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FIBER REINFORCED PLASTIC RODS FOR PRESTRESSED CONCRETE STRUCTURES

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The article describes a composite reinforcement with different types of reinforcing fibers, provides its basic properties, positive qualities compared with metal reinforcement. The article deals with the question of anchoring of rod reinforcement in composite prestressed concrete structures, presents different types of anchors.

Fiber reinforced polymers (FRP) are a particular typology of composite materials, made of high-tenacity fibers impregnated with polymeric resins. The mixing result is a material with properties between fiber and resin (Fig. 1).

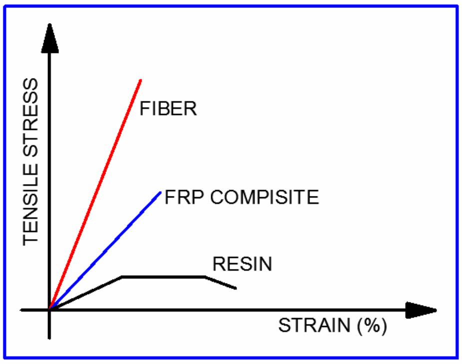

Fig. 1. Comparison among fiber's, resin's and composite's tensile properties

FRP materials have a high tensile strength in the fiber direction and a low resistance force in the direction across the fibers, indicating the anisotropic nature of these materials. Composites have no ductility and therefore they are elastic to failure, and they are also characterized by a relatively low modulus of elasticity in tension and compression. Their function is usually in adsorbing tensile stress due to shear and flexural actions. FRP properties make these materials particularly suitable for structural applications, especially in support or substitution of steel. The general advantages of FRP reinforcement compared to steel are:

– durability in aggressive environments;
– low specific weight;
– magnetic and electric neutrality;
– low axial coefficient of thermal expansion;
– high strength-to-density ratio.

The composite reinforcement can be produced in the form of round rod, strands, laminates, which leads to the widespread usage of such a reinforcement in building constructions (Fig. 2).

Fig. 2. FRP rods (left) and laminates (right)

Three most common types of FRP used in construction are made of carbon, aramid or glass fibers.

Carbon fiber: fibers obtained by heating an organic feed containing substantial amounts of carbon (93–95%), such as rayon, polyacrylonitrile (PAN), or black residue from petroleum distillation in an inert environment. This type of fiber is the most durable and tough. Carbon fiber, considerably more expensive than glass fiber, but provides an excellent combination of strength, low specific gravity, high elastic modulus and fatigue properties.

Aramid Fibers (ex. Kevlar): highly oriented organic fibers derived from polyamide incorporating into aromatic ring structure. This type of fiber has a high impact resistance, good dielectric and insulating properties, they are also resistant to organic solvents, races, various fuel and lubricants. They have a medium modulus and a very low density as compared to glass and carbon.

Glass fibers: fibers obtained from an extract product of melting inorganic glass which cools without crystallization. E-glass is considered predominant fiber for reinforcing polymeric matrix due to its high electrical insulating properties and low sensitivity to humidity. S-fiberglass has a high strength, heat resistance and elastic modulus. AR-glass has a high chemical resistance. On the other hand, the composite reinforcement of the S- and AR-glass has a sufficiently large value, compared to other glass fibers. E-glass fibers are made of ordinary glass, but such composites in future exceed the weight of aramid and carbon, and low modulus of elasticity requires special design standards where is necessary to provide the required rigidity of structures.

It should be noted that glass is the dominant fiber for reinforcing composites and is used in many engineering structures due to the economic advantages of cost and strength properties.

The comparison based on fiber area among sheets made of carbon (CFRP), aramid (AFRP), glass (GFRP) and reinforcing steel in terms of stress-strain relationship is depicted in Figure 3.

