Handling Prestressed Concrete Strand

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Long-time PCI member **H. Kent Preston** has been involved in the prestressed concrete industry from its beginnings. He was chief product engineer of the Construction Materials Division of John A. Roebling's Sons Corporation when seven-wire strand was being developed. During the past 40 years he has been a consultant to the industry on the many aspects of prestressing steel as it relates to the performance of prestressed concrete. From 1976 to 1979, he was chairman of PCI's Bridge Committee and is still an active member of that committee. Currently, he is an associate of Wiss, Janney, Elstner Associates, Inc. and a consultant to Florida Wire and Cable Company.

The wires used to make strand for prestressed concrete are much more complex than reinforcing steel bars and, in certain respects, must be treated with greater care. This article discusses the various material properties of strand that affect its performance and describes the procedures used in handling, placing and tensioning strand, and the effect concrete curing can have on tensioned strand.

The performance of prestressing strand is dependent upon the quality of its manufacture and the care with which it is handled on the job. Unlike reinforcing steel bars, the wires used to make strand are much more complex and therefore must be treated with greater care.

The purpose of this article is to review the material properties that affect the fabrication of strand and to discuss the necessary procedures and precautions in the handling, installation and tensioning of strand to ensure high quality prestressed concrete. In addition, the effect of concrete curing on tensioned strand is addressed.

Fabrication

Wires in prestressing strand derive their high strength from the chemical composition of the steel, controlled cooling at the rod mill, and cold working.

The chemical composition is such that the plain hot-rolled rod will have an ultimate strength of about 140,000 psi (965 MPa). The rod, as received from the steel mill, has a minimum tensile strength of 165,000 psi (1138 MPa) prior to drawing. The rod is then drawn through a series of dies, each of which reduces its diameter and increases its length. During the wire drawing process, the grains in the steel are drawn out into the long interlocking fibers that increase the strength to more than 270,000 psi (1862 MPa).

A seven-wire strand is made by helically wrapping six outside wires tightly around a single center wire to make a "green" strand. As a result of the wire drawing process plus the preforming of the six outer wires as the strand is made, the wires of the green strand are full of internal stresses. When a green strand is tensioned, the already stressed portions soon reach yield point, the load-elongation relationship is no longer a straight line and stress loss due to relaxation is high.

Green strand is subjected to a subcritical thermal treatment at a temperature of about 725°F (385°C) for a very short time and then water cooled. This short time-temperature treatment has no appreciable effect on wire properties, but since yield strength drops as temperature rises, many of the built-in wire stresses are relieved. The stress relieved strand has better elastic and relaxation properties than green strand.

Low relaxation strand is a more recent development which is now used for most prestressed concrete structures. It has a stress loss due to relaxation that is less than 20 percent of that of stress relieved strand when both are tensioned to 70 percent of ultimate. Low relaxation strand is made from green strand by subjecting it to a high tension during the stress relieving process. This treatment causes a 1 percent permanent elongation and eliminates much of the condition that causes stress relaxation.

Heat Effect

When a wire is subjected to excessive heat, the fibers revert to crystals which (since the cooling is not controlled as it is in heat treating) are identical to those in the original hot-rolled rod with an ultimate strength of about 140,000 psi (965 MPa).

Up to a point the intensity of heat required to cause damage is related to the duration of its application. A temperature of 750°F (398°C) applied for a considerable period of time will cause some loss of strength. Even briefly applied temperatures in excess of 1000°F (537°C) can cause the transition of fibers to crystals.

Fig. 1 was obtained by slicing a wire in half, polishing the sliced surface and taking photographs at a high magnification. It shows the fibrous structure of undamaged wire on the left and the recrystallized structure of an overheated portion on the right.

Wire does not have to be under tension to sustain heat damage and, in many cases, the damage is not visible to the unaided eye after the wire has cooled.

The most common sources of heat in a casting yard are arcs from electric currents, direct heat from a burning torch, and hot metal spatter from a welding or cutting operation. By observing simple precautions, heat damage from these sources can be avoided.

Never perform arc welding in the vicinity of strand. An arc can jump from a metal form, a hold-down device, the steel payoff reel or cage to the strand.

Never cut the steel straps on a coil of strand by burning. Use a standard scissors-type band cutter.

An acetylene torch may be used to cut strands to length when stringing up a casting bed, or to cut strands after the concrete has cured. In this instance, if the strand is burned straight through, the heat damaged area seldom extends more than 1 in. (25.4 mm) from the cut end, and at least an inch protrudes through the gripping jaws. Be sure the cutting operation is conducted so that both heat from the torch and molten metal spatter are kept away from those parts of the strands that will be under tension.

Corrosion

Rust is by far the most common form of corrosion of strand. A light, tight rust is not harmful and improves bond. Section 8.4 of ASTM Designation A416-88b states, "Slight rusting, providing it is not sufficient to cause pits visible to the naked eye, shall not be cause for rejection."

