Reinforcing steel is an aspect of civil engineering that plays a very important role. The main use of reinforcing steel is in concrete structures. Since concrete is low in tensile strength, reinforcing steel is placed in the forms of the concrete structure to provide tensile strength where needed. Not only does reinforcing help in tensile strength, but it also aids in flexural strength, torsional loads, and ductility of the concrete. Different stresses due to temperature changes and environmental changes cause the concrete to expand and contract in different manners. The reinforcing steel holds the concrete together stronger than if the concrete were not reinforced.

Iron, an aspect of steel, has been used since about 1500 B.C. Steel production did not begin until 1855 when Henry Bessemer of England invented the Bessemer furnace, which will be discussed later. The Industrial Revolution began the major production of steel. Currently, the production and cost of steel is low due to recent technologies incorporating computer use and automation to the process and production of steel. Steel mainly consists of iron and carbon. Three materials are used to process and make steel, and they are iron ore, coal, and limestone. The three main steps in the process of making steel are reducing iron ore to pig iron, refining pig iron to steel, and forming the steel into products. Mix design, chemical additions, proportioning, and processing all contribute to making different types of steels.

Reinforcing steel is classified into two different products. The first is long steel bars, more known as rebar. The second is known as wire fabric. Rebar is more widely used rather than wire fabric because of its ease of placement. Wire fabric is made as sheets of wires oriented in a grid-like shape. They are laid in place as the concrete is being poured. This is much easier than tying rebar together and setting them in place prior to the concrete being poured. Wire fabric also covers a larger area with much more ease. Wire fabric, however, is not used in all concrete structure applications because since wire fabric comes in sheets, it covers a large area. Not all concrete structures are large in surface area. Wire fabric also does not provide as much tensile strength as compared to rebar. Wire fabric is used mainly in slabs and pavement. Rebar is more used in footings, piles, beams and columns. The texture of the reinforcing steel also plays an important role. A plane bar is a smooth, round piece of steel that does not provide good anchorage in the concrete. A deformed bar does provide good anchorage. A deformed bar has deformations on the surface, such as frequent, intentional lips, in order to provide a strong interlock with the concrete. Both wire fabric and rebar are made in plane and deformed textures.

The one downfall to using reinforcing steel is that steel is a corrosive material. There are several methods, however, that can be used to prevent from corrosion. Epoxy coating the
reinforcing steel is one method that can be used. Epoxy allows moisture to get to the surface of the steel, but not oxygen. This is effective since oxygen causes rust. Another effective method for preventing corrosion is using galvanized steel. Galvanized steel is steel coated in zinc. This not only improves corrosion resistance of the concrete, but it also extends the life of the reinforcing steel and provides better prevention to early cracking. The third method that can be done is using stainless steel for the reinforcing steel. This is effective, but a lot more costly than other methods. Using stainless steel does, however, have good strength and durability. The final method that can be done is using steel fibers. This has been found to be useful in concrete design in marine applications.

Questions:
1. What is the main purpose of reinforcing steel?
2. What are 2 of the ways to prevent corrosion of reinforcing steel?
3. What are the two products that encompass reinforcing steel?
Asphalt concrete has been utilized as a road construction material for over 100 years. Since its introduction, research has been conducted to improve its performance and durability. Porous friction courses have been developed to reduce road noise, increase friction with the tire/road interface, and to improve driver safety.

Porous overlays differ markedly from conventional dense overlays. Dense overlays strive to be as impervious as possible to keep water out. This is because water has typically been thought of as asphalt’s worst enemy. If water were able to penetrate the surface, it would be detrimental to the structural integrity of the pavement due to frost heave. Advocates of Open Graded Friction Courses (OGFC), however, maintain a different philosophy. OGFC is designed to have a high air content to allow water to infiltrate the friction course. This prevents water from accumulating on the roadway surface, which eliminates hydroplaning. Allowing the penetration of water is not deleterious during freezing conditions because the volume of air voids is large enough to prevent frost heave.

