Tracer Wire for HDD Applications

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Executive Summary

An effective tracer wire product that is locatable, durable for horizontal directional drilling (HDD) installations, and easy to handle would be beneficial to the industry. A high performance tracer wire should promote the HDD installation from the following aspects:

1. Prevent wire breaks (either during or after installation) which result in un-locatable plastic pipe; therefore, reduce the risk of third party damage and potential incidents,
2. Reduce cost by allowing the use of a single wire for a directional-bore pullback instead of using multiple tracer wires (a practice currently followed in case one or two get sheared off), and
3. Decrease installation time by reducing person-hours required to deal with breaking, kinking, spring back of legacy tracer wire, and performing lateral and inline connections.

The objective of this project was to provide the gas industry with information on the properties and performance of currently used tracer wire products as well as new, potentially stronger, and more "HDD friendly" products. The tracer wire products evaluated in this project are summarized in Table 1.

In Task 1 of this project, GTI conducted a project survey with the sponsoring companies to identify the installation conditions, the requirements and the expected improvement for HDD applications. A comprehensive product review was also conducted on commercially available tracer wire products to compare the product characteristics. Several types of tracer wires, including conventional and new products, were identified for testing in laboratory and field environments. These products represent the tracer wire products that the sponsoring companies are currently using, as well as new products that the manufacturers recommend for HDD applications.

In Task 2, laboratory tests were conducted to evaluate the tensile properties of various type of wires selected in Task 1, together with the abrasion and scrape resistance of the wire insulation jackets. Corrosion evaluation with accelerated cyclic corrosion test (CCT-1) was also conducted to evaluate the corrosion performance of the wires that contained damaged insulation jackets. The laboratory test results indicate that:

1. Tensile Test Results:
    - The traditional soft drawn solid copper tracer wires have relatively low tensile break load, but they exhibit greater elongation in the plastic deformation range before the ultimate tensile loads (tensile break load) were reached.
    - The extra high strength-copper clad steel wires (EHS-CCS) significantly improves the wire tensile strength (>1,000 lb for 12 AWG wires). However, this type of wire is more brittle and breaks without significant plastic deformation in the tensile test. Therefore, the tensile break load is significantly reduced when the wire is kinked.
    - The high flex copper clad steel wires have a slightly higher ultimate tensile load than the traditional soft drawn copper wire and also exhibit similar elongation properties as traditional soft drawn copper wire.
    - Company F tracer wire exhibits a significantly high tensile load (~1,800 lb) attributed to the polymer fibers which provide the strength. This wire also exhibits the similar high tensile load when it was tested with a kink.
2. Abrasion and Scrape Resistance Test Results
    - The abrasion and scrape resistance of the tracer wire jackets varied based on the type of Polyethelene (PE) material and also the manufacturer of the wire. In general, high density polyethylene (HDPE) insulation jackets have a higher scrape resistance than low density

polyethylene (LDPE) insulation jackets with the same coating thickness. The increased thickness of the insulation jacket from 30 mils to 45 mils significantly increases the scrape resistance of the wires.

- The abrasion resistance of the HDPE jackets from Company E and Company A outperformed the other tested PE jackets (LDPE and HDPE). The HDPE jacket from Company D has the similar abrasion resistance as the LDPE from Company B and Company C.
- The scrape resistance of the Company F insulation (containing polymer fiber and HDPE coating) are significantly higher than the traditional HDPE and LDPE coating.

3. Corrosion Evaluation
   - The Company E CCS wires for HDD application were severely corroded at the locations where the insulation jacket was damaged by scrape test or through field installation. The wire lost continuity completely or reduced tensile break load at the damaged insulation due to corrosion.

In Task 3, several tracer wire products were selected for field evaluations based on laboratory test results. The two test sites selected were rocky and represented a difficult scenario in HDD installation. Although none of the wires broke during pull in, many of the wires that were evaluated in the field test experienced flaws on their insulation jackets and kinks in the wire after they were pulled through the bore hole. The field test results suggested that the wire manufacturers should take into account the selection of high performance insulation materials that have higher abrasion and scrape resistance in order to prevent wire insulation damage during HDD installation. Corrosion of CCS wire at the damaged insulation jacket reduced the wire tensile break load and may result in complete loss of wire continuity during the service.

The overall performance of the tracer wire products investigated in this project were rated using the laboratory test results on tensile break loads (with and without kink), abrasion and scrape resistance together with the corrosion performance post field installation. The rating scores of the wire performance are summarized in Table 2.

In all, the Company F wire outperformed the other traditional wires based on its rating for the various performance properties evaluated. The Company F wire has the highest score on the tensile break load (with and without a kink) and the scrape test. This wire was also tested in the two field test trials by HDD installation and did not show significant damage on the wire insulation. Furthermore, the continuity of this wire conductor was not affected after the 2000 hour corrosion test.

The high strength CCS wires designed for HDD installation had the improved tensile break load compared to the traditional solid copper wire, however, their tensile break loads were significantly reduced when the wires were kinked and then tensile tested. In addition, the abrasion and scrape resistance of the wires needs to be improved in order to prevent insulation damage during HDD installation (to prevent corrosion of the exposed wire). The performance of the high strength HDD CCS wires made from the various manufacturers was not significantly different from each other.

