Steel for Prestessed Concrete

by **William R. Anderson***

In a structure, concrete and steel work hand-in-hand, each complementing the other's strong point. Concrete is best used when in compression, and steel complements this with its excellent tensile properties. The mechanical properties of both steel and concrete have improved tremendously in the past decade. Today concrete producers are providing prestressed members to make structures that were unheard of 10 years ago.

To understand why certain care is necessary when handling prestressed concrete strand, it is well to know how it is made. The true beginning of prestressing strand is when high quality special grades of steel are combined in a furnace and poured. However, for this discussion, the beginning of prestressing strand is in the form of hot rolled rods. Rods are rolled hot from billets of steel into a round shape with diameters from 7/32 in. to 3/4 in., and are coiled neatly into bundles of around 700 pounds each. Figure 1 shows a bundle of these rods being tied with wire and, also, being given its identification tag. Here each bundle is individually identified to show the grade of steel, the size, and the heat number of the steel from which it came. The steel has had many checks and inspections before this as to its chemical content and surface condition. At this point the rod is checked further for surface condition and diameter. It is then sent to the wire mill for further processing.

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The first operation at the wire mill is a process called "patenting". This consists of passing the rod through a long furnace that has three stages of heat in it. Figure 2 shows the red hot rods emerging from the patenting furnace. The trip through the patenting furnace is a time-temperature controlled operation. It is designed to improve the internal structure of the rods used to make the wire for the prestressed concrete strand. Up to this point all the shaping and forming on this steel has been done while the material is red hot, but from here on further shaping is done while the material is cold.

The next step in manufacturing prestressed concrete stand is to make the individual wires of the strand. To do this the rods are drawn or pulled cold through special carbide dies which reduce the cross-section of the rod and at the same time improve its tensile properties. The steel is pulled through a set of dies as shown in Figure 3. The cross-sectional area can be reduced about 25% each time it passes through a die, so several dies are used in sequence, each reducing the diameter. Wire drawing machines for this job are especially designed to do this heavy work. Figure 4 shows a wire drawing machine that reduces the wire size 5 times, starting with the rod and reducing it to the desired size. This

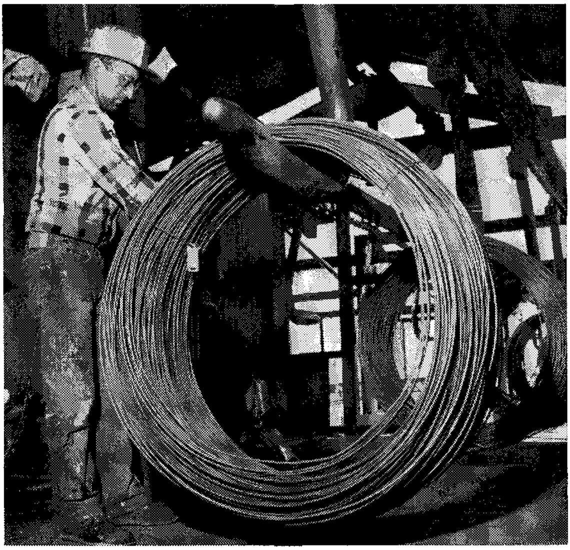

Fig. 1—Bundle of rods being tied with wire and given its identification.

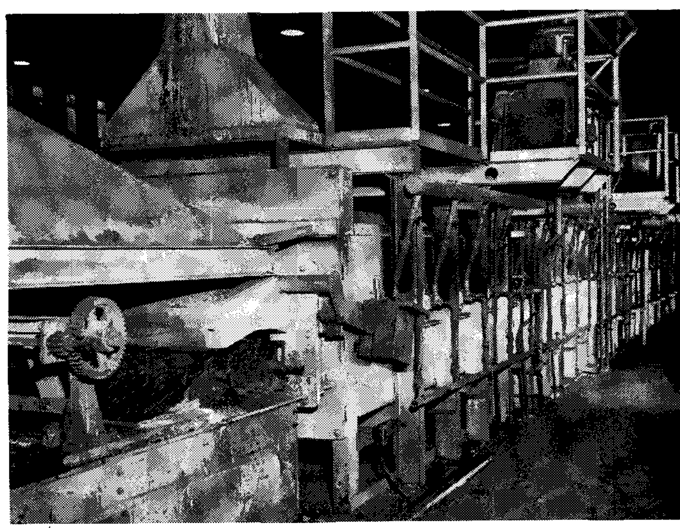

Fig. 2—Red hot rods emerging from the patenting furnace.

