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REPUBLIC OF THE PHILIPPINES

DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS

OFFICE OF THE SECRETARY

MANILA

JUN 17 2010

DEPARTMENT ORDER) **No.** 33) **Series of 2010** 06-17-10)	**SUBJECT** :	**DPWH Standard Specification for Carbon Fiber, Item 416**

In line with the mandate of the Department of providing effective standards for application in the implementation of various infrastructure projects and in view of the need of setting standard specifications for carbon fiber, the attached **DPWH Standard Specification for Carbon Fiber, Item 416**, is hereby prescribed, for the guidance and compliance of all concerned.

This specification shall form part of the DPWH Standard Specifications for Public Works Structures (Volume II – Highways, Bridges and Airport).

This order shall take effect immediately.

VICTOR A. DOMINGO
Acting Secretary

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DPWH STANDARD SPECIFICATIONS FOR

ITEM 416 – CARBON FIBER

416.1 Description

This Item covers carbon fibers for use to reinforced concrete structures as shown on the Plans or as directed by the Engineer.

416.2 Materials Requirements

416.2.1 Definition / Raw Material

A carbon fiber also called **carbon fibre**, graphite **fiber**, or **carbon graphite** is a long, thin strand of material about 0.0002-0.0004 in (0.005-0.010 mm) in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The yarn or fabric is combined with epoxy and wound or molded into shape to form various composite materials. Carbon fiber has many different weave patterns and can be combined with a plastic resin and wound or molded to form composite materials such as carbon fiber reinforced plastic (also reference as carbon fiber) to provide a high strength to weight ratio materials. The density of carbon fiber's also considerably lower than the density of steel, making it ideal for applications requiring low weight.

Raw Material

The raw material used to make carbon fiber is called the precursor. About 90% of the carbon fibers produced are made from polyacrylonitrile. The remaining 10% are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms.

Commercial forms of Carbon Fibers

Carbon fibers are available as "tows" or bundles of parallel fibers. The range of individual filaments in the tow is normally from 1000 to 200,000 fibers. Carbon fiber is also available as a prepreg, as well as in the form of unidirectional tow sheets. Typical properties of commercial carbon fibers are shown in Table **416.2.1.**

Table 416.2.1 Typical properties of commercial composite reinforcing fibers [constructed from Mallick (1988b) and Akzo-Nobel (1994)]

Fiber	Typical diameter (microns)	Specific gravity	Tensile modulus GPa (10^6 psi)	Tensile strength GPa (10^3 psi)	Strain to failure, percent	Coefficient of thermal expansion 10^{-6}/C	Poisson's ratio
Carbon PAN-Carbon T-300a	7×10^{-6} (7)	1.76	231 (33.5)	3.65 (530)	1.4	-0.1 to -0.5 (longitudinal), 7-12 (radial)	- 0.20
PITCH-Carbon P-555a	10^{-7} (10)	2.0	380 (55)	1.90 (275)	0.5	-0.9 (longitudinal)	-

[a] *Amoco*

416.2.2 Sampling and Testing

The product shall be subject to sampling and testing. The product shall meet ACI Guidelines and ASTM D-3039.

416.3 Construction Requirements

416.3.1 The Manufacturing Process

The process for making carbon fibers is part chemical and part mechanical. The precursor is drawn into long strands or fibers and then heated to a very high temperature with-out allowing it to come in contact with oxygen. Without oxygen, the fiber cannot burn. Instead, the high temperature causes the atoms in the fiber to vibrate violently until most of the non-carbon atoms are expelled. This process is called carbonization and leaves a fiber composed of long, tightly inter-locked chains of carbon atoms with only a few non-carbon atoms remaining.

The fibers are coated to protect them from damage during winding or weaving. The coated fibers are wound unto cylinders called bobbins.

416.3.1.1 Spinning

- Acrylonitrile plastic powder is mixed with another plastic, like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a conventional suspension or solution polymerization process to form a polyacrylonitrile plastic.

- The plastic is then spun into fibers using one of several different methods. In some methods, the plastic is mixed with certain chemicals and pumped through tiny jets into a chemical bath or quench chamber where the plastic coagulates and solidifies into fibers. This is similar to the process used to form polyacrylic textile fibers. In other methods, the plastic mixture is heated and pumped through tiny jets into a chamber where the solvents evaporate, leaving a solid fiber. The spinning step is important because the internal atomic structure of the fiber is formed during this process.

- The fibers are then washed and stretched to the desired fiber diameter. The stretching helps align the molecules within the fiber and provide the basis for the formation of the tightly bonded carbon crystals after carbonization.

416.3.1.2 Stabilizing

- Before the fibers are carbonized, they need to be chemically altered to convert their linear atomic bonding to a more thermally stable ladder bonding. This is accomplished by heating the fibers in air to about 390-590° F (200-300° C) for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously. They also generate their own heat, which must be controlled to avoid overheating the fibers. Commercially, the stabilization process uses a variety of equipment and techniques. In some processes, the fibers are drawn through a series of heated chambers. In others, the fibers pass over hot rollers and through beds of loose materials held in suspension by a flow of hot air. Some processes use heated air mixed with certain gases that chemically accelerate the stabilization.

