MATERIALS™ EXPLORERS

BIOMEDICAL MATERIALS

From hip implants to bone cement, medical devices can enhance patients' health and quality of life, but have you ever thought about the materials these devices are made of? In this chapter, you will learn about some of the important qualities that make biomedical materials safe and useful when placed in the body.

In this module students will be able to:

- Describe the properties of viscoelastic materials
- Compare and contrast solids and liquids
- Define biomedical materials and identify applications
- Classify and balance the reaction that occurs when magnesium is absorbed by the body
- Define polymers and identify an example of a polymer

Class Activity

Practical Prosthetics

Background:
Humanity has a long history of introducing materials into our bodies to replace broken parts or to help aid the body with its natural healing process. The ancient Egyptians used surgical sutures or “stiches” made from animal or plant components, and dental implants made of animal teeth and gold wire were used in Europe more than one thousand years ago. The materials used in these processes are known as **biomedical materials**. What is a biomedical material? Broadly speaking, it is any material being introduced into a biological system for a medical purpose.

Today, medical experts developing biomedical devices have a much wider selection of materials than their historical predecessors. This is thanks to the biomedical researchers who study materials to determine if their properties are suitable for use in a medical device.

One set of materials that are of interest to many biomedical researchers are **viscoelastic** materials, or those that exhibit both **viscosity** and **elasticity**. Many of the materials we encounter on a daily basis are viscoelastic. One example is skin. When skin is pinched, it takes a few moments before the skin returns to its original flat position. Another example of a viscoelastic material is a **polymer**. Polymers, or long chains of molecules, can exhibit properties of both solids and liquids and have a wide variety of uses. Biomedical engineers are currently experimenting with polymers and other viscoelastic materials to create artificial skin that can make prosthetics look, feel, and even function more like real skin.

Problem

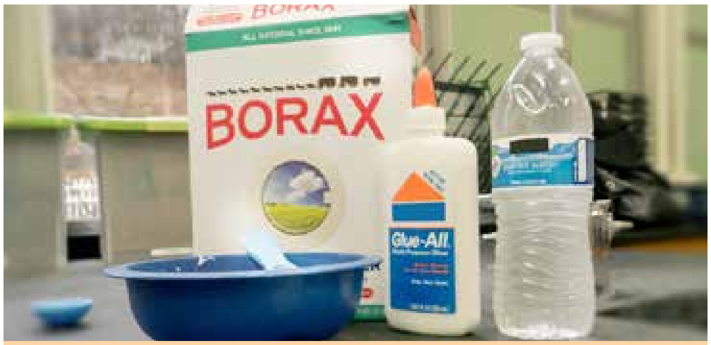
A group of materials scientists suspect that a highly elastic polymer has potential to be used in certain types of prosthetics. Before conducting further research on using the polymer as a biomedical material, the scientists have asked your class to investigate the properties of a viscoelastic putty that mimics the characteristics of their polymer. Your team will write an evidence-based conclusion explaining your findings and the feasibility of using a material with similar properties in prosthetics.

Task:
Your task is to create a polymer material using common household items that would mimic the characteristics of one being developed for use with prosthetics. You will test what happens when your polymer material is stretched, pulled apart, and rolled into a ball. Because the electrostatic forces that hold viscoelastic materials together can change depending on temperature, you must also test how temperature affects your polymer.

MATERIALS™ EXPLORERS

Class Activity

Requirements:
Create a polymer material using equal parts of the following ingredients: water, white glue, and borax. A few drops of food coloring may also be added. The polymer material should be kneaded until smooth and must be able to be easily stretched, pulled apart, and rolled. To determine whether the polymer would be effective in cold temperatures, record your observations of its behavior after being stored in the refrigerator for an hour.



Measure and mix equal parts of water, white glue, and borax.

Knead until smooth and easily stretched, pulled apart, and rolled.

Questions

1. **Record observations for the following scenarios at room temperature and after the polymer material has been chilled:**
   i. What happens when it is stretched?
   ii. What happens when it is pulled apart?
   iii. What happens when it is rolled into a ball?
2. **Create a Venn diagram comparing the properties of solids and liquids.**
3. **Would you classify the polymer material as a solid, liquid or both? Why?**
4. **Define cross-linking and explain how it pertains to your polymer material.**
5. **Compose an evidence-based conclusion consisting of your observations and the feasibility of using a polymer with similar characteristics for creating prosthetic skin.**

Definitions

Biomedical material
Any substance that has been modified or developed to be introduced into a biological system for a medical purpose.

Viscoelastic
Pertains to a substance that exhibits properties of both solids and liquids.

Viscosity
A measure of a fluid's resistance to flow. The less viscous a fluid, the more easily it flows.

Elasticity
The ability to return to its normal shape after being deformed

Polymer
A large molecule, or "macromolecule," composed of many repeated smaller units, or "monomers," bonded together.

Extension Activity

MAGNESIUM, MEDICINE, AND MATERIALS ENGINEERING*

You may not see them working in a hospital or doctor's office, but materials scientists and engineers play a big part in helping people recover from illnesses and injuries to enjoy a better quality of life.

Contact lenses, dental implants, pacemakers, and surgical sutures all fall under the category known as biomedical materials. A biomedical material is any substance that has been modified or developed to be introduced into a biological system for a medical purpose. Some of these applications include replacing diseased or damaged body parts, enhancing appearance through cosmetic implants or assisting the natural healing process.

