instruction, and even peer instruction techniques.

INTERNET RESOURCES

1. NASA technology transfer: www.sti.nasa.gov/tto/spinoff.html
2. Polymers in the automobile industry: http://polymerics.tripod.com/ index2.htm
   Polymers and people: www.beyonddiscovery.org/ beyond/beyonddiscovery.nsf/web/polymers
3. Artificial muscle research group: http://www.unm.edu/~amri/

4. Scaled Composites: www.scaled.com/
5. Ten Cate Advanced Composites: www.tencate-ac.com/ASCE
6. Journal of composites for construction: www.pubs.asce.org/journals/cc.htmlStanford
7. University Structures and Composites Laboratory: http://structure.stanford.edu/
8. Funda Engineering Fundamentals: www.efunda.com
9. Dartmouth toxic metals research program: www.dartmouth.edu/~toxmetal/
10. CERAM research metals technology group: www.ceram.co.uk/metals.html
11. Advanced ceramics research: www.acrtucson.com

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