Fig. 3—Set of wire drawing dies.

machine has 5 individual motors, each with its own DC power source. The motors are 75-83 h.p. each, so it can be seen that tremendous power is needed to draw this wire.

There has been a change of nomenclature at this point in addition to reducing the size of the material. After passing through the dies, the "rods" are now "cold drawn wire". Not only is the steel now at the correct size, but the tensile strength has changed from 190,000 psi as a hot rolled rod, to over 290,000 psi as wire.

Whenever steel is cold worked the mechanical properties, such as the yield strength and ultimate strength, change. To see what has happened inside the steel, take a look at the longitudinal section of the steel magnified 500 times. First look at the steel as a hot rolled rod in Figure 5a. Notice that the structure is coarse and granular-like. At this point the tensile strength of the rod is around 190,000 psi. In Figure 5b the steel structure has been refined after it has passed through the patenting furnace. Look at the difference in structure after the steel is in the form of wire as shown in Figure 5c. Notice how the grains are all elongated and lay lengthwise to the axis of the wire, the axis being horizontal. The rod had a tensile strength of 190,000 psi and now the tensile strength is over 290,000 psi due to the cold working of the material.

Of course, nothing is free, so with a gain of tensile strength the wire has lost ductility, and the wire must be manufactured with the right balance of increased tensile strength and loss of elongation. For a comparison, ordinary reinforcing steel meeting ASTM A 15 Intermediate Grade Specification has a minimum ultimate strength of 70,000 psi.

Although all of the wires in 7-wire strand appear to be alike in size, a micrometer will reveal that the center core wire is larger than the outer wires by a few thousandths of an inch. Strand is designed so that the outer wires will bear on the inner center-core wire, otherwise the center wire would not carry its share of the load. The outer wires must grip the center wire.

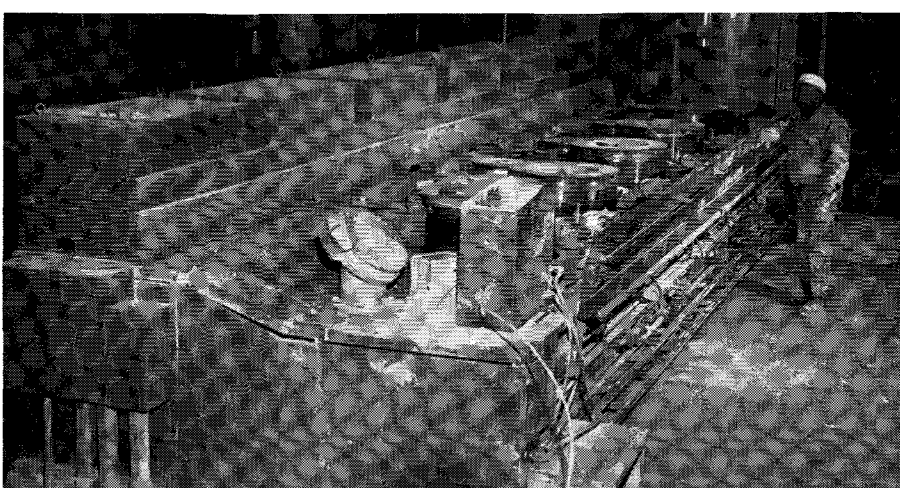

Fig. 4—Heavy wire drawing machine that reduces the wire size 5 times in sequence.

