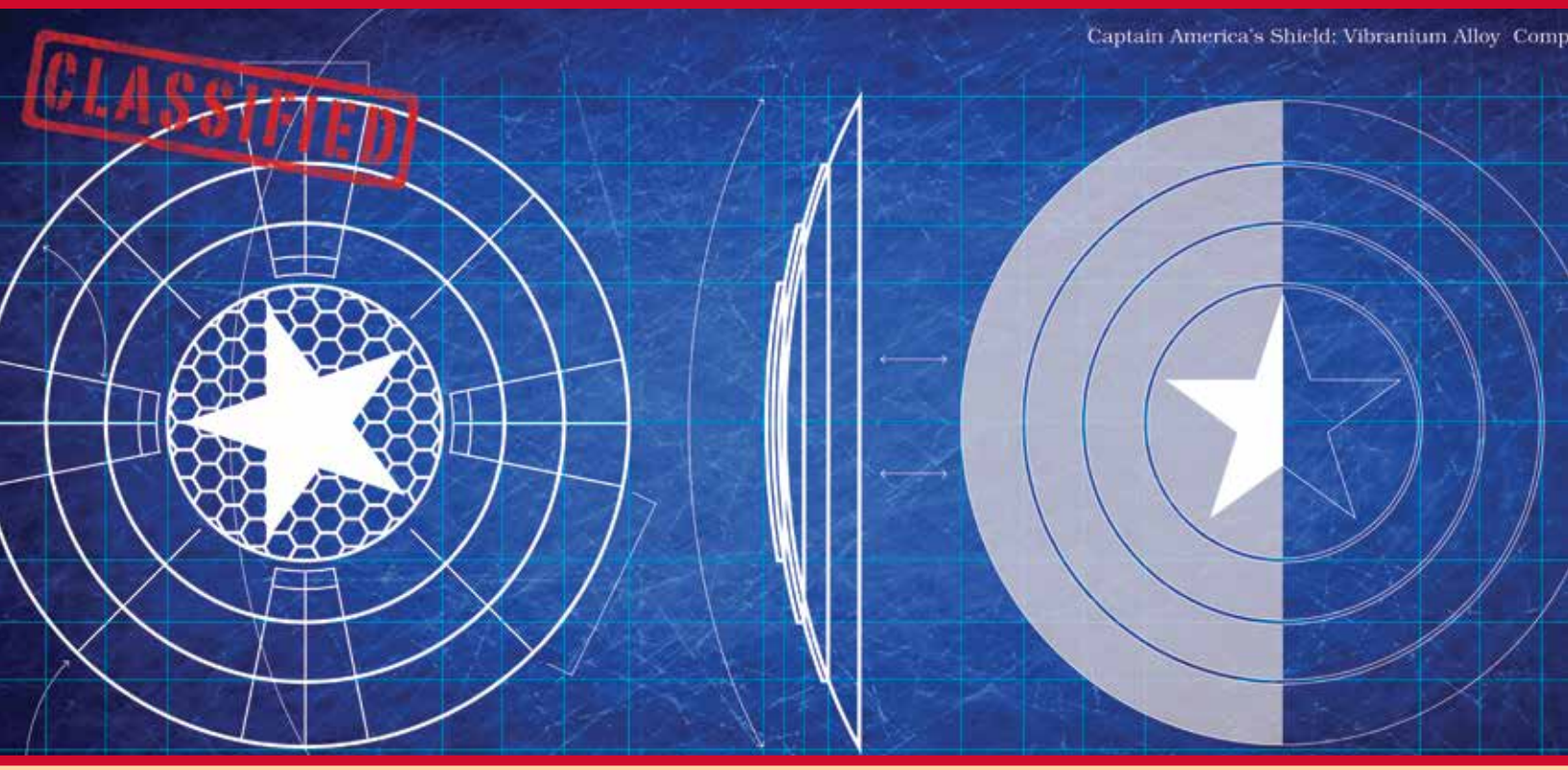
MATERIALS™ EXPLORERS

MATERIALS SCIENCE OF SUPERHEROES



Original artwork by David Rasel, TMS Media Manager

Scaling walls, super strength, and X-ray vision aren't just the stuff of comic books. In this chapter, you'll explore the importance of materials to the superhero world and learn about researchers who are accomplishing superhuman feats using science.