Table 1. The Evaluated Tracer Wire Products

Manufacturers	Tracer Wires	Lab Tested			Field Tested	Corrosion Evaluation
		Tensile	Abrasion	Scrape		
E	High Flex CCS (12 AWG)	X	NT	NT	X	X
E	HDD CCS (12 AWG)	X	X	X	X	X
D	Extra High Strength CCS (12 AWG)	X	X	X	NT	X
D	High Strength CCS (12 AWG)	X	NT	NT	NT	NT
D	Super Flex CCS (14 AWG)	X	NT	X	NT	X
D	Super Flex CCS (12 AWG)	X	NT	NT	NT	NT
A	HDD CCS (12 AWG)	X	X	X	NT	X
A	Fully Annealed CCS (12 AWG)	X	NT	X	NT	X
A	Stress Relieved CCS (12 AWG)	X	NT	NT	NT	NT
A	Solid Copper (12 AWG)	NT	NT	NT	X	X
C	Solid Copper (14 AWG)	X	X	X	NT	X
C	Solid Copper (12 AWG)	X	NT	NT	X	X
B	Solid Copper (12 AWG)	X	X	X	NT	X
B	Solid Copper (10 AWG)	X	NT	NT	NT	NT
B	Hard Drawn Solid Copper (10 AWG)	X	NT	NT	NT	NT
B	Dead Soft Annealed (DSA) CCS (12 AWG)	X	NT	NT	NT	NT
B	Stress Relieved CCS (12 AWG)	X	NT	NT	NT	NT
F	Fiber and Solid Copper (19 AWG)	X	X	X	X	X

X = Tested

NT = Not Tested

Table 2. The Overall Performance Chart

Wire #	Manufacturers	Tracer Wires	Overall Performance Rating*							
			Tensile Break Load		Insulation Jacket		Corrosion Performance		Wire Flexibility	
			No Kink	Kinked	Abrasion	Scrape	Continuity	Break Load	Rigidity	Spring Back
1	A	Solid Copper (12 AWG)	NT	NT	NT	NT	Yes	NT		
2	B	Solid Copper (12 AWG)	12	12	51	34	Yes	NT		
3	B	Solid Copper (10 AWG)	18	NT	NT	NT	NT	NT		
4	B	Hard Drawn Solid Copper (10 AWG)	26	25	NT	NT	NT	NT		
5	C	Solid Copper (14 AWG)	8	8	65	18	Yes	NT		
6	C	Solid Copper (12 AWG)	12	12	NT	NT	Yes	100		
7	A	Fully Annealed CCS (12 AWG)	16	16	NT	9	Yes	NT		
8	A	Stress Relieved CCS (12 AWG)	32	24	NT	NT	NT	NT		
9	A	HDD CCS (12 AWG)	61	28	76	45	Yes	NT		
10	D	Super Flex CCS (14 AWG)	11	11	NT	10	Yes	NT		
11	D	Super Flex CCS (12 AWG)	17	17	NT	NT	NT	88		
12	D	High Strength CCS (12 AWG)	23	23	NT	NT	NT	NT		
13	D	Extra High Strength CCS (12 AWG)	63	25	53	44	Yes	NT		
14	B	Dead Soft Annealed CCS (12 AWG)	16	16	NT	NT	NT	NT		
15	B	Stress Relieved CCS (12 AWG)	30	29	NT	NT	NT	NT		
16	E	High Flex CCS (12 AWG)	19	19	NT	NT	Yes	NT		
17	E	HDD CCS (12 AWG)	61	45	100	56	No	63		
18	F	Fiber and Copper19 AWG	100	100	62	100	Yes	NT		

*The overall performance rating:

- Rating of tensile break load (with and without a kink) was calculated using the laboratory tensile test results by the ratio of the break load of the evaluated wire to that of the best performed wire (#18 having the highest tensile break load with and without kink).
- The rating of abrasion resistance was calculated using the laboratory abrasion resistance test results by the ratio of the insulation thickness loss of the evaluated wire to that of the best performed wire (#17 having the lowest number of thickness loss).
- The rating of scrape resistance was calculated using the laboratory scrape resistance test results by the ratio of the scrape-through cycles of the evaluated wire to that of the best performed wire (#18 having the highest cycles that the insulation was scrape through).
- The rating of the wire tensile performance at exposure to corrosion environment was calculated by the ratio of the break load measured after corrosion test to the break load measured on the as received specimens made from the same wire product.

Introduction

For the last 20 years, the use of solid copper tracer wire has been the standard practice in the gas industry for locating plastic pipe. It is readily available, highly conductive and relatively easy to handle. The increased use of more demanding operations such as horizontal directional drilling (HDD) installation techniques creates challenges, such as causing breaks in solid copper tracer wire during installation. To mitigate the threat of a broken tracer wire some operators install multiple wires with diameters as large as 8 AWG, and others may use on a single large gauge wire (as large as 4 AWG). Copper tracer wires come in a variety of jacket insulation types with abrasion resistance and workability characteristics that are different than the wire. In addition to more demanding applications, higher copper material costs have also led to the desire for tracer wire alternatives such as copper-clad steel (CCS) wire and other alternatives.

There are many tracer wire variables for operators to consider with different properties such as: conductor type, gauge size, hardness, and insulation thickness. New tracer wire options for locating plastic pipe have been brought to market. These systems primarily attempt to address a lack of tensile strength of traditional tracer wire. One such product, Polymer Fiber Reinforced Solid Copper addresses the tensile strength issue while not compromising workability.