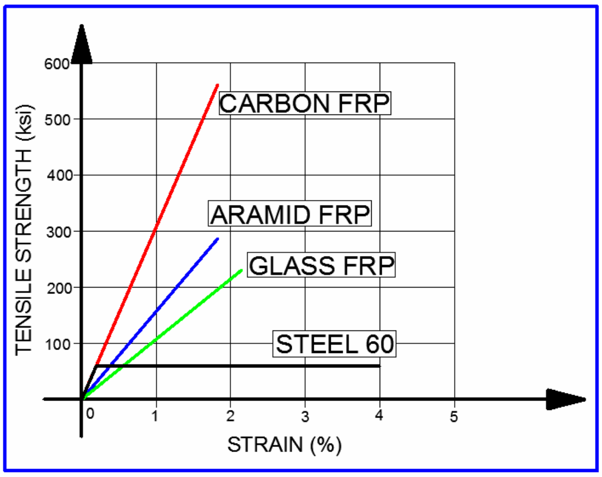

Fig. 3. Comparison among AFRP, CFRP, GFRP and Steel

Composite reinforcement produced by pultrusion: fiber is pulled through a bath with a resin, molding guide and held in a heated mold to cure. The most important issue affecting the design of concrete elements with composite reinforcement, is the connection between the reinforcement and concrete. Rods made during the pultrusion process, have a smooth surface. At the moment, three different ways to apply the rod surface treatment to give the desired coupling rod with concrete exist. The first method of obtaining the necessary profile is wrapping the rod with additional fiber impregnated with resin during the rod hardening. The second method comprises applying to the core surface the sand which after cooling and hardening of the composite makes its surface rough. The third method is rips stamping on the core. It should be noted that the reinforcement with the untreated surface requires special anchoring devices, which is particularly necessary in the construction of prestressed structures.

Mechanical properties. Composite rods used in construction are unidirectional composites. The direction parallel to the axis of the rod, called the longitudinal direction in which the mechanical properties depend on the fiber strength. The transverse direction perpendicular to the axis of the rod has lower mechanical properties, depending on the properties of the resin and the surface of the polymer matrix. It suggests that the reinforcement mechanical properties depend on the properties and content of the fibers in the longitudinal direction. **Tensile behavior.** Under the influence of the tensile load, composite materials do not show up ductility until rupture. The work of rods consisting of one type of fiber is characterized by a linear elastic stress-strain state before the destruction. **Bond behavior.** It is known that in a polymer composite reinforcement external forces are transmitted through the polymer to the fiber that makes destruction of the rod or loss of connection with the shift of the polymer and fiber possible. When a deformed rod in concrete is under increasing tension, adhesion between the rod and the surrounding concrete is deteriorating, and the strain on the surface of the rod causes the tangent force between it and the surrounding concrete. The stress at the surface of the bar resulting from the force component in the direction of the bar can be considered the bond stress between the bar and the concrete. **Durability.** FRP bars are susceptible to changes in the environment before, during and after constructing, with a change in the strength and stiffness. The types of the environment are water, ultraviolet radiation, elevated temperature, acidic and alkaline solutions, saline solutions. The strength and stiffness may increase, decrease or remain unchanged, depending on the material and the conditions of exposure. When stretching and bending properties of composite rods are the main parameters to analyze in reinforced concrete structures.

In order to ensure reliable adhesion of concrete with composite reinforcement in the prestressing, anchor devices must be provided to the rod. Anchor types can be divided into three groups: wedge, resin/grout potted, and spike systems. The wedge systems can be further subdivided into direct contact (plastic and steel wedges) and systems utilizing a sleeve. The potted anchors group varies depending on the internal configuration of the socket – straight, linearly tapered, and parabolically tapered sockets. The following observations are made for the three anchor groups:

Wedge Anchors. To ensure proper adhesion reinforcement, there must be abrasive on the surface of the wedge. This observation comes from comparisons between the stress of carbon and reinforcement rods, both of which use plastic wedges. Carbon intensive system is coated with sand do not slip in the untreated rod wedges. Steel wedges cause some local damage to the fibers, although there was no evidence of loss of efficiency. Systems with a dry lubricant on the outer surface of the wedge is easier to understand than other systems, although the use of force is required to release the wedges.