In this module students will be able to:

- Compare theoretical superpowers to real-world scientific applications that make them possible
- Use their knowledge of an element to synthesize their own superhero
- Explain the arrangement of elements on the periodic table
- Research the role of materials science and engineering in simplifying modern life
- Discuss the relationship between valence electrons and reactivity, and the importance of reactivity in materials science

MATERIALS™ EXPLORERS

Class Activity

POWERS OF THE PERIODIC TABLE

Background:
Often, when superheroes face seemingly insurmountable odds and unbeatable villains, they gain an advantage by teaming up with other superheroes and combining their unique superpowers. A similar approach can be applied to science and engineering problems. In fact, the minerals, metals, and materials workforce needs professionals from a wide variety of backgrounds to contribute their unique viewpoints and approaches to solve complex problems. See how a few of these individuals are contributing to making our world a better place as members of their own version of a superhero league, The Minerals, Metals & Materials Society. Then, create a superhero of your own inspired by the elements of the periodic table.

NAME: Akane Suzuki

Base of Operations:
> Principal Engineer
> *GE Global Research, New York*

Last Seen: Developing new alloys that can withstand very high temperatures and harsh environments.

Mission: Make aircraft engines and electricity power plants work more efficiently and safely for longer hours.

Powers: Grants "superpowers" to alloys by designing and optimizing the chemical formula and processes.

NAME: Amy Clarke

Base of Operations:
> Associate Professor
> *Colorado School of Mines*

Last Seen: Filming the formation of metal structures to understand and control how they develop.

Mission: Create everyday materials that perform better, last longer, and use less energy to make.

Powers: Can see through metals, using x-ray and proton vision.

Photo Courtesy of Michelle S. Kim, University Communications

NAME: Dele Ogunseitan

Base of Operations:
> Professor of Public Health
> Chair, Department of Population Health and Disease Prevention
> *University of California, Irvine*

Last Seen: Identifying the risks of toxicity that can cause disease in humans or damage to the ecosystem due to materials used in every day products.

Mission: Help manufacturers use safer, less toxic materials in products such as cellphones, computers, batteries, and light bulbs.

Powers: Research that permits "time travel" to the past, present, and future of a material to know where the dangers are for people and for the environment.

Background Photo: Magnesium engine block, US Automotive Materials Partnership (USAMP)

NAME: Joy Hines Forsmark

Base of Operations:
> Technical Expert
> Research and Innovation Center
> *Ford Motor Company, Michigan*

Last Seen: Studying lightweight metals, such as aluminum and magnesium alloys, for use in automobiles.

Mission: Make lighter cars that use less gas and create less air pollution.

Powers: Starts with atoms to build the lightest and best parts for a car.

Class Activity

Background Photo: Francesco Tomasinelli and Emanuele Biggi

NAME: Markus J. Buehler

Base of Operations:
> Professor and Head
> Department of Civil and Environmental Engineering
> *Massachusetts Institute of Technology*

Last Seen: Discovering how the toughest materials found in nature are constructed at the molecular level, and then using that knowledge to develop new, synthetic materials.

Mission: Taking simple, natural ingredients, such as wood or protein, to make sustainable, durable materials.

Powers: Amazing insights into why spider silk is one of the Earth's strongest materials. Ability to work with many other scientific fields to someday create a "super fiber" that mimics what spiders naturally produce.

NAME: Paul R. Ohodnicki, Jr.

Base of Operations:
> Materials Scientist
> *U.S. National Energy Technology Laboratory*

Last Seen: Researching and developing materials that could lead to new types of sensors and devices for power generation and electrical energy conversion.

Mission: Improve energy efficiency of power plants and their transmission and distribution systems.

Powers: Designs unique materials in a way that makes them useful for application in devices.

NAME: Michele V. Manuel

Base of Operations:
> Professor and Department Chair
> *University of Florida*

Last Seen: Designing materials to make machines smarter.

Mission: Help create machines with unprecedented power and behavior through the use of designer materials.

Powers: Molecular Transmutation—the ability to manipulate matter on a molecular level for the betterment of human kind.

NAME: Ricardo J. Zednik

Base of Operations:
> Vice President / CTO / Principal Engineer, *Arrhenius Failure Analysis International (Arrhenius, Inc.)*
> Professor, *University of Quebec*

Last Seen: Collecting evidence and following clues hidden in materials to solve how engineering designs fail—often catastrophically—in applications like medical implants, natural gas pipelines, digital cameras, and satellite solar arrays.