OGFC is not to be confused with porous asphalt with infiltration beds. Porous asphalt with infiltration beds are to be used in parking lots and secondary roads. They allow water to pass through all layers of the pavement system and eventually reach the water table. Porous overlays consist of gap-graded coarse aggregates and asphalt binder. In some cases this binder may be modified with fibers or polymers to augment its strength characteristics. Furthermore, OGFC utilize high quality aggregates to ensure good aggregate interlock, which mitigates rutting. Polymer modified binders are also typically employed to increase durability in colder climates where raveling may be problematic. Nominal maximum aggregate size is generally around 12.5 millimeters, but can vary from state to state depending on the environmental conditions it may be subjected to. The porous friction course usually contains between 20 and 24 percent air voids due to the lack of fine gradation particles. Additionally, porous overlay courses can range from 1 to 2 inches thick at the discretion of the design engineer.

Improved safety and friction with the road surface during wet weather conditions can be attained by utilizing OGFC. In porous overlays, tire pressure pushes the water through the voids so it can travel laterally to the shoulders of the roadway. As a result, water does not pond on the surface like dense graded asphalt, which enhances the driving environment. Conventional pavement only retains ¼ its frictional value during wet weather conditions, whereas OGFC maintains the same amount of friction. Moreover, sight-reducing back spray and headlight glare are not produced by porous overlays.
Porous friction courses afford noise attenuating effects that can be much cheaper than conventional noise abatement barriers that can be as costly as 3 million dollars per mile. OGFCs mitigate noise by allowing the air pressure that produces noise in conventional asphalt, to be pumped through the voids of the friction course. Essentially, the OGFC is absorbing the sound energy produced from the rolling tire. Porous overlays can diminish road noise by 3 decibels in dry conditions, and up to 8 decibels during wet conditions. This is equivalent to a 50% reduction in noise. Porous friction courses fix the road noise problem at the source – the tire/road interface.

When utilizing polymer modified binders and high quality aggregates, porous overlays resist rutting extremely well and have longer life spans than conventional HMA. OGFC provides a safer alternative to conventional friction courses that can be used to resurface existing highways or to pave new highways.

Porous overlays generally have higher initial construction costs than conventional HMA. Although a ton of OGFC costs more than dense graded asphalt, OGFCs are lighter; therefore, a ton of OGFC can cover more area than a ton of conventional asphalt. The cost is even more equalized due to the fact that OGFC has a longer life span than HMA.

Although much success has been observed recently with OGFC, it took many years of experimenting with different combinations of maximum aggregate size, air content, and layer thickness, to develop a quality blend. Many states discontinued their use of OGFC in the mid-1980s due to performance failures; however, most of these problems were fixed recently due to increased air content and the introduction of modified polymer binders. Oregon has been experimenting with OGFC since the 1930s and over time has developed a quality mixture that is structurally stable and durable, even in cold conditions. Other states throughout the United States have also seen great success with porous overlays; currently 22 states utilize porous friction courses to some extent.

**Questions**

1. List three benefits of Open Graded Friction Courses

2. Why must the friction course have such high air content?

3. Why might polymer modified binders be utilized in porous friction courses?
Foamed Polystyrene
A Brief Summary

Group 3: John Cavalueci, Ryan McGowan, Dan MacInnes, Ken Marshall, Dana Pancoast

Polystyrene is a very versatile product that has come to serve in many applications. Though its discovery was at first less than remarkable, later research and experimentation lead to the development of products like foamed polystyrene. Foamed polystyrene is the foam board insulation most commonly seen in the form of Styrofoam brand insulation. Developed and released by the Dow Chemical Company in 1957, Styrofoam insulation is today a familiar sight at construction sites across the country. Ironically, the disposable dishware and cooler insulating materials with which the Styrofoam name is most commonly associated are not even made from Styrofoam. True Styrofoam comes in the form of blue boards used for insulation in housing and commercial applications.

Chemically Styrofoam is a foamed version of the organic compound styrene. Styrene independently is a Benzene ring with 2 attached hydrocarbon atoms. In the Polystyrene formation, Styrene atoms link together to form a long chain of hydrocarbons in which every other carbon atom is connected to a benzene ring. This unique atomic configuration is what gives polystyrene its distinctive properties.

Foamed Polystyrene provides an excellent R value per unit weight while providing unparalleled resistance to water permeation. These characteristics make it ideal for building applications for various reasons. The high R value gives it good insulating characteristics preventing energy losses through exterior walls and foundations. Also, with a high R value per unit weight, Styrofoam insulation exerts virtually no additional load onto the structure which it insulates. Its relative light weight also makes it incredibly easy to install and therefore a reasonably priced capital investment toward future energy savings.