The Polymer Fiber Reinforced Solid Copper product differs from traditional tracer wire products in that it employs a layer of insulation placed over the conductive metallic core. This wire utilizes a high tenacity polyester woven fiber core with an insulated wire integrally woven internally. Such woven strip configurations have a very high strength-to-weight ratio and are commonly used in industrial lifting and towing applications at very high levels of loading. In theory, the woven fabric in this wire would contribute to the bulk of the product's tensile strength and provide additional abrasion resistance, both protecting the wire from damage thereby reducing the chance of breakage. Therefore the manufacturer has been able to configure the wire with a relatively small diameter wire at 19 AWG. The manufacturer also provides connectors to facilitate product installation.

Given the number of tracer wire configurations available, along with new products such as Polymer Fiber Reinforced Solid Copper, there is a need for a comparative evaluation to allow operators to select a cost effective tracer wire that can withstand the stresses of installation techniques in various environmental conditions.

The objective of this project was to provide the industry with information on the properties and performance of currently used tracer wire products as well as new and more "HDD friendly" products.

GTI conducted a survey with the project sponsors to identify the environmental conditions, performance requirements and the expected improvement for HDD application. A comprehensive product review was conducted on various commercially available tracer wire products to compare the product characteristics. Several types of tracer wire, including conventional and new products, were identified for testing in laboratory and field environments. These products represent the tracer wire products that the project sponsors are currently using as well as the new products that the manufacturers are recommending for HDD applications.

A test protocol was developed and used for the tracer wire testing and includes the following:

1. Laboratory Tests:
   - Tensile Test
   - Linear Taber Abrasion Test
   - Modified SAE AS4373 Method 701

  - Corrosion Evaluation of field tested tracer wires and scrape tested wires at the locations containing the damaged insulation

2. Field Tests:
   - HDD field installations
   - Tracer wire insulation inspection

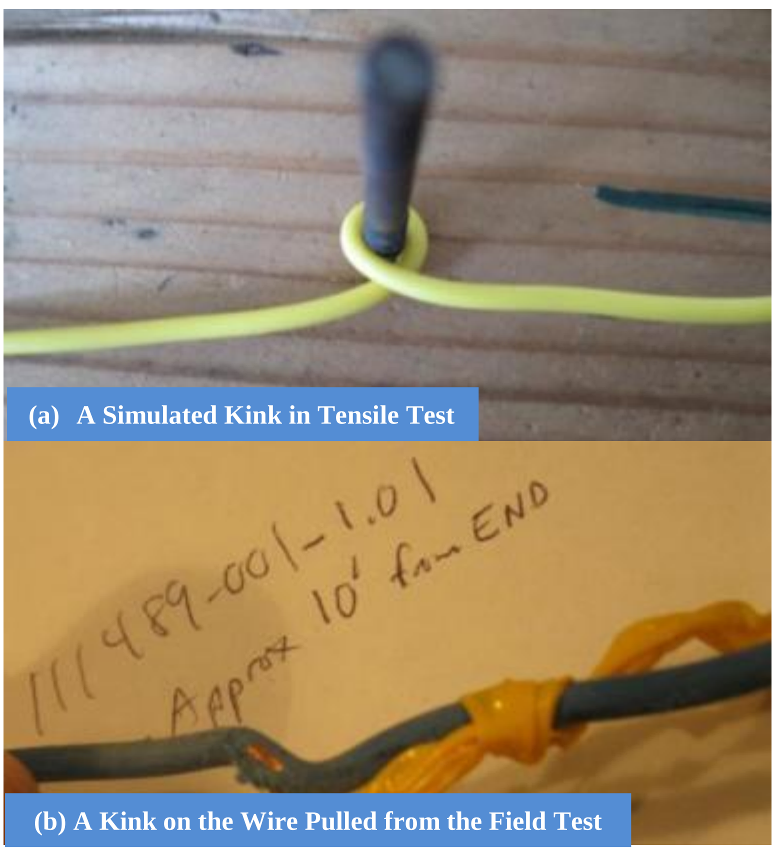
Below are the manufacturers for the tracer wires that were tested in this project:

- Agave
- Kris-Tech
- Paige
- Copperhead
- Pro-Line
- NEPTCO

Task 2. Laboratory Testing

Task 2.1: Tensile Test

- ***Test Samples:***
  - The length of the tensile wire specimens were 7 ft long.
  - Three replicates were used for each test (straight and kinked specimens).
  - The kinked specimens were made by wrapping the wire around a nail, see Figure 1.
- ***Test Setup :***
  - Figure 2 shows the tensile test setup.
  - Special wire tension grips were used to prevent the wire from slipping.
  - The wire samples were pulled on a MTS machine at 1 inch per minute until failure.
- ***Test Results:***
  - The tensile plots are attached in Appendix I
  - The tensile test results are summarized Table 3.
  - Comparative analysis of the tensile properties of the tested wires is discussed in Task 2.4.



(a) A Simulated Kink in Tensile Test

(b) A Kink on the Wire Pulled from the Field Test

Figure 1. The Simulated Kink for Tensile Test vs. a Kink on the Field Tested Wire