Mission: Protect society by understanding what causes accidents, fractures, and explosions.

Powers: Brings smashed objects "back to life" so they can tell us what happened.

Now that you've learned about some of the materials science and engineering superheroes out there, it's time to create your own character inspired by the periodic table of elements.

As you review the Periodic Table, you may notice that elements are grouped by a certain logic. When Dmitri Mendeleev originally arranged the periodic table in 1869 he did so by atomic mass, but today's periodic table looks a little bit different. That is because Henry Mosely rearranged the table according to increasing atomic number. This arrangement means that elements in the same group have the same number of **valence electrons** and exhibit **periodicity**, meaning they have similar physical and chemical properties. Perhaps some of these properties will inspire your superhero.

Problem

The Ensemble of Elements, a group of sophisticated superheroes, needs your help. Their membership is dwindling after surviving a surprise attack by trans-dimensional aliens. The Ensemble believes that anyone who understands the materials around them and how they function can become a superhero. They have reached out to you, urging you to develop your sophisticated superhero persona so that you can join them in defeating the alien invaders.

Class Activity

Task:
Your task is to create a superhero persona inspired by one element on the periodic table.

Requirements:
You must create a digital presentation, poster, or mobile displaying the following information:

1. Name of superhero
2. Element symbol
3. Element atomic number
4. Element atomic mass
5. Element's location on the periodic table (i.e. group name)
6. Element's electron configuration
7. Physical and chemical properties of element
8. Strengths of the superhero (based on the element's properties)
9. Weaknesses of the superhero (based on the element's properties)
10. Superhero's powers (based on the element's properties)
11. Pictorial representation of the superhero

Questions

1. **How are the elements arranged on the periodic table?**

2. **How do valence electrons relate to reactivity?**

3. **Why is the reactivity of materials particularly important in materials science?**

4. **Research a material or technology that has made your life better. Who invented it? How long has it been around? How does it improve your quality of life?**

5. **While scientists and engineers have their sights set on the future, discoveries are made each day that can simplify our lives now. List one material and one technology that you wish currently existed.**

Definitions

Valence electrons
electrons in the outermost energy level of an atom that are responsible for the chemical properties of the atom

Periodicity
When elements are arranged in order of increasing atomic number they exhibit similar physical and chemical properties

Teacher Resources & Answer Key

Standards:	NGSS	HS-PS1-1

Notes:

1. Students may be assigned or self-select an element.
2. Students may use books, the periodic table, or the Internet to conduct their research.
3. Students may be directed to websites such as www.autodraw.com for assistance creating a digital drawing of their superhero.

1. **How are the elements arranged on the periodic table?**

   The elements on the periodic table are arranged according to increasing atomic number. The elements are also grouped according to their properties.

2. **How do valence electrons relate to reactivity?**

   Valence electrons are the outermost electrons in an atom, making them more likely to interact with other atoms. Valence electrons determine bonding behavior and are the highest energy electrons, making them most likely to participate in a chemical reaction.

3. **Why is the reactivity of materials particularly important in materials science?**

   Materials science requires scientists to make connections between the structure of a material and its properties. Once this connection is understood, the performance of the material in various applications can be tested.

4. **Research a material or technology that has simplified your life. Who invented it? How long has it been around? How does it improve your quality of life?**

   Student answers will vary. An example includes smartphones which were created in 1992 by IBM. Smartphones allow us to connect with one another via social media, phone calls, text messages, or emails.

5. **While scientists and engineers have their sights set on the future, discoveries are made each day that can simplify our lives now. List one material and one technology that you wish currently existed.**

   Student answers will vary. Examples include a material that would prevent water bottles from leaving condensation marks while cold or technology that would remotely alert homeowners of gas leaks.