Equally important, Styrofoam’s water resistance ensures that the product will have a long effective lifespan while protecting the structure it insulates. Water infiltration is the enemy of insulation in that heat flows easily through water, completely contrary to the goals of insulating. When water infiltrates into an insulator, the insulator is rendered ineffective as heat is transferred through the insulation by the water molecules. Insulators also need to be water resistant for biological reasons. Mold tends to grow in warm, dark, damp places. If insulation was to absorb and retain water, it would be an ideal environment for mold to flourish endangering the occupants both biologically, and potentially structurally. This is where Styrofoam holds its primary advantage over insulations like fiberglass. While fiberglass has a low unit weight for its R value,
it has very little resistance to water infiltration which will greatly reduce its initial R value and eventually lead to the growth of mold.

Another application where Styrofoam has proved to be ideally suited is as a provider of buoyancy. One cubic foot of Styrofoam buoyancy billets can float 55 pounds. These billets are lighter and easier to install compared to steel drum floated structures. Also with billets there is an inherent stability the greatly reduces rocking that might be experienced with the use of something like a steel drum. Again, Styrofoam’s unique properties make it ideal in that Styrofoam billets do not waterlog or corrode. They also resist attack of destructive marine growths such as barnacles and marine plant life and are unaffected by the presence of either salt or fresh water. Styrofoam remains unaffected even through numerous freeze thaw cycles.

Even in this summary it can clearly be seen that Polystyrene is an important material possessing very useful characteristics. Its unique combination of material properties makes it an ideal material in many applications and its use continues to grow as more and more companies experiment with different ways to utilize the advantageous properties possessed by polystyrene. Its applications in water and in homes and commercial buildings make Styrofoam an important construction and engineering material and its continual development and implementation ensures it will remain an important material for many years to come.

Questions:

1) Are “Styrofoam” cups and plates really made from Styrofoam?
2) List two advantages of using Styrofoam insulation over fiberglass insulation.
3) What is the primary organic compound in Styrofoam?
Summary of Fiberglass Reinforced Polymers

Group # 4: Brian Arledge, Brad White, Anthony Sinn, Ryan Tether, Dennis Fox

A composite is a multiphase material that exhibits many of the properties of the constituents. The main idea behind composites is to combine materials to make a final product that has desired properties. Most composites are composed of two phases, a matrix and a dispersed phase. The properties of a composite depend heavily on the properties of the constituents.

Fiberglass is an inorganic synthetic material. There are three categories of fiberglass, S-glass, E-glass, and C-glass. E-glass is the most common type of fiberglass used in polymer composites. Fiberglass is noncrystalline and isotropic. In the manufacturing process of fiberglass, melted glass is drawn through small orifices and a protective coating is applied to the drawn filaments. The filaments are then wound on a spool.

The matrix component of fiber-reinforced composites serves three purposes:

- To transfer stresses between the fibers.
- To provide a barrier against an adverse environment.
- To protect the surface of the fibers from mechanical abrasion.

The matrix is not important in carrying tensile loads. However, the matrix is important in members subjected to bending, torsion, and compression. A polymer is a solid, nonmetallic compound composed of small repeating units. The two main categories of polymers are thermoplastic and thermosetting. A thermoplastic polymer can be repeatedly softened and hardened. Thermosetting polymers are permanently hardened after they are initially formed from chemical reactions. Thermosetting polymers are used more in fiberglass-reinforced polymers.

The use of fiber-reinforced composites dates back to 800 B.C. in Israel. The first modern application in civil engineering was a dome built in Benghazi, Libya in 1968. The fiberglass reinforcement in the polymer may be aligned, randomly oriented, or partially oriented. Usually the composite is stronger when the fibers are aligned along the direction of loading. Fiberglass-reinforced polymer also contains fillers to reduce cost and improve properties. There are four main steps in the manufacturing process of fiberglass-reinforced polymers. These steps are impregnation, lay-up, consolidation, and solidification.

Polymers reinforced by fiberglass are strong, mostly non-flammable, non-conductive, and almost totally corrosion-resistant. Reinforced polymers are very sensitive to abrasion. These composites have tensile strengths exceeding 30,000 psi.