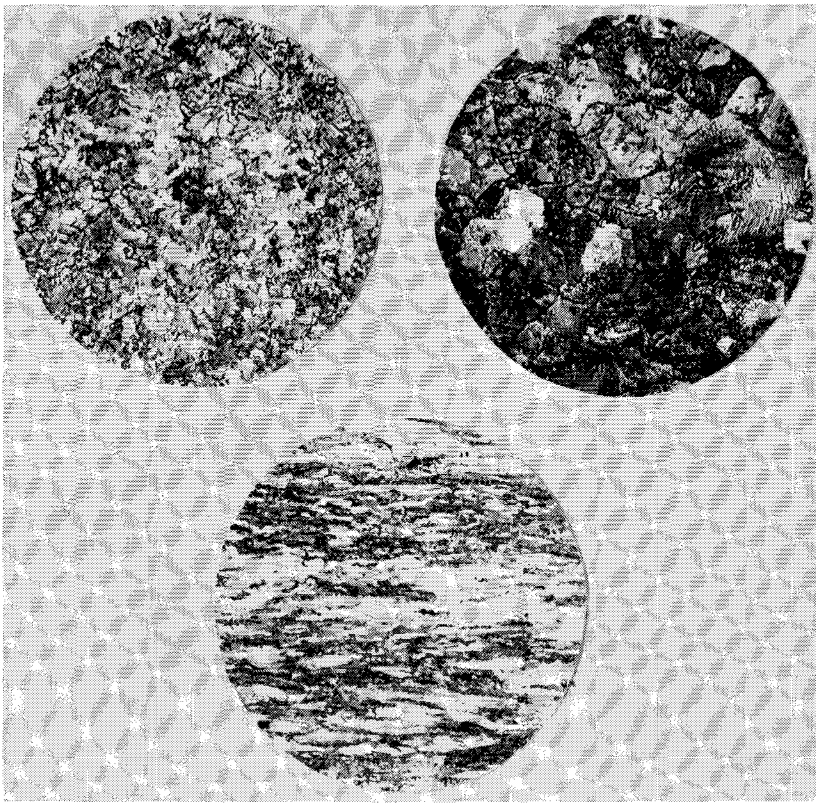

Fig. 5—*Longitudinal-section of steel magnified 500 times.* Upper Left—a. Coarse granular-like structure of hot rolled rods. Upper Right—b. Refined structure after passing through patenting furnace. Lower—c. Elongated grains of cold drawn wire lay lengthwise along the horizontal axis.

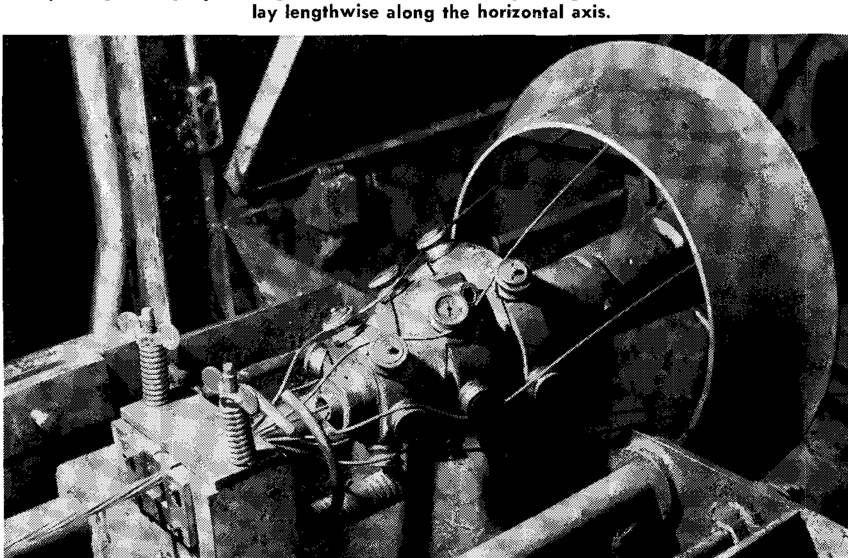

Fig. 6—Preforming head of the stranding machine.

The next operation in the manufacture of strand is the stranding operation itself where the 6 outer wires are formed around the center wire. To make the 6 outer wires wrap around the core wire, they are formed to the proper shape in the preforming head of the stranding machine. Figure 6 shows the wire in the preforming head and passing through the closure dies. It is well known that strand can be unraveled and then twisted back together again, and preforming makes this possible.

The 6 individual outer wires are formed to a definite curvature in the preforming head and then these wires are closed around the center core wire. It would appear that the strand would now be ready for use, but the stranding operation puts stresses into the wire because the wire is bent in the preforming operation. To remove these "residual stresses" and insure that the strand lays straight and flat when the customer stretches it out, the strand is next put through an operation called "stress relieving". In this process the strand is heated to a temperature of about 650 deg. F. in a very carefully controlled time-temperature operation. This procedure eliminates the stresses introduced as a result of the stranding operation and yet does not harm the wire.

The strand is payed off of one reel, travels through the stress relieving furnace, goes around a capstan, and finally back onto a takeup reel. This furnace is designed so that no open flame contacts the strand, and the capstan has a variable speed drive so that the speed of the material through the furnace can be carefully controlled. It is very important that the strand pass through the furnace at a very definite speed. If, by chance, the strand would stop in the furnace in the middle of a reel, this portion of the strand would have to be cut out. After the stress-relieving operation the reel is ready to be packaged for shipment.