Teacher Resources & Answer Key

Activity Grading Rubric

CATEGORY	5	4	3	2	1-0
Graphics - Clarity	Graphics are all in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content is easily viewed and identified.	Many graphics are not clear or are too small.	Assignment incomplete or not submitted.
Creativity	The strengths, weaknesses, and powers are creative and original.	The strengths, weaknesses, and powers are original, but lack creativity.	The strengths, weaknesses, and powers are creative, but not original.	The strengths, weaknesses, and powers are not creative or original.	Assignment incomplete or not submitted.
Content - Accuracy	All facts are accurately displayed on the project.	4-3 accurate facts are displayed on the project.	2-1 accurate facts are displayed on the project.	No accurate facts are displayed on the project.	Assignment incomplete or not submitted.
Attractiveness	The project is exceptionally attractive in terms of design, layout, and neatness.	The project is attractive in terms of design, layout and neatness.	The project is acceptably attractive though it may be a bit messy.	The project is distractingly messy or very poorly designed. It is not attractive.	Assignment incomplete or not submitted.
Grammar/ Spelling	There are no mistakes on the project.	There are 1-3 mistakes on the project.	There are 4-6 mistakes on the project.	There are more than 6 mistakes on the project.	Assignment incomplete or not submitted.

Extension Activity

THE SUPER MATERIALS OF THE SUPERHEROES

Peter Parker may have gained physical superpowers from the bite of a genetically altered spider. But, in *Spider-Man: Homecoming*, it's Peter's own scientific and engineering talents that create Spider-Man's main weapon—synthetic spider webbing that he can trigger from "web shooters" mounted on his wrists. In fact, it's the only part of Peter's original Spider-Man costume that Tony Stark doesn't openly ridicule when he meets him. ("This webbing! Tensile strength is off the charts.") Stark goes on to include his own web shooter technology in the super suit that he designs and gives to Peter (and later confiscates) in the film. Presumably, Stark's web formula is made from ingredients other than what Peter could find in his high school chemistry lab or Aunt May's household supplies.

This is just one of many, many examples of how the heroes and villains in the comic realm rely on materials to boost their powers, provide protection, and even define who they are.

The stories of how these materials are created and used do tend to push and exceed the boundaries of what may be possible. But, they are also rooted in the fact that scientists and engineers are "living superheroes" who change—and save—the world every day.

The real source of Iron Man's power, for instance, is the mind of Tony Stark, a brilliant engineer and wealthy industrialist. In the *Iron Man* and *Avengers* movies, Tony uses computational tools, 3D-visualization, and advanced manufacturing techniques to tailor his collection of Iron Man suits to specific needs. This also means that Iron Man's suits contain very little actual iron. Heavy, dense and prone to rust, it was not a suitable material for his superhero exploits. Instead, Stark has dabbled with various titanium alloys, carbon fiber, and nanotechnology. In *Iron Man 2*, he even synthesized a new element to replace the poisonous palladium core in his Arc Reactor.

Suveen Mathaudhu, a materials scientist at Pacific Northwest Laboratory, professor at the University of California, Riverside, and an avid comic fan, believes that modern processing approaches, advanced microscopy, and computational material design tools have closed the gap between comic fiction and science reality. "There really is very little reason that we should not be able to microstructurally engineer whatever materials we want for the future," he said.

A materials scientist and avid comic fan, Suveen Mathaudhu has the "super power" of being able to modify the microstructure of metals by using advanced scientific tools and techniques. In this photo, he is shown erforming a compression test on a Dake 70-ton uniaxial load press, pushing a metal sample until it fails and recording the load and displacement along the way. This helps him determine how a material will perform in a real-world application.

Extension Activity

To illustrate his point, Suveen goes back to the origin story of Captain America's shield, as it was told in the comics (Captain America VI V303 March 1985). As also seen in the *Captain America* and *Avengers* movies, the shield is capable of absorbing, storing, and redirecting all the kinetic energy and vibrations hurled at it. The more energy it absorbs within the bonds between its molecules, the more powerful the material becomes. The fictional element making these unique properties possible is vibranium, obtained from a meteorite that fell to Earth and gave rise to the technologically advanced African kingdom of Wakanda—where Black Panther calls home. The shield was born when the vibranium bonded with steel and an unknown catalyst, forming a disc of indestructible alloy that could only be reshaped by molecular rearrangement.

Replica of Thor's hammer, Mjölnir, signed by Chris Hemsworth, from the collection of The Minerals, Metals & Materials Society

To Suveen, the real hero of this part of the Captain America legend is Dr. Myron MacLain, an American metallurgist. At the urging of President Roosevelt, Dr. MacLain was attempting to develop an indestructible tank armor that would give the Allied forces an edge on the battlefield. While experimenting with vibranium, he nodded off and the alloy mysteriously formed while he slept.