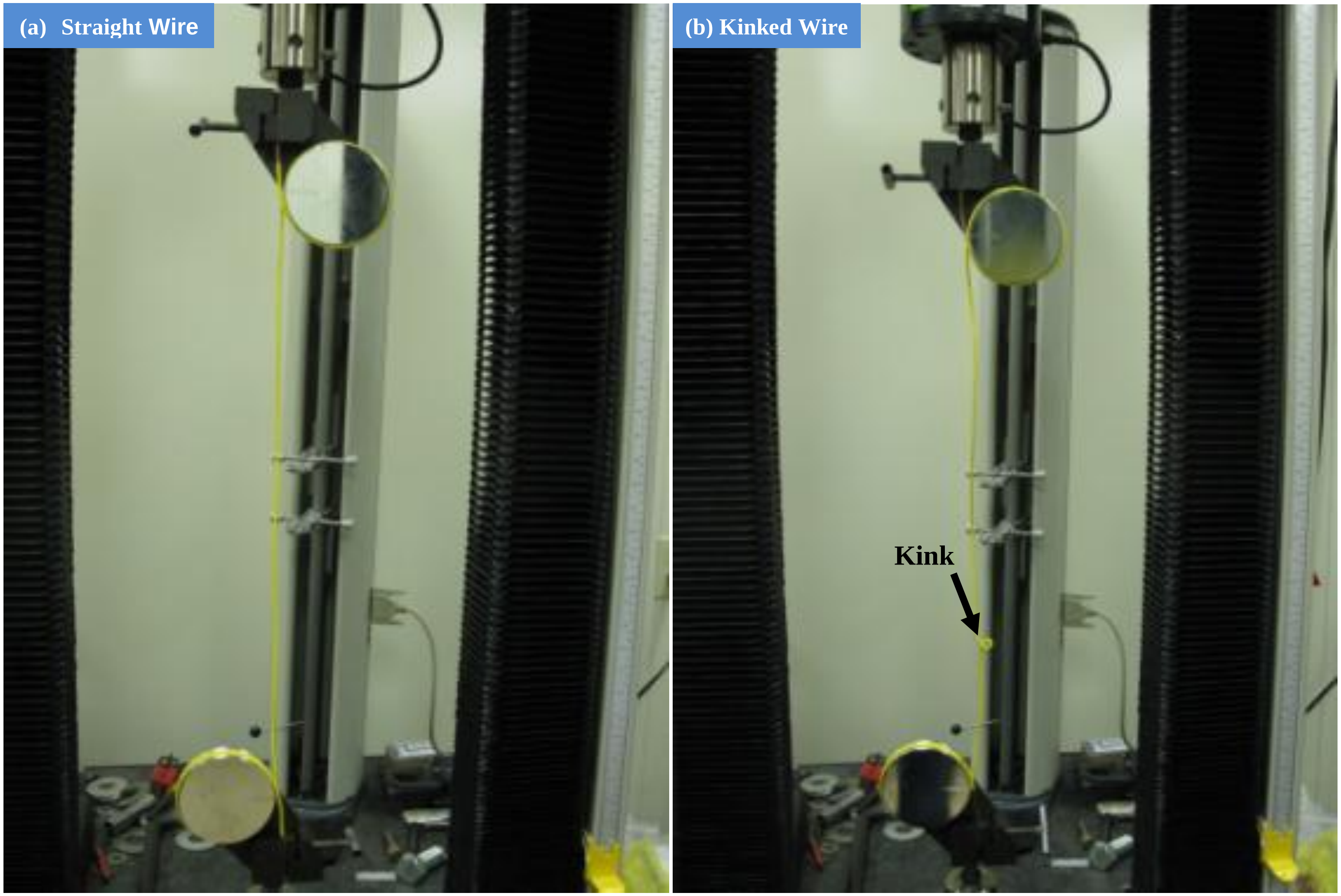


Figure 2. Wire Tensile Test Setup

Table 3. Summary of Tensile Test Results with the Ratio of Yield/Ultimate (Y/T)

Group	Manufacturer	Tracer Wire	Straight			Kinked		
			Break Load (lbs)	Min Yield (lbs)	(Y/T)	Break Load (lbs)	Min Yield (lbs)	(Y/T)
I	C	14 AWG Copper	135.3	89.7	0.663	135.6	92.0	0.678
	C	12 AWG Copper	205.9	144.3	0.701	205.0	145.0	0.707
	B	12 AWG Copper Soft Drawn	218.7	152.3	0.697	218.3	151.3	0.693
	B	10 AWG Copper Soft Drawn	309.0	216.5	0.701	NT	NT	NT
	B	12 AWG CCS DSA	279.4	189.3	0.678	279.9	189.3	0.676
	E	12 AWG CCS High Flex	338.4	233.7	0.691	332.2	244.3	0.736
	A	12 AWG CCS Fully Annealed	286.7	200.0	0.698	285.1	200.0	0.702
	D	14 AWG CCS Super Flex	198.9	137.7	0.692	198.7	138.0	0.694
	D	12 AWG CCS Super Flex	299.9	227.3	0.758	297.9	212.0	0.712
	D	12 AWG CCS High Strength	398.3	293.3	0.736	405.5	303.5	0.749
II	D	12 AWG CCS Extra High Strength	1113.7	861.5	0.774	440.8	*	*
	A	12 AWG CCS HDD	1074.0	856.0	0.797	491.3	*	*
	E	12 AWG CCS HDD	1067.4	971.7	0.91	803.3	*	*
III	A	12 AWG CCS Stress Relieved	566.6	536.7	0.947	428.2	*	*
	B	12 AWG CCS Stress Relieved	518.6	508.3	0.99	513.2	508.3	0.99
	B	10 AWG Copper Hard Drawn	462.4	458.7	0.992	443.1	*	*
IV	F	Fiber and 19 AWG Solid Copper	1757.6	*	*	1775.1	*	*

Note:

The precision of the tensile instrument is ±0.1 lbs.

