APPLICATION OF TENSIONED PULLOUT TESTS TO INVESTIGATE THE EFFECT OF PRESTRESSING WIRE INDENT GEOMETRY ON BOND AND SPLITTING CHARACTERISTICS

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Abstract:

An experimental program was conducted at Kansas State University to study the geometric properties of indented prestressing wires that induce splitting of the surrounding concrete. Tensioned wire pullout specimens using 5.32-mm-diameter prestressing wires were tested to investigate the angles of the indent that caused the specimens to split. Indent patterns were custom machined to various unique geometries on smooth prestressing wire. The custom geometries provided controlled experiments analyzing various geometrical features influence in concrete splitting.

Each test consisted of a single wire that was bonded 2.5 inches in a rectangular specimen. The wire was tensioned to 75% of its ultimate strength before concrete was cast in a mold around it. The force in the wire was decreased after the concrete had reached strength of 4,500 psi. The force in the wire above and below the specimen was measured along with the amount of slip on each end of the specimen.

Different geometry patterns were shown to cause the specimens to split as the wire moved through the specimen. Controlled variation in the machining of indent geometries allowed for detection as to what geometrical features are prone to cause splitting and which geometrical features increase bonding capability.

Keywords: Prestress, Wire, Splitting, Pullout, Tensioned, Indent

Introduction

Tensioned wire pullout tests have been shown by Holste et al.[1] to provide an accurate representation of the transfer of prestress into a concrete member. This representation was found to show what types of commercial indents caused splitting by Holste et al.[2]. The testing of commercially made indent patterns limited the variables that could be looked at due to the similarities between the indents. These wires are mainly used in the production of concrete railroad ties which consists of multiple wires being arranged along the cross section of the railroad tie. This research project looks at the testing of custom machined indents using a tensioned wire pullout test. This information can be useful in using pretressing wire in other applications then railroad ties. Prestressing wires could be used for the production of thinner panels that are too thin to be produced using strand.

Problem Statement

Commercial reinforcement wires are all individually unique. Each commercial reinforcement wire has varying indent depth, width, edge wall angle, and overall shape. With every wire uniquely different it is difficult to perform a controlled experiment on the influence of individual geometrical features by using commercially available reinforcements. Since commercial reinforcements have multiple parameter variations, testing these wires only shows the influence of these multiple parameter changes and not the influence of a single parameter.

Objective

The solution to this problem is to make custom reinforcement wires where the variation in geometry of the indent pattern is controlled. By manufacturing several reinforcements with the same geometry and only varying indent edge angle, or the same geometry with only varying indent depth. It is possible to determine the influence of the individual parameter. This can lead to a better understanding as to what indent edge wall angles and indent depths result in a high propensity for fracture. The custom machined reinforcements may also lead to a better understanding as what an ideal indent geometry should be in order to minimizes the transfer length and the propensity for fracture for the pre-stressed concrete railroad ties.

As machining custom reinforcement geometries is expensive, pre-tensioned pullout experiments are an ideal testing procedure for custom machined geometries. By using pre-tensioned pullout experiments the reinforcements made only need to be 5 inches in length to conduct a pre-tensioned pullout experiment. This is advantageous in comparison to casting the samples into concrete prisms or concrete cross ties as the samples would need to be several feet in length.

Wire Machining Setup

For these experiments 2 parameters are considered – indent depth and indent edge wall angle. The indent patterns were machined into a smooth non-indented sample of prestressing reinforcement wire. The reinforcement wire had a Rockwell C hardness of 45. The wire diameter is 5.32mm. The indents were machined with a single pass from a 1/8” end diameter end mill. In order to make indents with different edge wall angles, custom made end mills were used. The end mills had 6 different chamfer angles on them to machine 6 different edge wall angles.

In Fig. 1 the geometries of the end mills used for the machining are shown. The 1/8” end mills are made of tungsten carbide with an aluminum-titanium-nitride (AlTiN) coating. The 6 different end mills shown have edge chamfers of 15°, 15°, 30°, 45°, 60°, and 75°. Another end mill was also used with no chamfer to create a 90° edge wall. Two end mills were used at the 15° angle as it is difficult to create deep depths of cuts with a 15° chamfer and maintain the edge wall angle all the way up to the edge of the indent.