416.3.1.3 Carbonizing

- Once the fibers are stabilized, they are heated to a temperature of about 1,830-5,500° F (1,000-3,000° C) for several minutes in a furnace filled with a gas mixture that does not contain oxygen. The lack of oxygen prevents the fibers from burning in the very high temperatures. The gas pressure inside the furnace is kept higher than the outside air pressure and the points where the fibers enter and exit the furnace are sealed to keep oxygen from entering. As the fibers are heated, they begin to lose their non-carbon atoms, plus a few carbon atoms, in the form of various gases including water vapor, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others. As the non-carbon atoms are expelled, the remaining carbon atoms form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber. In some processes, two furnaces operating at two different temperatures are used to better control the rate de heating during carbonization.

416.3.1.4 Treating the surface

- After carbonizing, the fibers have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibers better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. Oxidation can be achieved by immersing the fibers in various gases such as air, carbon dioxide, or ozone; or in various liquids such as sodium hypochlorite or nitric acid. The fibers can also be coated electrolytically by making the fibers the positive terminal in a bath filled with various electrically conductive materials. The surface treatment process must be carefully controlled to avoid forming tiny surface defects, such as pits, which could cause fiber failure.

416.3.1.5 Sizing

- After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others.

- The coated fibers are wound onto cylinders called bobbins. The bobbins are loaded into a spinning machine and the fibers are twisted into yarns of various sizes.

416.3.2 Quality Control

The very small size of carbon fibers does not allow visual inspection as a quality control method. Instead, producing consistent precursor fibers and closely controlling the manufacturing process used to turn them into carbon fibers controls the quality. Process variables such as time, temperature, gas flow, and chemical composition are closely monitored during each stage of the production.

416.3.3 Health and Safety

There are three areas of concern in the production and handling of carbon fibers: dust inhalation, skin irritation, and the effect of fibers on electrical equipment.

During processing, pieces of carbon fibers can break off and circulate in the air in the form of a fine dust. Industrial health studies have shown that, unlike some asbestos fibers, carbon fibers are too large to be a health hazard when inhaled. They can be an irritant, however, and people working in the area should wear protective masks.

The carbon fibers can also cause skin irritation, especially on the back of hands and wrists. Protective clothing or the use of barrier skin creams is recommended for people in an area where carbon fiber dust is present. The sizing materials used to coat the fibers often contain chemicals that can cause severe skin reactions, which also requires protection.

In addition to being strong, carbon fibers are also good conductors of electricity. As a result, carbon fiber dust can cause arcing and shorts in electrical equipment. If electrical equipment cannot be relocated from the area where carbon dust is present, the equipment is sealed in a cabinet or other enclosure.

416.3.4 Applications

Carbon Fiber Reinforced Polymer (CFRP) becomes an increasingly notable material use in strengthening concrete, masonry, steel cast iron and timber structures. It's use in industry can be either for retrofitting to strengthen existing structures or an alternative reinforcement (or prestressing material) instead of steel from outset of the project.

Retrofitting has become the increasingly dominant use of Carbon Fiber Reinforced Polymer (CFRP) and applications include increasing the load capacity of old structures (such as bridges) that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed its strengthening using Carbon Fiber Reinforced Polymer (CFRP).

Applied to reinforced concrete structures for flexure, carbon fiber typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only a moderate increase in stiffness (perhaps a 10% increase). This is because the material used in this application is typically very strong (e.g., 3000 MPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa, a little less than steel, is typical). As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness.

Carbon Fiber Reinforced Polymer (CFRP) can also be applied to enhance shear strength of reinforced concrete by wrapping fabrics or fibres around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economical than alternative methods.

If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the carbon fiber wrap enhances the compressive strength of the concrete. However, although large increases are achieved in the ultimate collapse load, the concrete will crack at only slightly enhanced load, meaning that this application is only occasionally used.

Special ultra-high modulus carbon fiber (with tensile modulus of 420 GPa or more) is one of the few practical methods of strengthening cast-iron beams. In typical use, it is bonded to the tensile flange of the section, both increasing the stiffness of the section and lowering the neutral axis, thus greatly reducing the maximum tensile stress in the cast iron. Carbon Fiber Reinforced Polymer (CFRP) could be used as prestressing materials due to high strength. The advantages of Carbon Fiber Reinforced Polymer (CFRP) over steel as a prestressing material because it's lightweight and corrosion resistance should enable the material to be used for applications such as in offshore environments.

416.4 Method of Measurement

The carbon fiber shall be measured by the number of square meter placed and accepted as shown on the Plans.

416.5 Basis of Payment

The quantity to be paid for, as provided in Section 416.4Method of Measurement shall be paid for and for all labor, equipment, accessories, tools and incidentals necessary to complete the Item.

Payment will be made under:

Pay Item Number	Description	Unit of Measurement
416	Carbon Fiber (Thickness in mm)	Square Meter

REFERENCES:

1. ASTM (AMERICAN SOCIETY FOR TESTING AND MATERIALS)
2. ACI (AMERICAN CONCRETE INSTITUTE)
3. INTERNET - WORLD WIDE WEB (WWW)