Dr. McLain was never able to recreate the material in his lab again, although Suveen believes he would have a fighting chance with technologies from the "real world" that have eclipsed what was being imagined at the time that comic was written. "We have control over the atomic world that we didn't have 20 years ago," he said. "Through high-end microscopy tools, we can visualize and manipulate the very microstructure of a material to achieve ultrahigh strength and other truly amazing characteristics. The next frontier is the ability to accurately predict how we can create materials with specific properties. An indestructible material like vibranium does not exist, but we might be able to come close."

Shields, weapons, and superpowers enabled by science

Replica of Captain America's shield, from the collection of The Minerals, Metals & Materials Society

are actually a more recent concept explored in the comic world. The earliest superheroes tended to draw their superpowers from myth and magic—if they had any powers at all. This was particularly the case for Wonder Woman, who was introduced to the world in 1942, and as explained in the *Wonder Woman* movie 75 years later, "My mother sculpted me from clay and Zeus breathed life into me." A demi-god among the mythical race of Amazonian women, Wonder Woman's metal bracelets were her main defensive weapon, since they could repel nearly every projectile hurled at her. (And, as seen in the Wonder Woman movie, she uses the metal bracelets to channel her powers into seismic shockwaves. Take that, Ares.)

The nature of superheroes changed during the Cold War when the world was seized with anxiety by the prospect of nuclear war.

Extension Activity

Americans embraced technology as a way to make life better, but also realized it could be the means of wiping us out. The superheroes and their villains that came up through this time were metaphors for that conflict. New comic characters were developed as flawed individuals wrestling with a multitude of demons, many of them brought on by scientific recklessness.

Marvel Comics is credited with introducing this contemporary breed of superhero when Reed Richards, the brilliant and arrogant leader of the Fantastic Four, launched his stolen rocket into space in 1961. He and his crew were accidently bombarded with "cosmic rays," giving them all superpowers, and horribly disfiguring the pilot, Ben Grimm.

Most of the Marvel characters in this new era of comics, in fact, started out as scientists—and they weren't the stereotypical "mad geniuses." Reed Richards was the smartest man in the world and used his science for good. But, there was also a dark side to his story. He and characters like him symbolized the overall mood of the country toward science.

Science in service of national defense also became a target of suspicion—while the Steve Rogers character introduced during World War II willingly subjected himself to the experiments that ultimately transformed him into Captain America, the Wolverine character in X-men was kidnapped by a shadowy military operation that forcible implanted adamantium, yet another super-strong fictional alloy, into his skeleton.

"A common theme about this time was the consequences of military research—both good and bad," said Suveen."Materials science technologies were particularly dominant in these stories because they underpin nearly everything and were immediately recognizable to the public."

Many of the stories told through the comic pages of the past are now finding new life (and fans) with a seemingly endless stream of superhero movies and television shows. Characters have been updated, but many of them are still carrying—and even expanding upon—the scientific themes first explored in comic books. But, as dazzling as it is, can this new generation of comic science be believed?

Replica of Iron Man suit from the collection of The Minerals, Metals & Materials Society

According to Rick Loverd of the National Academy of Science's (NAS) Science & Entertainment Exchange, many creators of fictional universes are very serious about accurately portraying science in their work. The Exchange was established by NAS in 2008 to provide a resource for accurate scientific information to the entertainment industry, and has provide technical consulting to such projects as *Thor* and the *Avengers*.

"What we have found is that the science is much further ahead of what entertainers usually envision. The creative people who attend our sessions come away inspired and excited to use these cutting edge ideas in their work, said Rick. "Many in the entertainment industry feel it's very important to 'get the science right.' They know that everyone in the audience now has a supercomputer in their pockets. Audiences are more savvy to science than they were in the past, and more questioning of some of the ideas. If what they see on the screen doesn't mesh with information that they have access to online, it takes them out of the story."

"That's not to say that everything in a movie needs to be deadly accurate," Rick continued. "The story will always overshadow the science, but plausible science makes the story line stronger and

Extension Activity

more engaging. It creates the rules in which those imaginary worlds can logically operate."