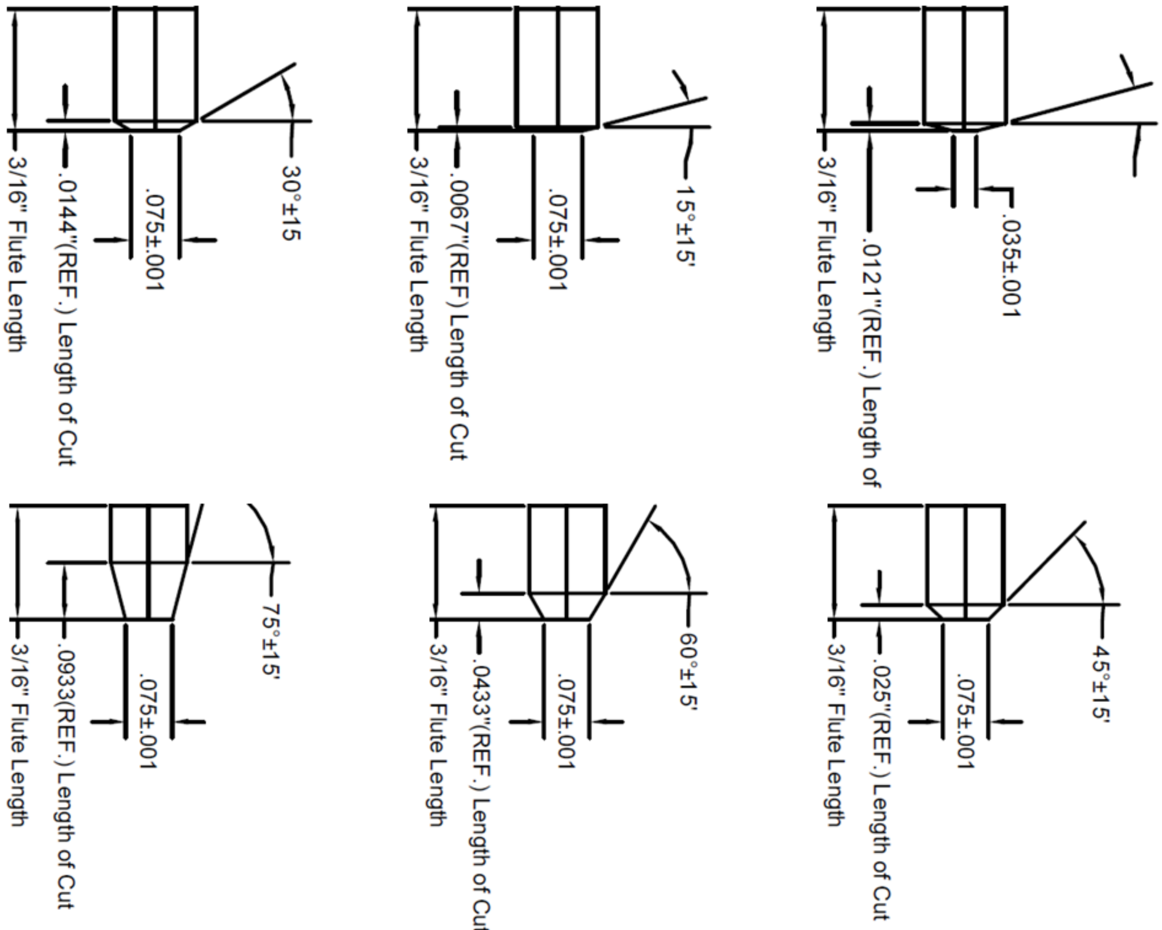

Fig. 1: End Mill Dimensions (in)

Machining the indents without wire flexing requires a unique fixture setup that locates the wire down its entire length. A fixture was machined out of aluminum to support the wire and provide a controlled clamping force down the length of the wire. The fixture also used a 120° indexer to rotate the wire to allow machining of 3 rows of indents. Fig. 2 shows a 3D model of the fixture design on the left and the actual fixture used on the right. The 4 edge clamps provide controlled clamping force to be able to get repeatable holding of multiple wire samples.

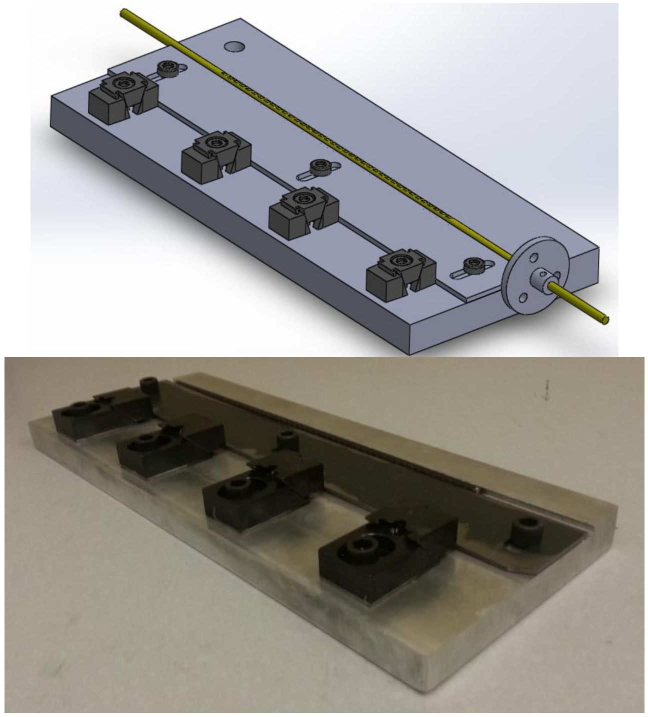

Fig. 2: Reinforcement Wire Fixture

The machining was conducted on a HAAS VF-2 CNC vertical mill. The machining path was at a 45° angle to the axis of the wire to create a similar indent orientation as to that of the commercial reinforcement wires. After 2 rows of indents were machined on the wire the third row would be cut with the path at an angle of 135° which is conventional for commercial reinforcement wires which have chevron style indent patterns. Fig. 3 shows the setup used for the machining. The direction the cutting tool was from in front of the fixture to behind on every single indent cut as to achieve the same indent cuts regardless of tool deflection.

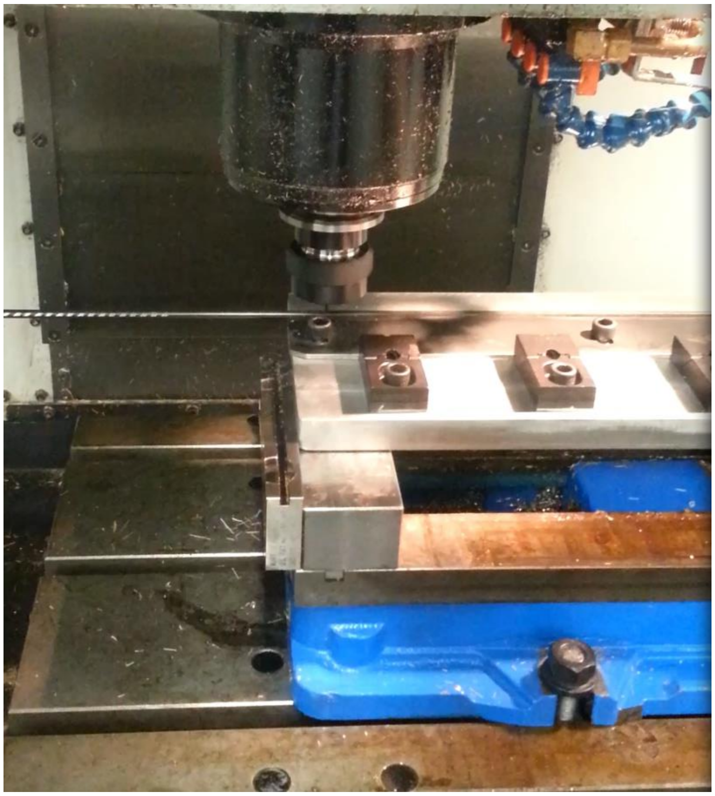

Fig. 3: Machining Setup

Fig. 4 shows the 12 machined samples. The machined length is 5 inches long on a wire sample with a total length of 37 inches. This is to give enough room for the sample to be chucked into the pre-tensioned pullout equipment.