NT: Not Tested

NA: Not Applicable

*failed before yield

Task 2.2: Linear Taber Abrasion Resistance Test

- ***Test Samples***
  - Three replicates were used for each product.
  - Tested wire products include:
    1. Company E solid copper wire (45 mil LDPE)
    2. Company C solid copper wire (45 mil LDPE)
    3. Company F (48 mil HDPE and insulation fibers)
    4. Company F HDD CCS (45 mil HDPE)
    5. Company A HDD CCS (45 mil HDPE)
    6. Company D Extra High Strength CCS (45 mil HDPE)
- ***Test Setup:***
  - The wire insulation jacket was tested with Linear Taber Abraser under a 1600 gram load using the H22 Abrader, see Figure 3.
  - The thickness of the insulation jacket before and after 1000 strokes was measured.
- ***Test Results:***
  - Linear Taber abrasion test results are plotted in Figure 4.
  - Company E and Company A HDPE insulation jackets exhibit higher abrasion resistance than other HDPE and LDPE insulation jackets.

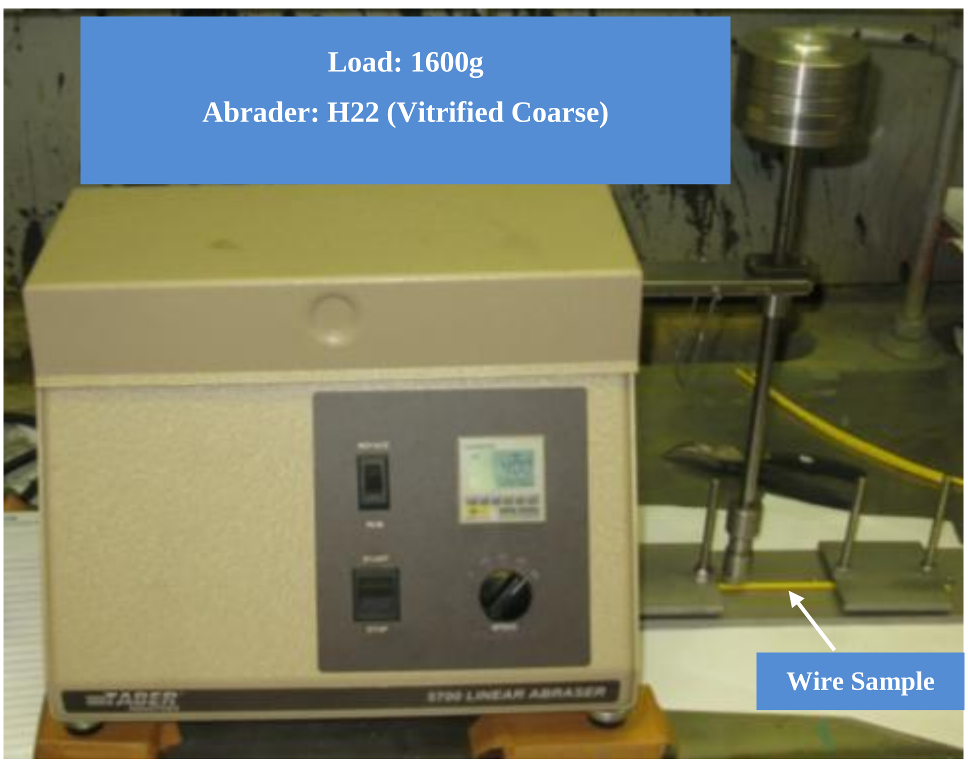


Figure 3. Taber Abrasion Test Setup

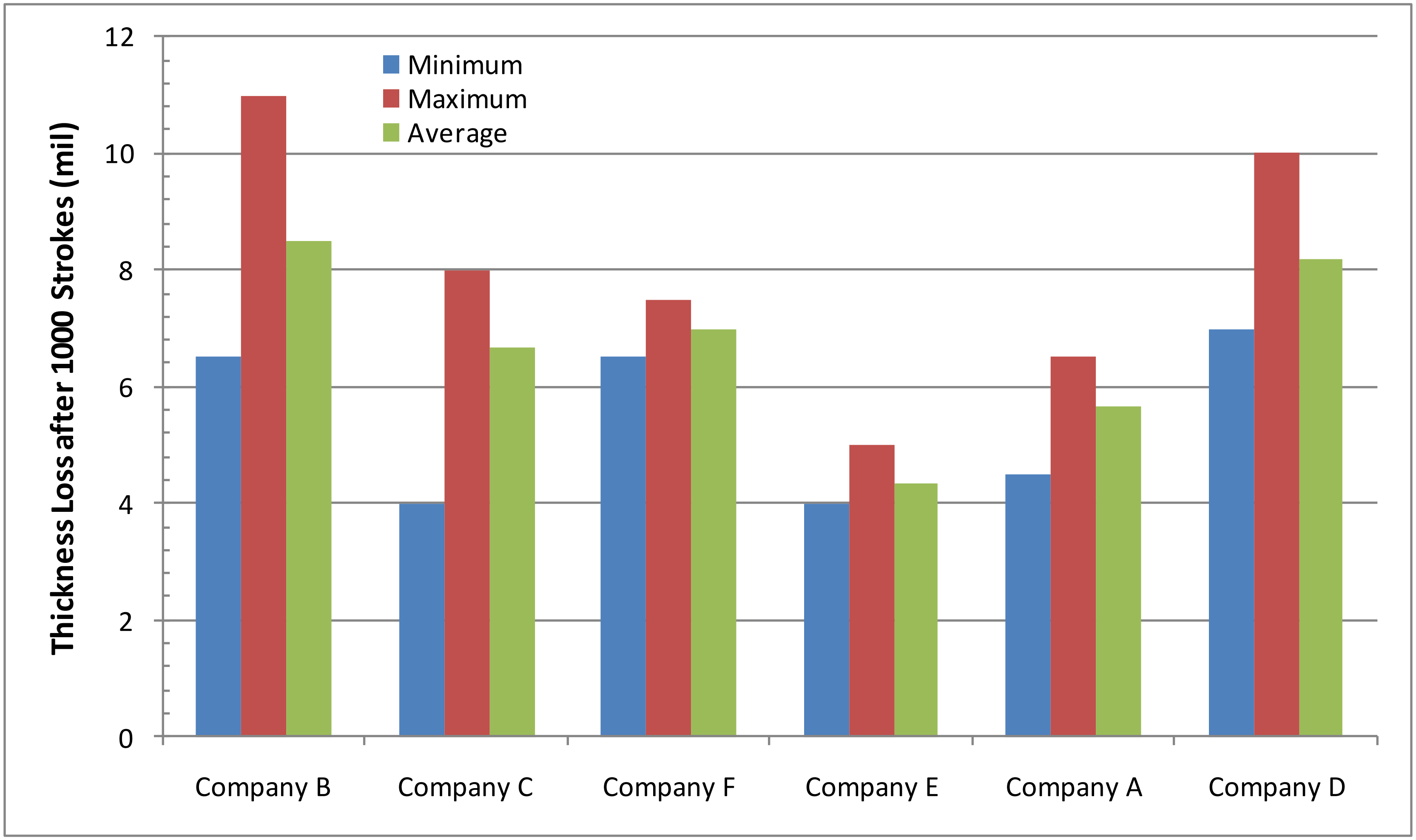


Figure 4. Taber Abrasion Test Results

Task 2.3: Scrape Abrasion Resistance Test

- ***Test Samples:***
  - Figure 5 shows the test specimen after scrape test.
  - Three replicates were used from each product and three locations were tested on each sample with total of 9 data points per product.