CARE AND HANDLING OF STRAND

There are two very important things concerning the care of strand —(1) high temperature, and (2) nicking. High temperatures are very detrimental to strand and can easily destroy its high strength properties. Figure 5 indicated that the cold drawing process at the wire mill changes the grain structure within the wire from coarse granular to an elongated structure. We should also remember that the granular structure has a tensile strength of 190,000 psi and the elongated structure has a tensile strength of 290,000 psi. If the temperature of the strand exceeds 1300 deg. F. the grain structure returns to the coarse granular form and the steel is returned to a 190,000 psi material. Therefore, if the strength has dropped from 290,000 psi to 190,000 psi and the strand is stressed it is going to break!

Included are some examples to show what heat does to the wire of prestressed concrete strand. Figure 7 shows cold drawn wire that has been cut off with an oxygen cutting torch by an experienced welder, and it can be seen that the entire structure has changed. The wire was cut on the left-hand side and this is the heat-affected area. On the cross-section of the wire in the bottom of the figure, three different internal structures of the wire are shown enlarged 250 times. On the right the wire still has the elongated structure of cold drawn wire, and on the left the structure is again back to the coarse granular structure of hot rolled steel. The middle view shows the transition area. There is no way to repair heat damage—the strand is destroyed.

Heat damage usually occurs from an oxygen cutting torch, but, besides the oxygen torch, an electrical arc is also a danger to strand. Figure 8 shows the effects on strand that was touched with a bare electrical conductor causing an arc. The spot where the bare electrical conductor touched the wire can be seen on the left. The right photo is a longitudinal section of this wire magnified 5 times. Notice that the structure of the wire has changed and at this point the wire failed. Figure 9 shows the inside of the wire magnified 500 times. Again the elongated grains of the cold drawing wire on the left have changed back to coarse-granular grains as they were in a hot rolled rod. This time the axis of the wire is vertical. Four samples have been taken at varying distances from the break. On the right is the break. The white area is a small glob of copper from the electrical conductor. The sample on the left has not been affected by the heat caused by the arc.

How can such dangers be avoided? Keep oxygen cutting torches away from strand unless it is to be cut. Use grounded electrical equipment and keep electrical cables in repair. Do not let the welder use the strand as a ground connection for arc welding. Probably the most important of all is to inform each man on the crew of what heat does to the strand.

All high carbon cold drawn wire, such as that used in prestressed concrete strand, is "notch sensitive". By that it is meant that high carbon wire breaks at a notch or nick more easily than low carbon wire. Heavy nicking by a strandvise causes something like this shown in Figure 10. Many times one wire breaks under load, suddenly transferring its load to the other wires and the whole

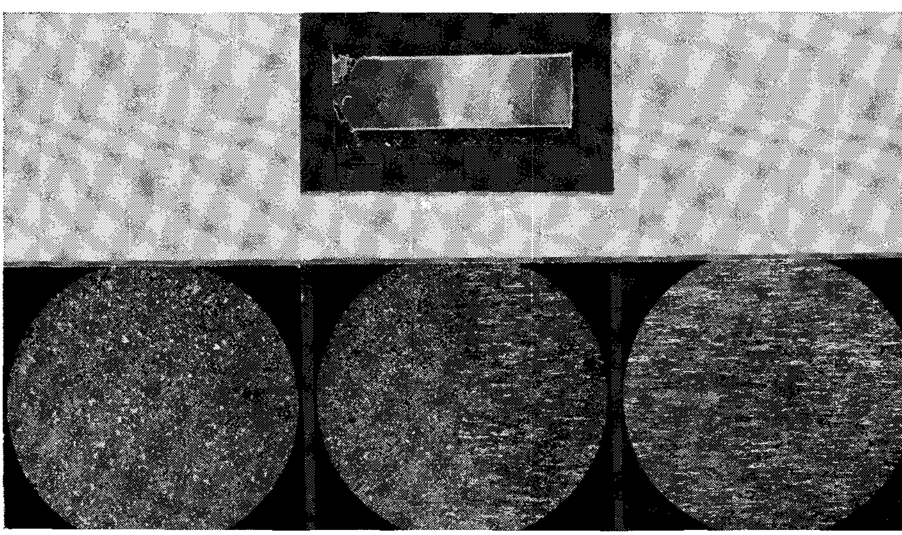

Fig. 7—Top—Cold drawn wire that has been cut off with an oxygen torch on the left-hand side, Magnified 5 times. Bottom—Longitudinal section of wire magnified 250 times. Right Hand view shows elongated cold drawn structure. Left Hand view shows coarse granular structure similar to hot rolled rods. Center view shows transition area from elongated to coarse-granular structure.