Fig. 4: Machined Reinforcements

Fig. 5 shows the machined reinforcements through a microscope. The indents have a highly reflective surface due to the machining in comparison to the dark color of the natural oiled surface of the wire. The indent depths were attempted to be made as close as possible from wire to the next, however, with the indents only being in the range of 100-400 microns in depth it is considerably difficult to get perfect repeatability through multiple fixture locations. As such it is necessary to measure the machined reinforcements to confirm their dimensions.

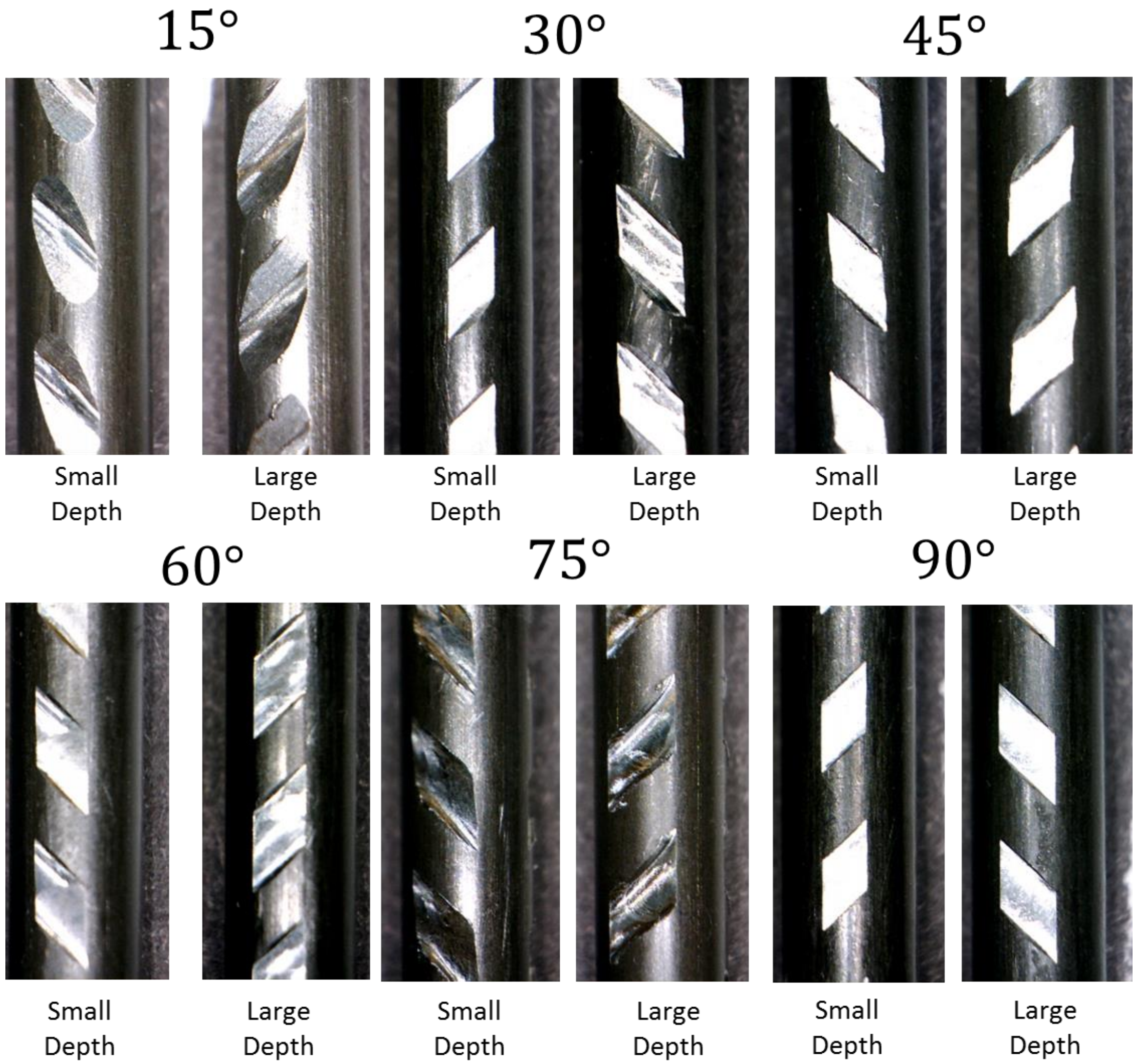

Fig. 5: Microscope View of Machined Reinforcements[3]

The wires were scanned on a custom developed 3D scanner. The scanner used a laser displacement sensor connected to a linear traverse and held the wire with a 6-jaw chuck connected to a rotary table. The wire was rotated while the laser was moved across the length of the wire to develop high resolution 3D scans. Fig. 6 shows the setup for the wire scanning process.

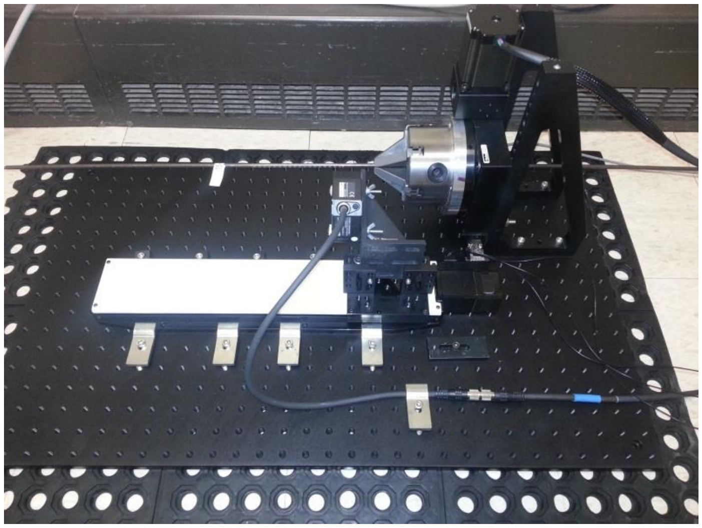

Fig. 6: Wire Scanning Setup

Fig. 7 shows the resultant 3D model from the scanning process. These 3D models allow for cross verification of the indent geometries created allowing for imperfections in the machining process to be taken into account during the testing of the wires. From these high resolution surface profile captures the critical dimensions of the reinforcement wire were re-measured. Table 1 shows the indent depths for each of the indents.