  - The Tested products include:
    1. Company A fully annealed CCS (30 mil HDPE)
    2. Company D super flex CCS (30 mil HDPE)
    3. Company B solid copper (45 mil LDPE)
    4. Company C solid copper (45 mil LDPE)
    5. Company F (48 mil HDPE and insulation fibers)
    6. Company E HDD CCS(45 mil HDPE)
    7. Company A HDD CCS (45 mil HDPE)
    8. Company D extra high strength (45 mil HDPE)
- ***Test Setup:***
  - The test method was a modified SAE AS4373 Method 701:
    - The wire insulation jacket was scratched with a needle under a load of 1500 grams.
    - The size of the needle used in the test was half the needle radius stated in AS4373.
  - The number of cycles that the needle took to abrade through the insulation was recorded.
- ***Test Results:***
  - The scrape resistance is displayed by the number of cycles that the needle penetrated through the insulation jacket, see Figure 6.
  - The average number of cycles for the needle to penetrate through the Company F wire insulation (containing polymer fiber and HDPE coating) was significantly higher than the traditional HDPE and LDPE coating.
  - HDPE insulation jackets had higher scrape resistance than LDPE insulation jackets at the same coating thickness.
  - The increase in insulation thickness from 30 mils to 45 mils significantly increased the scrape resistance of the wires.