Suveen agrees, both from his personal experience as a comic fan and in his attempts to inspire new thinking through comic mythology. "The superhero comic, like any science fiction, is the pulse of scientific possibilities," he said. "People relate to these stories and can tie them uniquely to their own ideas. I often use examples from comics in my presentations as a means of inspiring the next generation of engineers—to get them to think differently about what could be possible and then push to that next level."

"Even the superheroes born with powers have the technical acumen to augment them," Suveenn continued. "The focus in most superhero comic stories is a problem or puzzle that requires science to resolve. The hero is always the person who can figure it out and create the technology that saves the day."

"And, doesn't everyone want to be a superhero, when you come down to it?"

**Parts of this article are excerpted from "The Super Materials of the Superheroes" by Lynne Robinson, published in* JOM*, January 2012, Volume 64, Issue 1, pp 13-19, and* Comic-tanium™: The Super Materials of the Superheroes educational exhibit, *presented by TMS, the TMS Foundation, and the Toonseum of Pittsburgh in 2014 and 2015.*

Questions

1. **Choose a superhero not already explained in this article who owes his or her powers to science. Research the science behind their powers. Which aspects of their powers are scientifically plausible and which are entirely fictional?**

2. **Choose a superhero whose powers are not created by science. How would you propose recreating some of those powers in the real world?**

3. **Vibranium, a fictitious element used in Captain America's shield, makes the shield capable of absorbing, storing, and redirecting all the kinetic energy and vibrations hurled at it. The more energy it absorbs within the bonds between its molecules, the more powerful the material becomes. If vibranium were a realistic element, describe where it would fit on the periodic table and why.**

4. **Tony Stark upgrades Peter Parker's webbing with materials that cannot be found in a high school chemistry class. Fiberglass, however, is a material that is easy to obtain and has some of the same desirable properties as Peter Parker's web. Describe the properties of fiberglass that would be useful if it were developed into a web.**

5. **Peter Parker was not only famous for shooting webs, but also has the ability to quickly scale buildings. Geckos are similar to Peter Parker in that they can "stick" to walls. Explain the science behind this ability and research materials in development that can make scaling walls like Spiderman a reality.**

Extension Activity Answer Key

1. **Choose a superhero not already explained in this article who owes his or her powers to science. Research the science behind their powers. Which aspects of their powers are scientifically plausible and which are entirely fictional?**

   Answers will vary. For example, a student could expand on the dangers or radiation exposure, or research the work being done on robotic exoskeletons being developed.

2. **Choose a superhero whose powers are not created by science. How would you propose recreating some of those powers in the real world?**

   Answers will vary. Students may research answers such as mechatronic arms to create superhuman strength, the invention of jetpacks to create flight, x-rays to replace x-ray vision and so on.

3. **Vibranium, a fictitious element used in Captain America's shield, makes the shield capable of absorbing, storing, and redirecting all the kinetic energy and vibrations hurled at it. The more energy it absorbs within the bonds between its molecules, the more powerful the material becomes. If vibranium were a realistic element, describe where it would fit on the periodic table and why.**

   Answers will vary. For example, students may feel that it belongs with other transition metals or even close to the halogens indicating it is highly electronegative and has a high ionization energy.

4. **Tony Stark upgrades Peter Parker's webbing with materials that cannot be found in a high school chemistry class. Fiberglass, however, is a material that is easy to obtain and has some of the same desirable properties as Peter Parker's web. Describe the properties of fiberglass that would be useful if it were developed into a web.**

   Fiberglass is chemically resistant; it will not mildew or deteriorate and resists many acids. Fiberglass will not stretch or shrink. Fiberglass has good thermal properties and will dissipate heat rapidly. Fiberglass has a high strength-to-weight ratio and is twice as strong as steel wire. Fiberglass will not burn and maintains it strength at high temperatures. Fiberglass will not absorb moisture and is an excellent electrical insulator. Finally, fiberglass is cost effective compared to other synthetic and natural fibers.

5. **Peter Parker was not only famous for shooting webs, but also has the ability to quickly scale buildings. Geckos are similar to Peter Parker in that they can "stick" to walls. Explain the science behind this ability and research materials in development that can make scaling walls like Spiderman a reality.**

   Geckos "stick" to walls through intermolecular forces. Geckos foot hairs split, increasing surface density. A strong adhesive force is created as the foot hairs come into close contact with the surface. For materials in development, students may explore items such as "Geckskin," or "Synthetic Gecko" adhesives.

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.

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