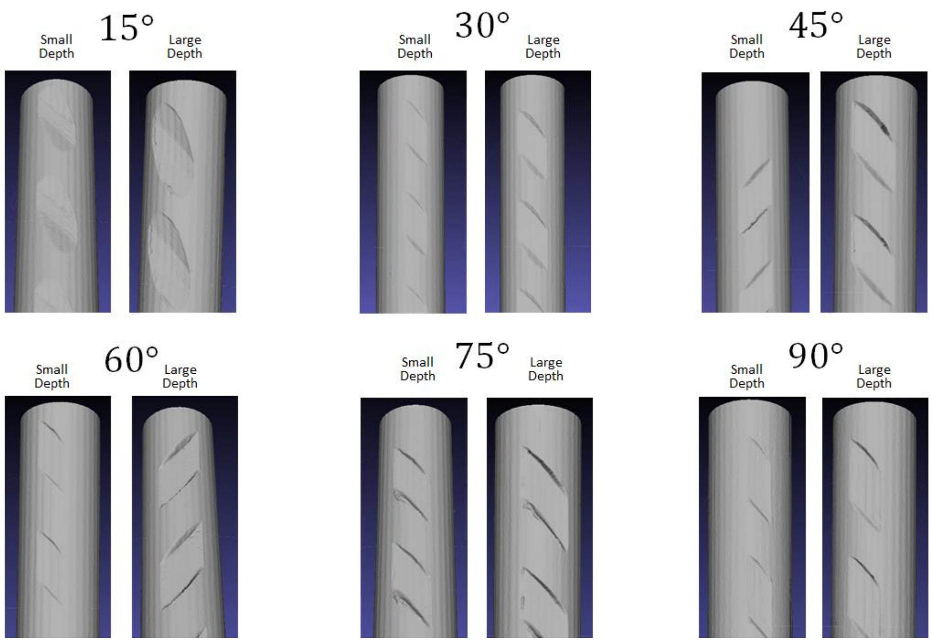

Fig. 7: 3D Models of Machined Wires

Table 1: Indent Depth for Each Indent Angle (in mm)[3]

	15°	30°	45°	60°	75°	90°
Shallow	0.310	0.158	0.156	0.142	0.286	0.142
Deep	0.400	0.261	0.245	0.245	0.387	0.217

Tensioned Pullout Testing

The wires that were machined were tested using a tensioned wire pullout test as described by Holste[3]. The wires were tensioned to 75% of their ultimate capacity before the specimens were cast. After the specimens were cast and had cured to a strength of 4,500 psi, the force in the wire above the specimen was reduced by turning the jack that the wire ran through. This reduction of force caused the wire to slip through the concrete specimen. Force above and below the specimen was measured using S-type load cells. The end-slip above and below the specimen was also measured during testing. The specimens cast were 3.5-inch by 1.75-inch rectangles with a height of 2.5 inches. Each specimen was instrumented with an internally cast vibrating wire strain gauge. These gauges were used to measure the lateral expansion of the specimen along the gauge as the wire was detensioned. Fig. 8 shows the specimen dimensions, wire location and gauge location. Fig. 9 shows one of the two testing frames that were used. Fig. 10 shows the specimen form prior to casting of the specimen.

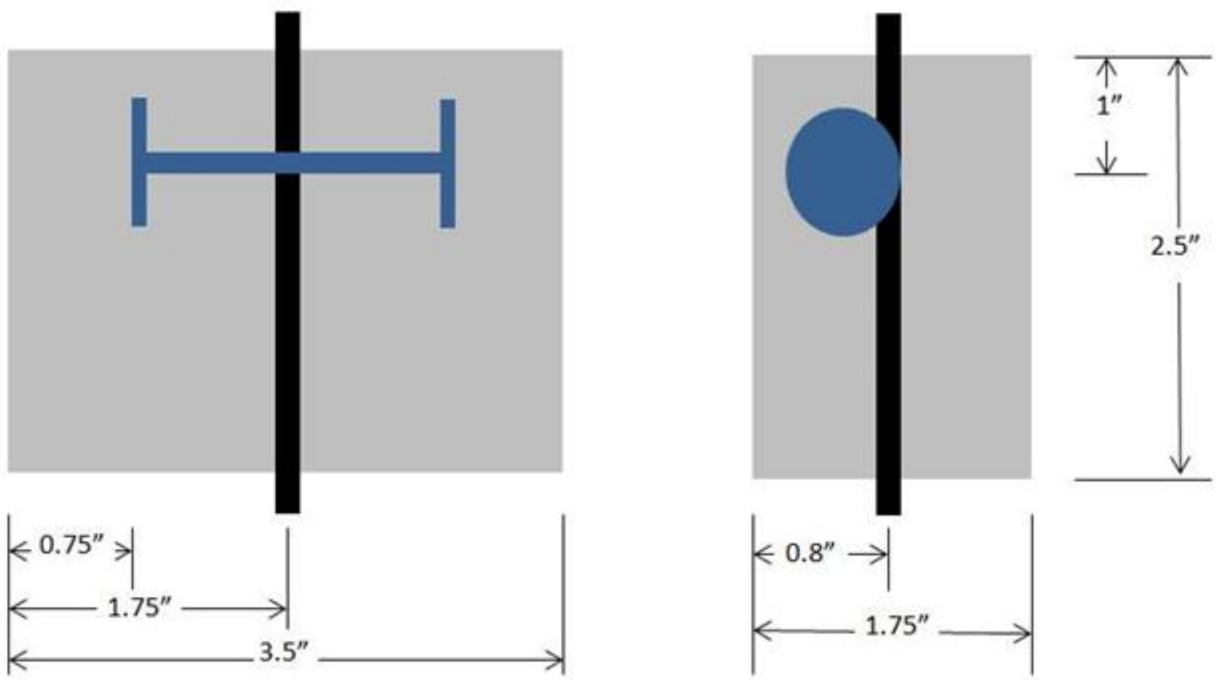

Fig. 8: Specimen Dimensions and Vibrating Wire Strain Gauge Location[3]