Figure 5. Wire Sample after Scrape Test

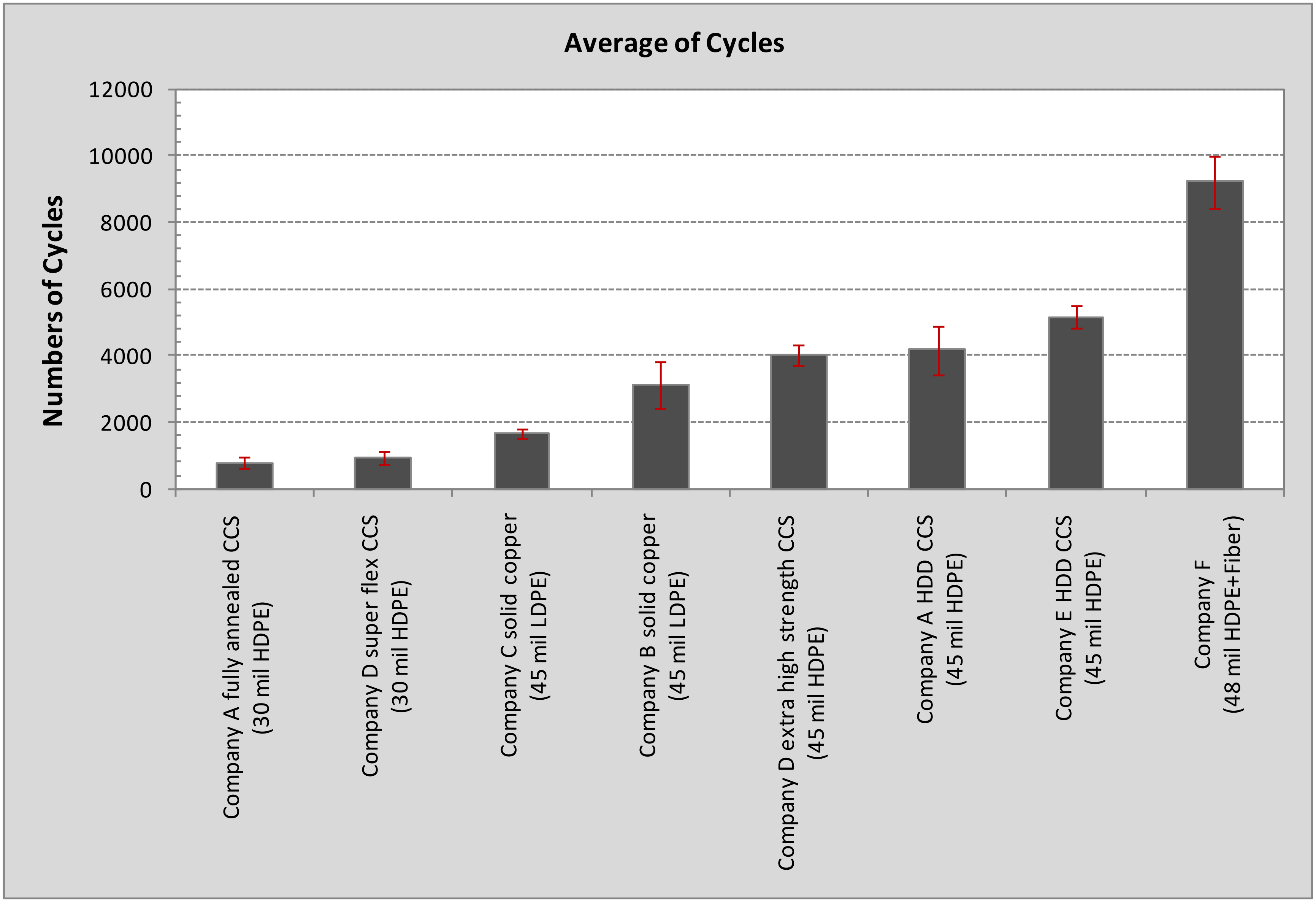


Figure 6. Scrape Test Results

Task 2.4: Comparative Analysis of Tensile Properties

Tensile Properties

A full analysis was conducted to evaluate the tensile test results. The ratio of the minimum yield strength over the ultimate tensile strength (also called tensile break load, or peak load) was used as a parameter (Y/T) to evaluate the tendency of the tested wires to break at a kink. In general, the lower the value of the parameter (Y/T) of the wire indicates that the wire can still take larger tensile load by plastic deformation after its yield strength is reached. Therefore, the break loads of the wires with lower value of the parameters (Y/T) are less affected by the large plastic deformation at a kink. The results are summarized in Table 3. The parameter (Y/T) and ultimate tensile strength (tensile break load) of the straight wires are plotted in Figure 7. The ultimate tensile strength (tensile break load) of the straight and kinked wires is plotted in Figure 8.