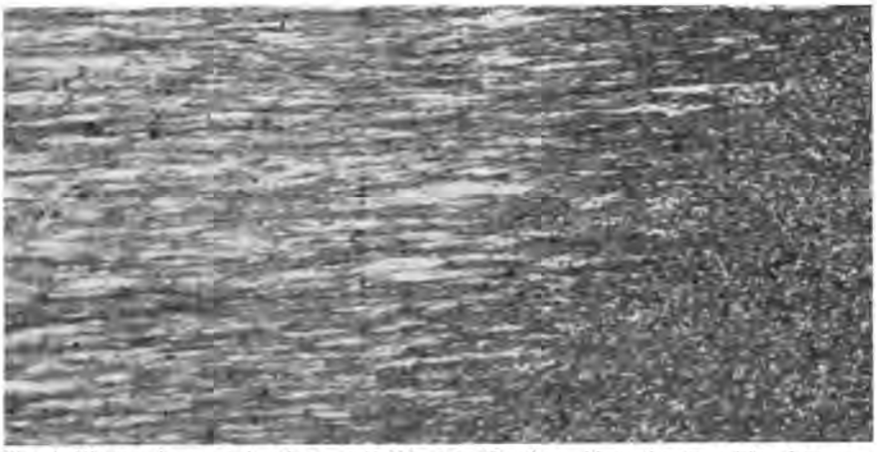

Fig. 1. Photomicrograph taken at 150X magnification. Note the transition from fibrous cold drawn structure on the left to granular heat affected structure on the right.

ASTM A416 specifically approves "slight rusting." This is important. Each wire passes through from four to eight reducing dies as it goes from a rod to final wire size. It is lubricated as it enters each die. Even through the heat of stress relieving some of the lubricant remains on the wires of the finished strand.

Tests show that strand which has been exposed to the atmosphere for a short time, even though it has no visible rust, has better bond than strand protected from manufacture to casting in concrete. The transfer length of strand with light tight rust is about two-thirds that of unrusted strand. Strand with slight rusting in accordance with ASTM A416 should not be rejected.

Pits visible to the unaided eye are stress raisers. In many cases they have little effect on the static tensile strength, but they greatly reduce the ability of the wire to withstand fatigue or repeated loadings. Heavy rust can cause poor bond. The rust bonds to the concrete but comes loose from the wire when bond stress develops.

Contact with chemicals and contaminated ground must be avoided

Placing and Tensioning

Avoid oil and grease. Removal of oil or grease with a rag still leaves a film which lessens or destroys bond.

Proper maintenance and installation of anchor grips is a very important part of maintaining casting bed safety. In a faulty grip, strand failure can occur during tensioning while workers are in the bed preparing for casting of concrete or while the concrete is curing.

When it is anchored in grips of the type used in casting yards and loaded to failure, seven-wire strand always fails in the grip. There are two basic reasons for this:

1. The jaws of the grip exert a large lateral pressure which creates compression in the wires in a direction perpendicular to the tensile stress. Ultimate tensile capacity is reduced by addition of lateral compression.

2. Capacity is further reduced by stress concentrations that develop in the indentions in the wire that are made by the pressure of teeth in the wedges of the grip. Fig. 2 shows this condition.

For use in testing machines in its laboratory, Florida Wire and Cable Company has developed extremely efficient wedge grips which frequently produce a strand failure in the clear between the grips. Unfortunately, they are too large in diameter, too long, too cumbersome and too expensive to use in the casting yard.

While some makes are more efficient than others, most of the grips available for use in the casting yard will give adequate results if properly handled. They should be treated in accordance with instructions issued by their supplier. These usually include:

(a) Cleaning between each use — Foreign matter between the teeth of the wedge, or between the back of the wedge and the inside of the chuck body, will decrease efficiency.

(b) Inspection of cleaned chuck — Look for cracked wedges, worn teeth and the condition of the ring that makes the wedges advance together as they are drawn into the chuck body. Check the inside of the body for smoothness and lack of ridges. After numerous uses, some chuck bodies develop a ridge near the small end of the tapered hole. This can retard forward movement of the wedges.

(c) Proper lubrication is extremely important — Insufficient lubrication will cause too much friction between the back of the wedges and the inside of the chuck body. This will retard the forward motion of the wedges so that they do not grip tightly enough, and the strand may slip through. On the other hand, a lubricant that is too slippery will provide a very low coefficient of friction, and the wedges will slide forward so easily that they create too much pressure on the wires and cause failure at a low load.

Use the cleaning and lubricating materials recommended by the grip's supplier.

The lubricant must be properly maintained. For example, one is a wax in a solvent. Wedges are dipped into this and, as a result, are coated with a proper amount of wax. If this material is not kept properly covered, the solvent evaporates and the resultant coating of wax on the wedges is too heavy.