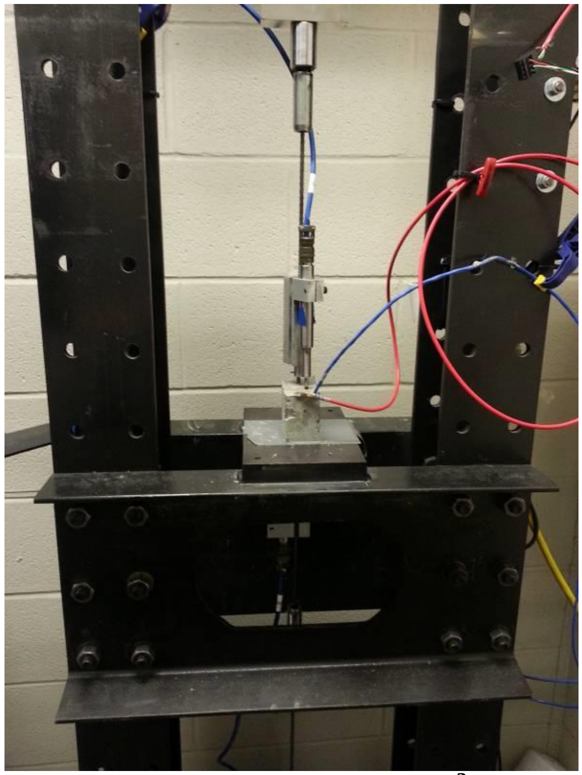

Fig. 9: Test Frame Setup[3]

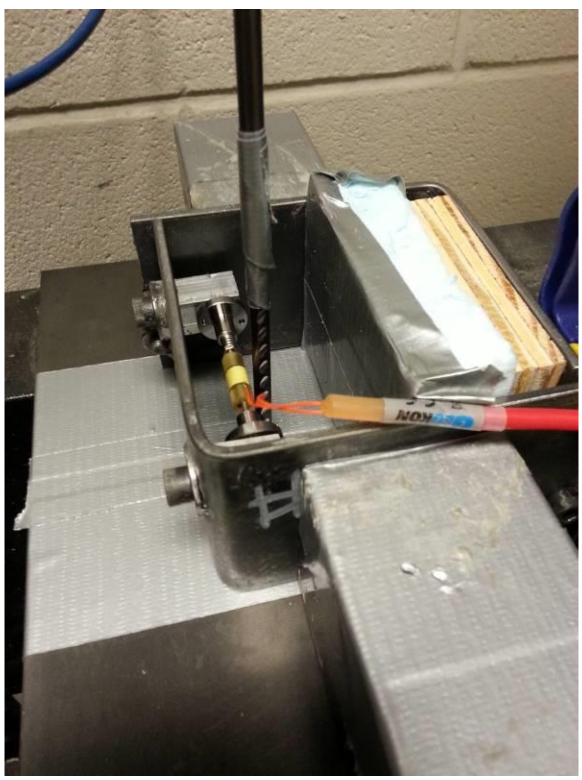

Fig. 10: Test Specimen Forms Before Casting[3]

The concrete mix used during testing was identical to the mix used by Holste et al.[2]. The mix consisted of Type III cement, sand, 3/8-inch gradation pea gravel, water and a high range water reducer. Table 2 shows the mix proportions used.

Table 2: Mix Proportions[3]

Material	*Quantity per Batch (0.25 ft^3)*
Type-III Cement	9 lbs.
Sand	16 lbs.
3/8" Aggregate	12 lbs.
Water	2.88 lbs.
Type-F HRWR	25 ml

Results and Conclusions

Shallow and deep indent wires for each angle were tested using the same concrete batch. The readings from the load cell and end-slip measurements were used to calculate the end-slip and bond stress for each set of tests. The bond stress and lateral expansion for each test was plotted. The max crack width for each specimen was also recorded if the specimen cracked. Fig. 11 shows the results from the deep 30-degree indent test. Fig. 12 shows the cracked specimen after testing. Fig. 13 shows the shallow and deep 30-degree indent bond stress results for the two tests.