The reinforced composites are better in tension than compression and are used in beams to support flexural loads. Polymers can be cast into many structural member shapes such as
beams, boards, and sheets. Fiberglass-reinforced polymers can be bolted, glued, or molded around a structural member being strengthened. Randomly oriented glass fibers in the polymer matrix can effect how the material reacts under loading. Polymers are homogeneous solutions meaning they carry an even distribution. Any impurities in the matrix can cause an uneven distribution in the material causing the material to respond to the load improperly.

The cost of fiberglass-reinforced composites is relatively cheap compared to other building materials. Compared to stainless steel, this material is about 20 percent of the cost making the material practical for low-budget, large scale projects.

Fiberglass-reinforced composites have a variety of applications. Steel and other metals have a tendency to corrode over time when exposed to chemicals and weathering. This material is lightweight, requires no welding, and can very easily worked with in reconstructing and shaping. Because of these aspects of fiberglass-reinforced polymers, little maintenance is required.

The fiberglass industry is growing faster every year. The demand for this material is based off of new construction applications more than remodeling or replacement. Sales of fiberglass-reinforced polymers are expected to increase a significant percentage over the next year.

**Questions**

1. What are the three main types of fiberglass?
2. What are three applications of fiberglass-reinforced polymers?
3. What fiber orientation makes the composite strongest?
   a) Aligned
   b) Partially aligned
   c) Randomly oriented
Fiber Reinforced Polymer Summary

Group #5 Lauren Di Giovanni, Dustin Kuzan, Danielle Scrivani, Jim Zamorski

Civil engineers have been in search of replacements for steels and alloys to contest the high costs of repair and maintenance for many different structures. Fiber reinforced polymer is one type of material that can be used for these civil engineering applications. Modern applications of composite materials include aerospace, sporting goods, automotive, military, communications, prosthetics, and building infrastructure. Fiber reinforced polymers (FRP) are increasingly being used as reinforcement in new concrete structures to replace the typical steel rebar. FRP has a lot of appeal because of its high specific strength, high specific stiffness, and high corrosion resistance.

Fiber reinforced polymers have many different properties associated with it including physical, chemical, and mechanical. The tensile strength of typical structural steel and high strength alloy steel is about 400 and 760 MPa respectively, while FRP ranges from about 540 to 1700 MPa; however, when compared to steel its modulus of elasticity is much lower. There are three different categories that fiber reinforced polymers can fall under: FRP as rebar, FRP in bridges or FRP in column and beam repair.

Fiber reinforced polymers can be used as rebar in concrete structures. This idea was founded on the concept that FRP is just as strong as steel in many ways but will not corrode with the chemicals that are found in concrete. The shear strength of the FRP rebar was tested and studied by creating slabs of concrete with embedded rebar of either carbon fiber reinforced polymer (CFRP) or glass fiber reinforced polymer (GFRP). These values for shear strength are important because the fiber reinforced polymers and steel rebar can be compared for this property. The bond strength of the FRP rebar to concrete is about 40-100% of the bond strength of steel rebar with concrete. This means if the same load were applied to a structure with FRP rebar and with steel rebar, the FRP will separate from the concrete and have unpredicted behavior sooner. Another property of FRP as rebar is its susceptibility to temperature change. If FRP in the concrete is highly susceptible, the structure may fail sooner than desired. After tests were conducted it was found that the critical temperature was defined as the temperature at which the material lost 50% of its ultimate tensile strength.

Fiber reinforced polymers can also be used in bridge deck design. Many tests have been performed on the new hybrid material to ensure that it can stand up to its desired applications such as bridge decks and girders. The major concerns when dealing with this application is the strength and fatigue of the system overtime and the dynamic response to moving loads such as vehicles. The tests concerning these properties revealed that adding concrete to the design
increased the stiffness of the FRP material by 19%. Also, it was discovered that this FRP-concrete composite structure was able to support 8.2 times more than the AASHTO required.

Columns and beams can be repaired by using FRP to wrap the weak columns or beams. The main issue with wrapping is the shape of the column or beam as the strain and stress levels will vary. FRP wrapping is not as effective as it is rebar and bridge design.

There are many benefits in using fiber reinforced polymer. FRP is non-corrosive and resistant to chemical attacks, non-magnetic, transparent to radio frequencies, and electrically and thermally non-conductive. These polymers also have a tensile strength greater than that of steel and weighs four times less than steel. Some construction issues must be taken into consideration before using fiber reinforced polymers. Lower productivity and differences in construction operations might be expected since this material is not as widely used as steel rebar. The cost of fiber reinforced polymer is approximately eight times more expensive than steel reinforced bars. This is the one major disadvantage when using FRP in design.