Resin/Grout Potted Anchors. Potted anchors often fail to go through pullout of the tendon from the resin/grout anchor without rupture of the tendon. The parabolic system has showed splitting and cracking of resin plugs. The potted anchors are the easiest to setup for testing when they are pre-installed. The practical drawbacks include precutting the tendons to length and the curing time for the resin/grout.

Spike Anchors. The spike anchors used with the dry fiber ropes work out relatively well. This system requires field setup time, which resulted from the combination of removal of the plastic sheath, combing and spreading of the individual fibers and proper placement of the spike with a uniform distribution of fibers all around it.

A variety of devices for anchoring a composite reinforcement is shown in Figure 4.

Fig. 4. Anchors for FRP rods

Prestressing rods. Interest in the usage of FRP composites in prestressed concrete is mainly based on the durability of structural issues. Corrosion of steel rods tendon caused a serious deterioration of the widespread usage of metal reinforcement for prestressed concrete. Such properties as high tensile strength and high corrosion resistance, it would seem, make FRP good candidates for prestressing bars. A problem is that FRP materials are very time and service dependent. Under steady load they show varying degrees of creep deformation: CFRP does not creep, GFRP shows a negligible creep, AFRP shows long-term deformations due to creep. In addition, fiberglass rods have premature rupture under sustained tensile load. Conducting constant voltage, a tensile strength of GFRP falls to values as low as 20% that causes rupture. Because of these reasons, the carbon fiber seems the most appropriate for FRP prestressing. Another problem that must be solved is the strengthening of rods. Special devices must be due to low strength in the transverse direction of the fibers. The advantage is that the FRP rods have a high tensile strength with moderate modulus and less sensitive to aging of concrete.

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CONSTRUCTION OF FLUIDITY BORDER TAKING INTO ACCOUNT PLASTIC ANISOTROPY

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Anisotropy due to plastic deformation was studied on tubular steel specimens. This type of anisotropy is found to influence the plastic strain increment vector as the stress point moves over the yield surface associated with a prescribed prestraining. The length of the plastic strain increment vector is found to decrease as the stress point moves from the point associated with the prestraining program. An appropriate measure of this effect is introduced in the form of a modulus of the effective plastic strain increment. Variation of the modulus over the yield surface is compared with the results furnished by the existing flow theories.

Standard theories of plastic flow are formulated to calculate deformations along a given loading path only. Material anisotropy due to plastic deformation is either not accounted for, as it is the case in the theory of isotropic hardening, or is considered only as regards the change of shape and position of subsequent yield surfaces. In all such theories the following ratio:

$$K = -\frac{\delta Э^{P}}{\delta S_{\delta Э}}.$$

Is assumed to be constant on each subsequent yield locus. This ratio - we shall call it the modulus of the effective plastic strain increment - involves $\boldsymbol{\delta Э}^{P}$ which is the length of the plastic strain increment vector and $\boldsymbol{\delta S}_{\delta Э}$, which stands for projection of the stress increment vector on the direction of $\boldsymbol{\delta Э}^{P}$. According to this assumption all the vectors $\boldsymbol{\delta S}$ with equal $\boldsymbol{\delta S}_{\delta Э}$ at any point of the yield surface which corresponds to an actually prestrained material produce the same $\boldsymbol{\delta Э}^{P}$ [1].

The results of experiments [2, 3], suggest however, that the deformation induced anisotropy manifests itself not only through the change of shape and position of subsequent yield surfaces but also makes the modulus K to vary with the stress profile on these surfaces.

The aim of the present paper is to examine how the modulus (1) varies with the loading path and with stress trajectory on the yield surface.

The experiments have been carried out in plane stress under combined tension and torsion. A suitable experimental outfit has been developed, resembling that described in [4]. The deformations were measured by means of mirror extensometers.

Thin-walled, tubular specimens were manufactured from drawn mild steel tubes. The outer diameter and the wall thickness of the specimens were 12 mm and 0.5 mm respectively. Initial anisotropy was removed by annealing.