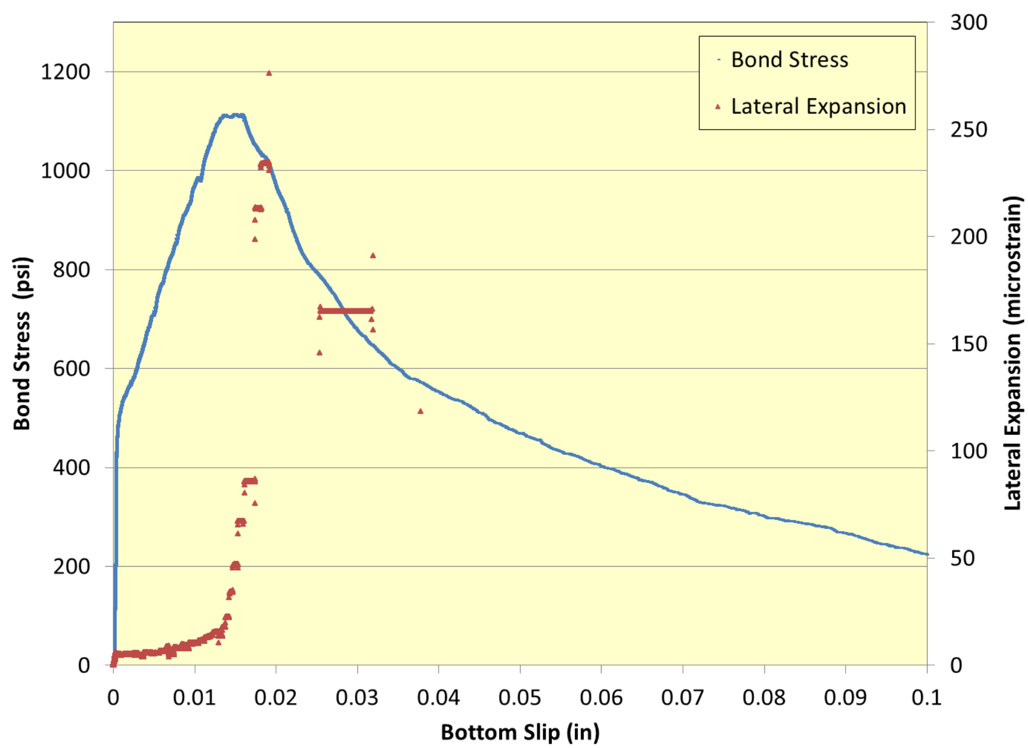

Fig. 11: Bond Stress and Lateral Expansion Relationship for Deep 30-degree Indent[3]

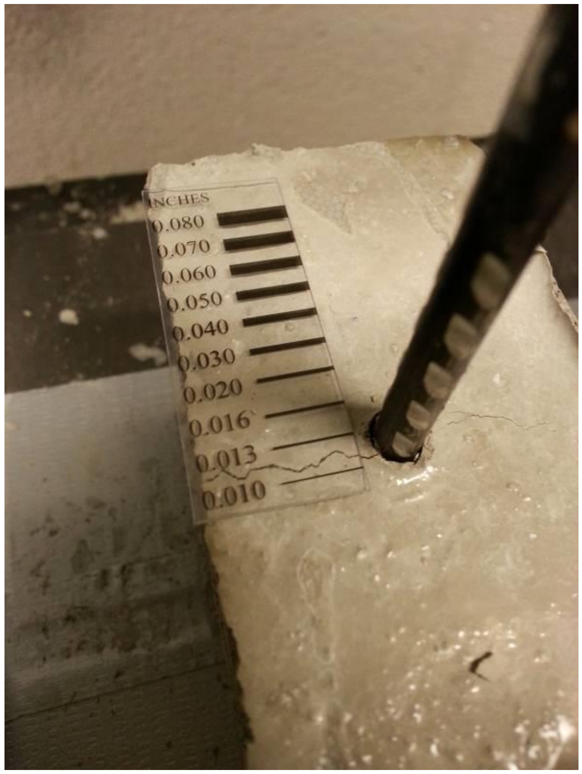

Fig. 12: Deep 30-degree Indent Specimen after Testing[3]

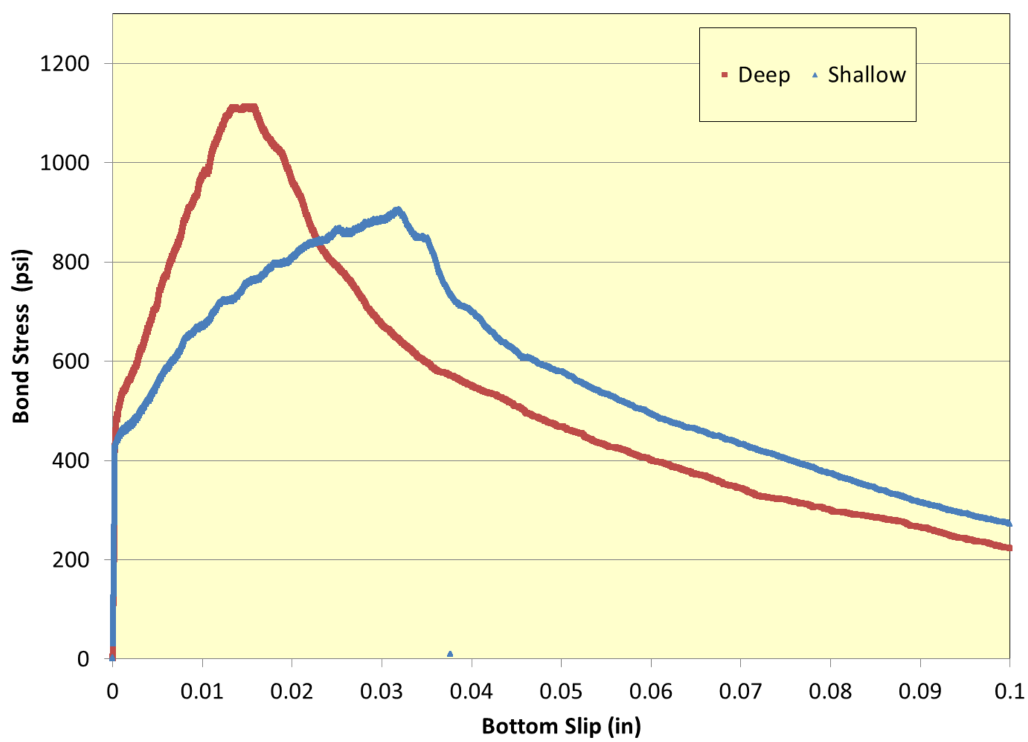

Fig. 13: Bond Stress versus Bottom Slip Relationship for Both 30-degree Indents[3]

Fig. 14 shows the results from the shallow 45-degree indent. The specimen didn't crack during testing as seen in Fig. 15. The results from the two 45-degree indents tests are shown Fig. 16. The results from all of the shallow indents are shown in Fig. 17. Fig.18 shows the results from all of the deep indents. The deeper indents showed higher bond stresses than the shallower indents. The higher bonding ability of the deep indents matched with the splitting of the specimens.