Mechanical Damage

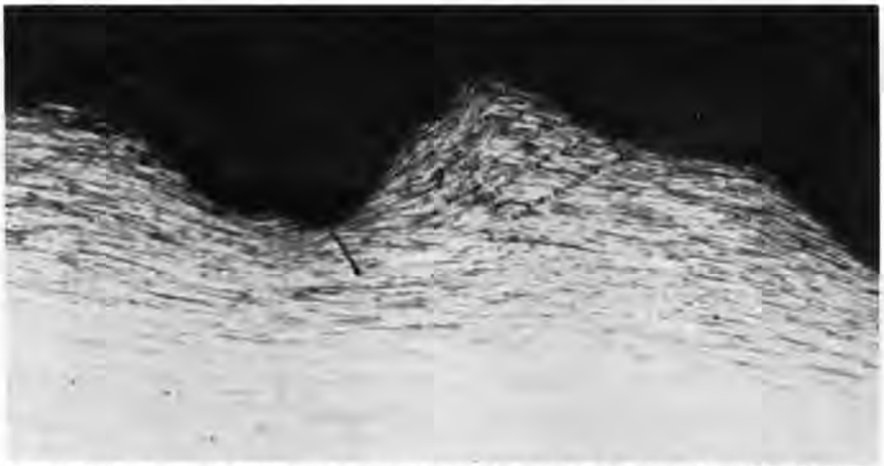

Fig. 2. Enlargement of section in one wire cut by tooth of a strand wedge. Note stress concentrations and hairline cracks.

The wire in prestressed concrete strand is made of high carbon steel, which is more notch sensitive than the lower carbon steel used in most reinforcing bars. A pit from rust, a nick from a wedge grip, or other such damage will greatly reduce the fatigue strength of a strand. Such conditions should not be allowed on that portion of the strand which is within the concrete member.

Laboratory tests have been made where the strand has been tensioned to 80 percent of ultimate using typical casting yard grips, detensioned and loaded to failure with the section containing the teeth marks from the grip in the center of the section being tensioned. Surprisingly, these strands have reached practically the same ultimate tensile strength as undamaged samples from the same coil. The damaged area would have considerable loss in strength with respect to an undamaged strand if subjected to secondary stresses such as being bent around a hold-up pin or being subjected to an impact load.

Curing

Under some conditions of curing, strand tension can increase to the point where some or all of the strands fail before the yard operators cut them. In most cases this does not affect the serviceability of the members being cast.

Several factors, discussed below, can contribute to such failures. Failures of this type are most common where air curing at ambient temperatures is used. They seldom occur where members are steam cured and strands are cut shortly after the steam is turned off.

1. Temperature drop during curing — When the temperature of the concrete drops, the concrete wants to shorten by an amount that is equal to its length times its coefficient of expansion times the temperature drop. Shortening of the concrete is resisted by the unencased strands that stretch between the concrete members and between the end concrete members and strand grips at the ends of the bed.

Since the AE (area times modulus of elasticity) of the concrete members is very large with respect to the AE of the unencased strands, the actual shortening of the concrete is about 95 percent of the amount it would shorten if unrestrained. As the strands are still anchored at the ends of the bed, the unencased strands must elongate an amount equal to the total shortening of the concrete.

This elongation can cause an appreciable increase of tension in the unencased strand because a relatively large increase in length is being absorbed by the relatively short length of unencased strand. The increase in strand tension is a function of the ratio of length of concrete in the bed divided by the length of unencased strand. The larger the ratio, the larger the tension increase.

The unencased strand will experience an additional increase in tension of 1800 psi (12.4 MPa) for every 10°F ($5^1/_2$°C) drop in tension.

2. Shrinkage of concrete — Concrete shrinks as it cures. Shortening of the concrete members due to shrinkage will increase tension in the unencased strand in the same way as shortening occurs due to temperature drop. Minimizing the time from casting of concrete to cutting of strand will minimize tension increase due to shrinkage.

3. Overtensioning — Most specifications permit a difference of 5 percent between tension established by measurement of elongation and tension established by pressure reading at the jack or on a load cell. When there is a difference, some specifications require that the strand be anchored in accordance with the one that will cause the highest tension in the strand.

4. Grip efficiency — Maintaining maximum grip efficiency is one of the best ways to minimize the problem of breakage during curing. In many cases, failure in the grip occurs at a load where the load-elongation of the strand is just bending over. An increase of a few hundred pounds in the load at failure can produce a considerable increase in elongation.

Choose a grip that is efficient and have a well-organized maintenance program.

Detensioning

Strands are usually cut singly or in pairs. Each time a strand is cut it creates compression in the concrete member. This causes the concrete to shorten which elongates the remaining uncut strands and increases their tension. After some strands are cut, those remaining may fail. This seldom affects the serviceability of the concrete members being cast.