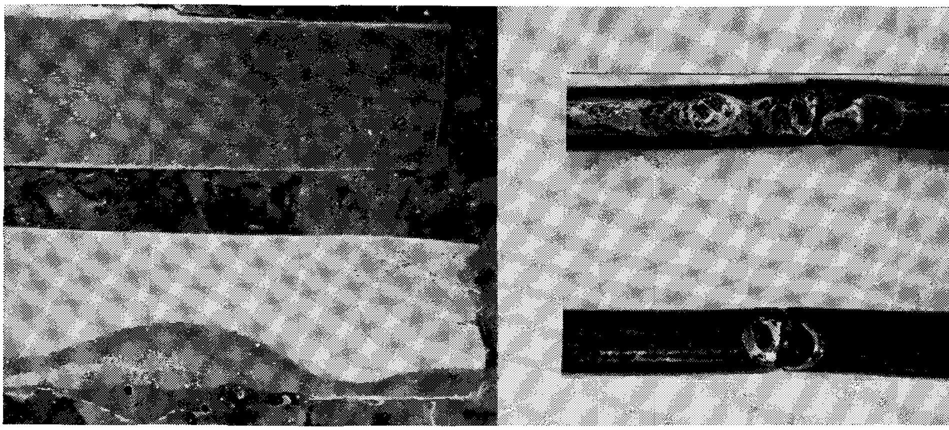

Fig. 8—The effects on strand that was touched with a bare electrical conductor causing an arc.

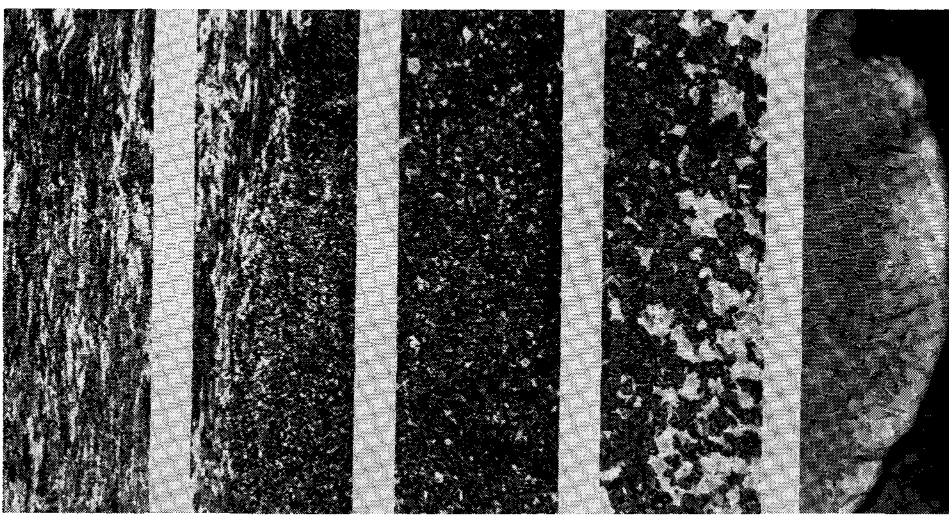

Fig. 9—Longitudinal section of wire that failed because of heating by an electrical arc. The elongated grains of cold drawn wire on the left were changed back to the coarse granular grains similar to hot rolled rods as shown on the right. The axis is vertical.

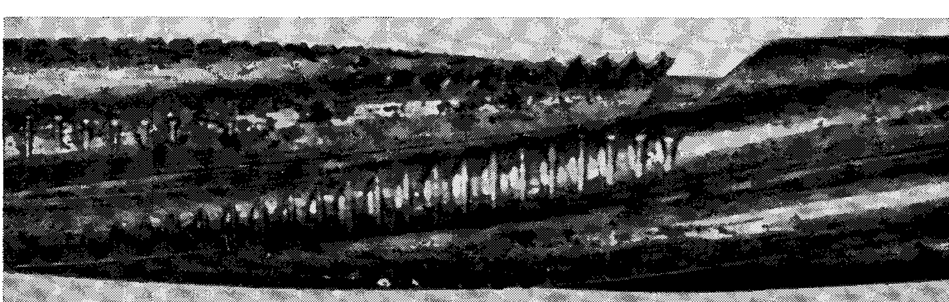

Fig. 10—This was caused by heavy nicking of the strandvise.

strand will break. Notice how heavily this wire is nicked and the nick at the break was evidently even heavier. Several of these heavy nicks were examined and one is shown in Figure 11. This nick has been magnified 400 times, and it can be seen how the wire has been distorted and a crack has started at the stress riser. Such a failure results in a diagonal break.