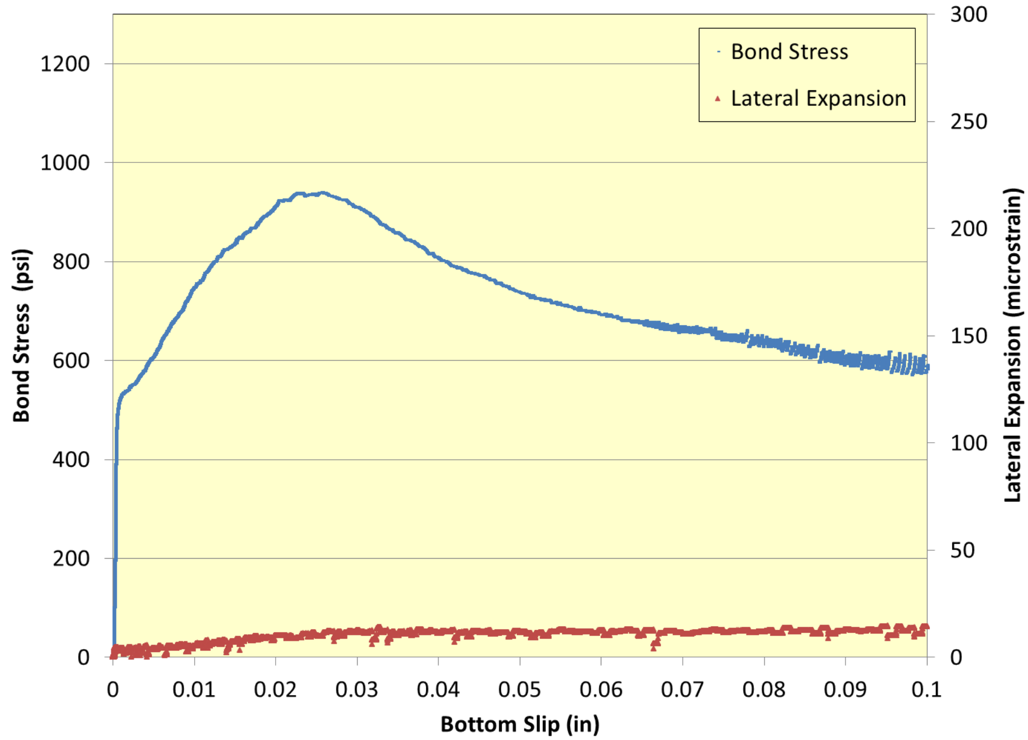

Fig. 14: Bond Stress and Lateral Expansion Relationship for Shallow 45-degree Indent[3]

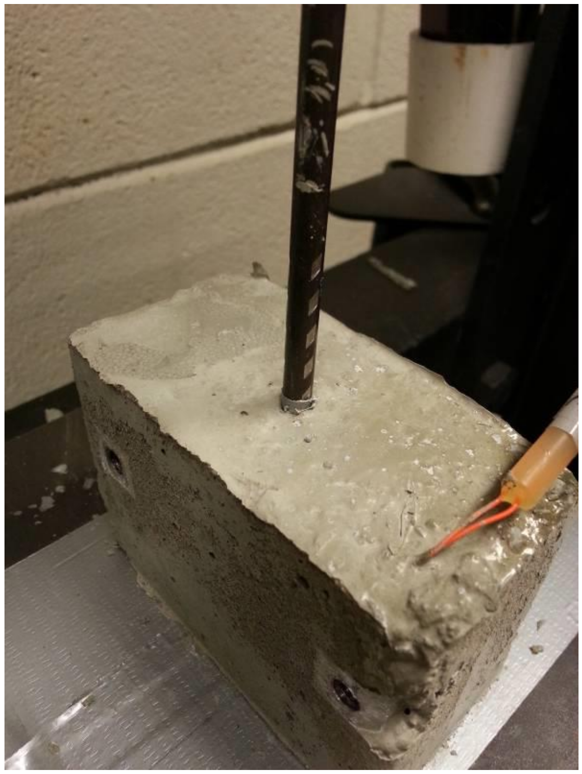

Fig. 15: Shallow 45-degree Indent Specimen after Testing[3]

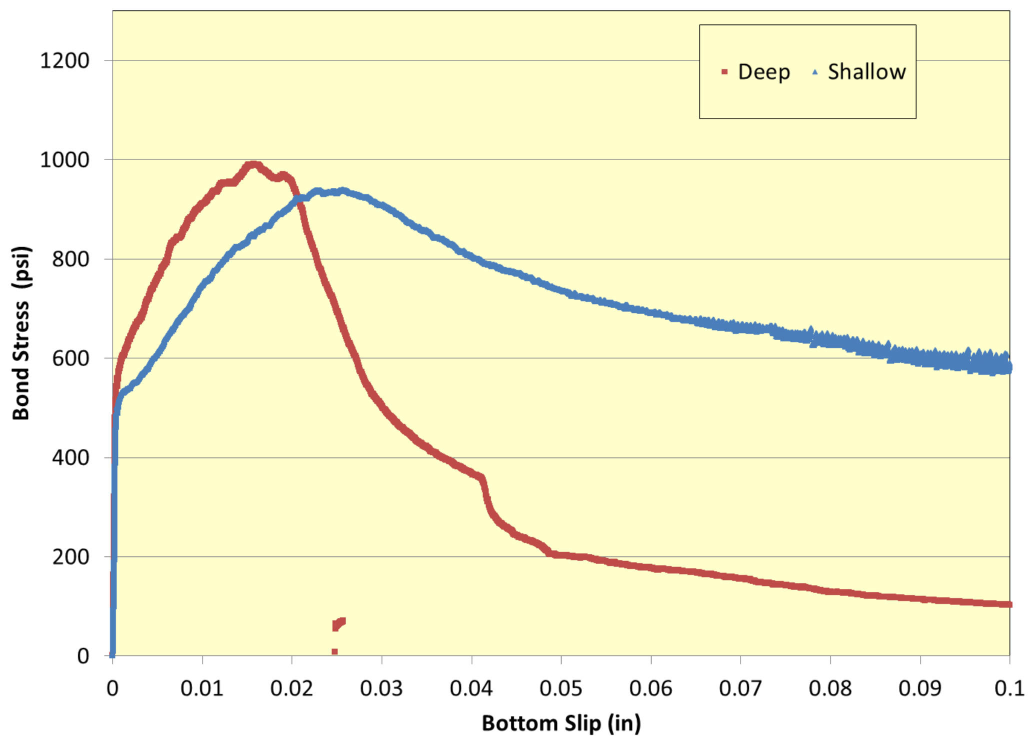

Fig. 16: Bond Stress versus Bottom Slip Relationship for Both 45-degree Indents[3]