Many biomedical materials are designed to permanently stay in the patient's body, but sometimes implants are only needed temporarily. An example of this would be pins used to keep bones in place while they heal. When the pins are made of traditional materials such as stainless steel, cobalt-chromium, or a titanium alloy, the patient often needs to undergo an additional surgery after healing in order to remove the implants. Because further operations create additional expense and risks for patients, materials scientists and engineers have recently researched and developed new biomedical materials that are safely absorbed into the body after the healing process is complete.

The most commonly used biodegradable and bioabsorbable implant materials are the polymers, poly-glycolic acid (PGA), poly-lactic acid (PLA), and poly-dioxanone (PDS). However, these materials have limitations. Their low **specific strength** means that they aren't suitable for load bearing andtissue supporting roles and their **radiolucency** makes it difficult to accurately place implants that are made of these materials.

Metals, on the other hand, have many of the desirable qualities these polymers lack, such as high strength and fracture toughness. However, most metals are either non-absorbable for the body or can produce toxins as they corrode. One notable exception to this is magnesium (Mg); and it has received a lot of attention among biomedical researchers.

Magnesium has a high specific strength and an **elastic modulus** that is closest to the human bone when compared with traditional metallic implant materials. Studies have also confirmed that magnesium has the ability to stimulate bone growth and healing, and that its degradation leads to harmless corrosion products which are excreted through the urine.

However, magnesium has its own limitation as an implant material. It reacts with water to produce a mildly protective film of magnesium hydroxide. Although this film slows corrosion in a moist environment, it reacts with water present in the human body to produce magnesium by-products and hydrogen gas. This reaction accelerates corrosion and absorption into the body, which can undermine the mechanical integrity of the implant before the bone or tissue has sufficiently healed. Magnesium's tendency to produce hydrogen gas and form gas bubbles that accumulate around the implant can also delay the healing of the tissue.

In order to make magnesium effective for use in **bioabsorbable** temporary implants, materials scientists and engineers need to find a way to keep it from degrading before the patient's bones or tissue have healed enough to support themselves. Efforts to control the corrosion rate of magnesium have used various processing methods such as purification, alloying, anodizing, and surface coating.

Studies have shown that purification of magnesium reduces the corrosion rate considerably. However, due to the low **yield strength** of pure magnesium, its application in orthopedics and other load bearing applications is limited. Alloying elements can be added to increase the strength of pure magnesium, but they must be selected carefully to maintain the magnesium's biocompatibility. Creating a magnesium alloy with elements such as iron, nickel, copper, and cobalt actually increases the corrosion rate of the magnesium. Aluminum and zirconium are not bio-compatible and instead may have long term effects, including dementia and cancer, respectively. Rare earth elements such as cerium, lutetium, and praseodymium are generally considered toxic for the human body.

Extension Activity

So what materials can be safely used? Scientists propose choosing materials that are already essential to the human body to serve as alloying elements. Calcium and zinc are two examples. They are essential elements found in most vitamins that also provide mechanical strengthening in magnesium-based alloys. In simulated body fluid, calcium has been reported to improve the corrosion resistance of magnesium-based alloys. Meanwhile, zinc additions increase the strength of magnesium-based alloys through precipitation strengthening.

Despite the challenges that magnesium and its alloys present, teams of chemists, materials scientists, and physicians are determined to unlock this element's full potential as a biomedical material. The impact that fully biocompatible and biodegradable magnesium alloy implants could make on the lives and healing of so many people is well worth the effort.

**This article is excerpted from "Magnesium as a Biodegradable and Bioabsorbable Material for Medical Implants" by Harpreet S. Brar, Manu O. Platt, Malisa Sarntinoranont, Peter I. Martin, and Michele V. Manuel, published in* JOM, *September 2009, Volume 61, Issue 9, pp 31-34.*

Questions

1. **Write out the reaction for magnesium and water.**
2. **Balance and classify the type of reaction that occurs between magnesium hydroxide and water.**
3. **What is precipitation strengthening?**
4. **Scientists are looking towards elements such as magnesium, calcium and zinc because they are already used in the body. How does your body use each of these elements in its day to day functioning?**
5. **Materials are all around us and even in us. Advancements in biomedical engineering have led to the creation of a variety of implants. There are many challenges that must be overcome to create an implant. Depending on the implant, those challenges can include difficulties with bioabsorption, resistance to corrosion, and durability.**
   Select one of the following implant categories and research the materials that compose the implants and the challenges that accompany them: dental, cardiovascular, brain, spine, and orthopedic.

Definitions

Specific Strength:
A measure of a material's strength relative to its density. It is also known as the strength to weight ratio.

Radiolucency:
Radiolucent materials allow radiant energy such as X-rays to pass through them. They therefore appear as dark spots on an X-ray image.

Elastic Modulus:
Also known as Young's modulus, the elastic modulus is a measure of the elasticity of a material. The higher the elastic modulus of a material, the more the material will resist stretching. It can be calculated by dividing stress by strain.

Bioabsorbable:
Capable of being broken down or dissolved within the body.

Yield Strength:
The stress at which a material begins to deform plastically. That is, the point at which enough stress is applied that the material does not return to its original shape after the stress is removed.

MATERIALS™
EXPLORERS

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

TMS
The Minerals, Metals & Materials Society