Most of the trouble of breakage from nicks has come from the strandvises. How does the strandvise cause this nicking? The strandvise has to nick some to grip the strand, but it is designed to grip the wires *evenly* all the way around the strand. The trouble arises when one jaw gets ahead of the others, takes more of the total load, and thus nicks heavily. All of the strandvises on the market have a method of holding all the jaws evenly in the chuck until they are seated around the strand. Strandvises use stainless steel washers, neoprene washers, and spring wire clips, to hold the jaws of the strandvises evenly. Some strandvises have a spring retainer designed to make the jaws advance evenly into the barrel of the strandvise.

Two of the biggest sources of trouble arise when the washer is omitted or the spring retainer is left off. There are a number of cases of complete strand failure just because of this. The strandvises must also be kept clean as dirt will jam one of the jaws and keep it from advancing into the chuck evenly. It is obvious, therefore, that the strandvises should be kept clean and the use of the special cleaners and cleaning methods recommended by the manufacturers of the devices pays dividends. Grease or wet lubricants do a very poor job. A dry lubricant such as graphite is much better.

CENTER PULL DISPENSING

Center pull dispensing of the new type of reel-less pack provides savings for the concrete producer in several ways, so more and more of this type of package for prestressed concrete strand will be appearing on the market. This type of packaging is very easy to use and most concrete men have made their own dispensers. The dispensers have been made from old reel heads bolted onto the pack, old reel heads as a base and top for the pack with the core in a vertical position, and

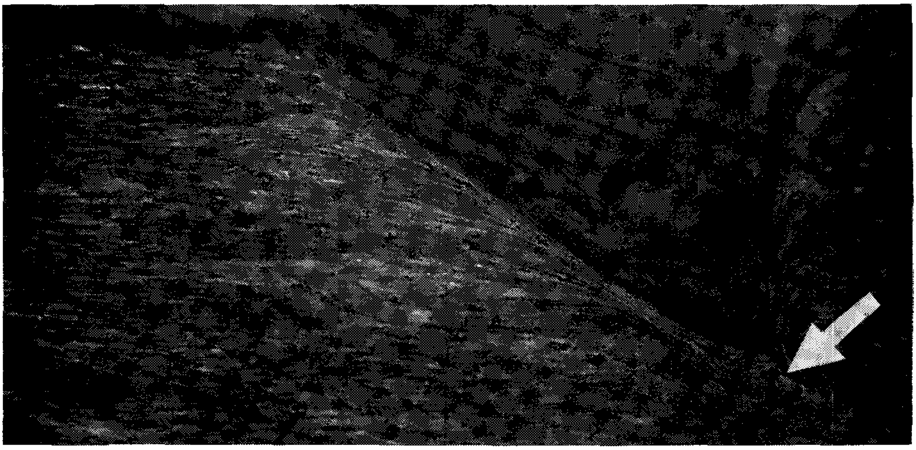

Fig. 11—Stress riser at a heavy nick.

a cage made of reinforcing bars, all working very satisfactorily. The only precaution in handling the strand is to make sure that the strand pays off counterclockwise. The reason for this is that the strand must twist or rotate one time for each length around the circumference of the reel. It is important to have the strand pay off in a counterclockwise direction as it comes out of the center pull dispenser so that the twisting of the strand will tend to tighten the lay of the strand. If the strand is put in backwards the twisting motion will tend to make the strand unravel.

SUMMARY

Prestressed concrete strand goes through many carefully controlled processes to produce a high strength, high quality material. High carbon rods are first patented to improve their structure, the rods are then drawn through a series of dies which reduce their cross-sectional area and increase their tensile strength. The cold drawing process changes the internal structure of the steel and thus increases the tensile strength of the wire used to make the strand. If the strand is heated with an oxygen torch or grounded with an electrical cable, the cold working properties of the steel are lost and the high strength of the material is destroyed. High carbon wire is notch sensitive, and heavy nicking usually arises from the improper use of strandvises, such as omitting the washer; not using the spring that makes the jaws seat evenly; or using dirty strandvises. In using the center pull dispenser, care should be exercised so that the strand will pay out in a counterclockwise direction when coming out of a reel-less pack.