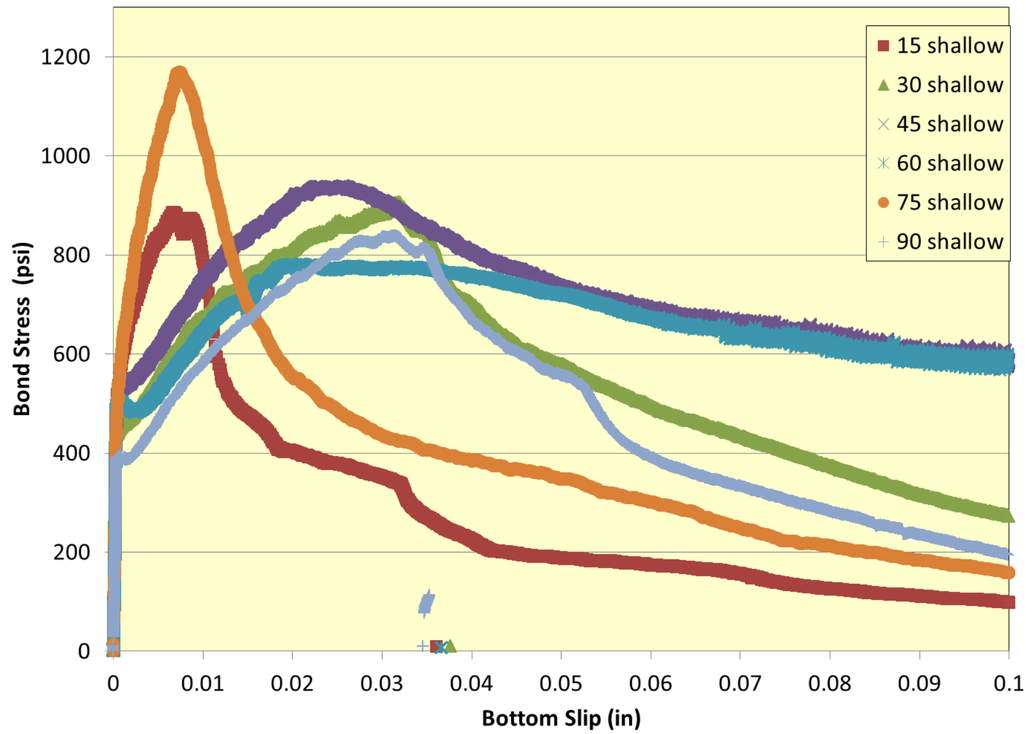

Fig. 17: Bond Stress versus Bottom Slip Relationship for all Shallow Indents[3]

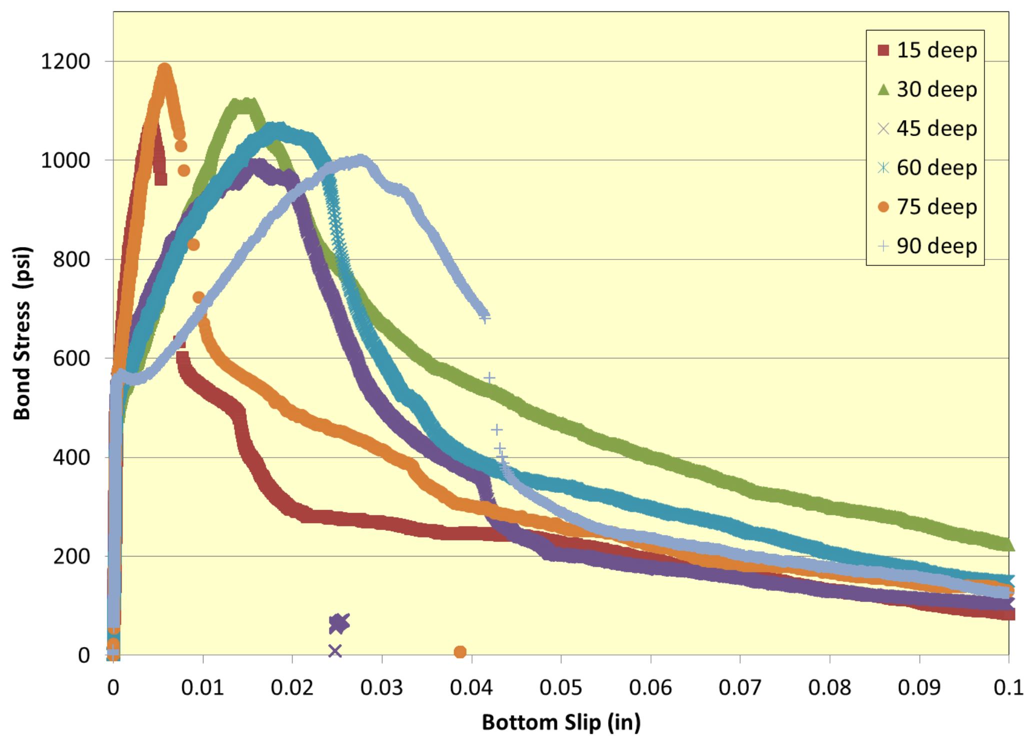

Fig.18: Bond Stress versus Bottom Slip Relationship for all Deep Indents[3]

Table 3 shows the crack widths for each of the tests. The deeper indents were shown to produce wider cracks on the top surface of the specimens.

Table 3: Crack Widths for Each Indent (in inches)[3]

Angle	Shallow Indent	Deep Indent
15-Degree	0.016	0.025
30-Degree	0.003	0.008
45-Degree	No Crack	0.012
60-Degree	No Crack	0.003
75-Degree	0.005	0.012
90-Degree	0.004	0.008

The results from the testing showed that the deeper indents caused higher lateral expansion. The vibrating wire strain gauges showed lateral expansion of the specimen prior to cracking. The higher lateral expansion was shown to cause all of the deeper indents to crack the test specimen. The shallower indents with 45 and 60-degree indents didn't cause cracking. This information provides a basis for the development of an indent that is less likely to cause splitting in prestressed members. These results can be used to help understand the cracking nature of prestressed members and would be useful in using prestressing wires to produce thinner panels.

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