Several applications in the civil engineering industry can use fiber reinforced polymers. New construction can include bridges, pre-stressing tendons, reinforcing bars, grid reinforcement, and dowels. The more common uses for fiber reinforced polymers are with rehabilitation and repair. This material can also be used for architectural applications such as siding, roofing, and flooring.

The use of fiber reinforced polymers can have a significantly increasing impact in the civil engineering industry. As for long term potential, this material can have a promising future, most notably for its increasing use in bridge construction. Fiber reinforced polymer has the potential for more durability and greater cost-effectiveness in many bridge designs.

Questions

1. What are four modern day applications of fiber reinforced polymers?
2. Three categories fiber reinforced polymers can fall under?
3. What are three benefits of using fiber reinforced polymers?
Summary of Carbon Nanotubes

Group 6: Dan Giacobbe, Samuel Hahn, Malay Patel, Nolan Towers, Ryan Veasy

In Civil Engineering industry many materials are used or have been used for construction projects, such as bridges, roads, buildings, foundations, etc. Some of the most common civil engineering materials are wood, cement concrete, asphalt concrete, and steel. There are many other materials that are used everyday in civil engineering projects such as aggregates, plastics, and fiber re-inforced composites. A new material being tested is carbon nanotubes. The purpose of this paper is to explain an unknown material that will or has been used in the construction of some sort of structure. The properties of the material being used in the structure has to be known in order to make sure the structure will not fail and will last. The paper will also take into account the properties, history, cost, feasibility, and availability of the material for use in construction.

One of the newest materials being studied and experimented for use in civil engineering materials is carbon nanotubes. Carbon nanotubes were observed earlier, but not discovered until 1991. These molecular structures are made up carbon atoms in its graphite form. The bonding of the atoms creates hexagons which wrap around forming a cylindrical tube of atoms. The ends are capped off with similar structures of carbon atoms. This structure gives the nanotube great stability and other desirable properties for use in the civil engineering materials field. A lot is still to be learned about the physical, mechanical, and chemical properties of carbon nanotubes.

Currently carbon nanotubes are mainly in the experimental phases but they have been used in some construction projects. Carbon nanotubes were discovered for use in electrical components first. The unique structures of carbon nanotubes allow for it to be either metallic or a semiconductor depending on the numerous arrangements. Metallic carbon nanotubes can actually be the best thermal and electrical conductors known to date, only being surpassed by superconductors.

The combination of size, structure, and topology of carbon nanotubes allow them to have important mechanical properties. After continued testing they were found to have great structural properties. Although they were found to be weak in compression due to having a hollow body, carbon nanotubes are at least 30-50 times stronger in tensile strength than steel. They also have been determined to have extremely high Young’s modulus values lying around 1TPa. This allows carbon nanotubes the have very flexible behavior with respect to high loads.

Although carbon nanotubes show a great potential in the field of civil engineering, they are still a long way off from being a useful material. Currently the methods to make carbon nanotubes are very expensive and have not been able to be made into useful civil engineering
products. Research is currently underway to develop methods that are more cost efficient and can make carbon nanotubes into a useful structural material.

Every year there are more and more applications that nanotube technology is applied to. Recently, carbon nanotubes have been implemented into the civil engineering industry into materials such as concrete, cement, glass, and steel. The tensile strength of carbon nanotubes have a positive influence on the strength of concrete when included in the mix design. Nanotubes have also been designed into ropes for the possibility of using them in suspension bridges. If implemented in the cables for bridges, nanotubes will give the ability to build longer and stronger bridges than ever because of their tensile strength. They are also used in composites to improve the mechanical, thermal, and electrical properties.

The use of carbon nanotubes in structures is currently limited and it may be a couple of years before they are used. Carbon nanotubes have structural properties that can be extremely useful due to its size, shape and, physical properties. Even though this material is new and still basically in the experimental phases the potential of this could help strengthen other materials or could be used by itself. Currently, the new physical properties are still being found and disputed at this time.

Questions

1) When year were carbon nanotubes discovered?

2) Approximately how much stronger are carbon nanotubes than steel in tensile strength?

3) What are the two categories that carbon nanotubes are divided into?
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