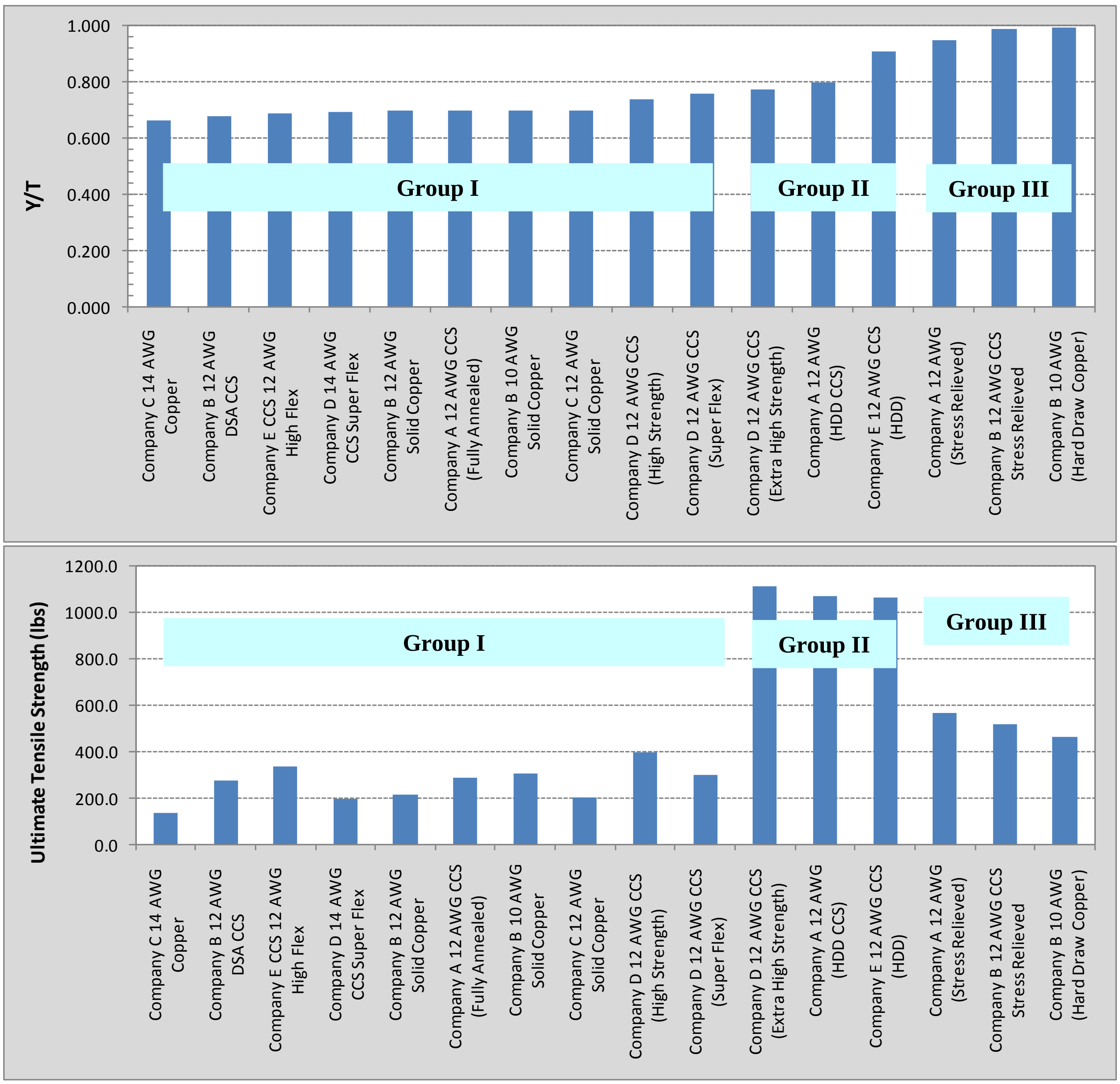


Figure 7. The Y/T vs. the Ultimate Tensile Strength of Straight Tracer Wires

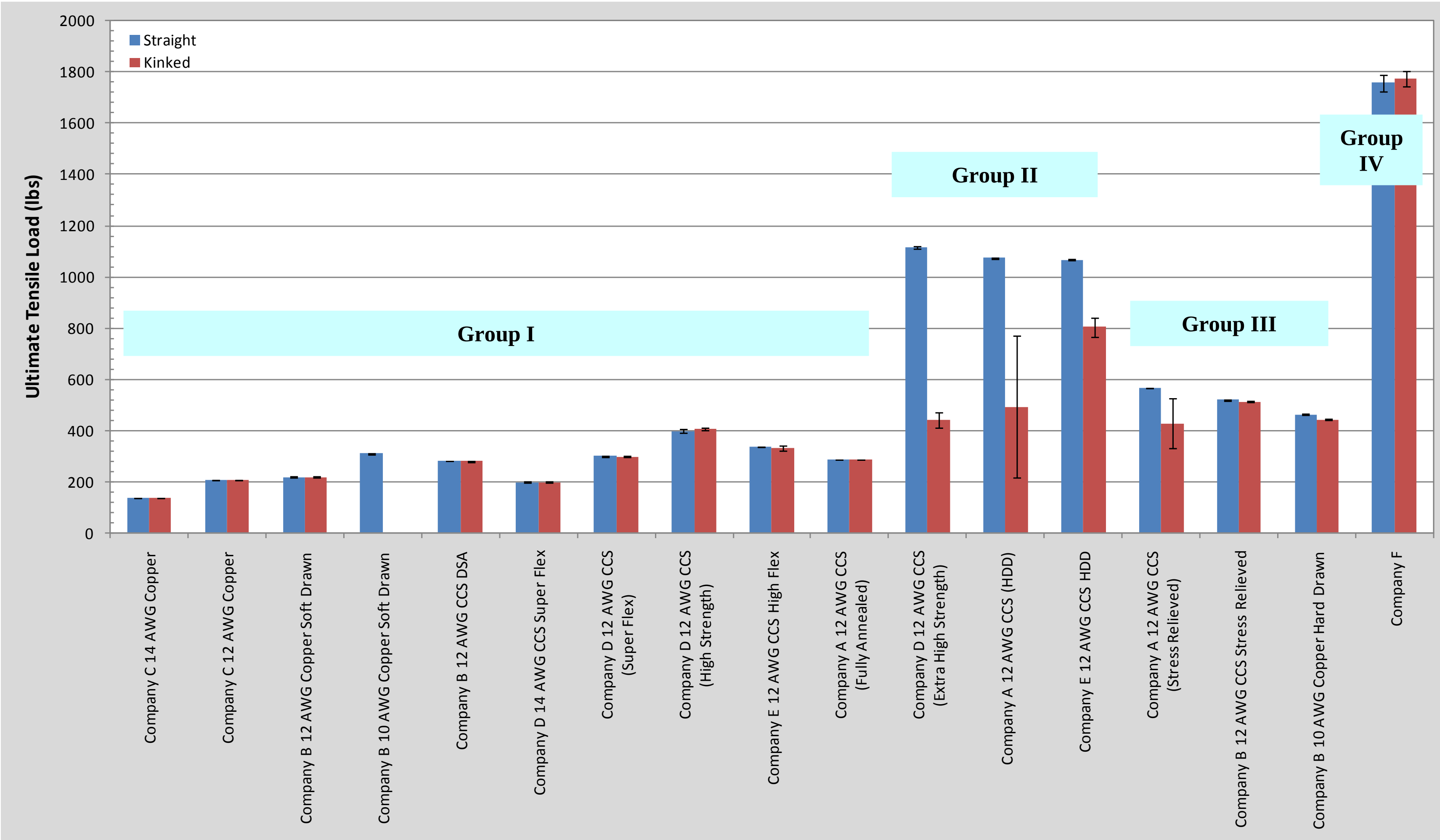


Figure 8. Ultimate Tensile Strength of the Straight and Kinked Tracer Wires

Based on the tensile results, the wires are categorized in four groups:

- ***Group I: Solid Copper Wires and High Flex CCS Wires***

  Group I includes solid copper wires and high flex CCS wires that are made to have similar flexural property as solid copper. The wires in ***Group I*** have lower tensile break loads (less than 400 lbs). They have relatively lower "Y/T" compared to the wires in the other groups, especially the wires in ***Group III***. In addition, the tensile break loads of these wires had minor variances when they were tested with a kink in the wire.

  - Company C solid copper (12 and 14 AWG)
  - Company B soft drawn solid copper (12 and 10 AWG)
  - Company B dead soft annealed CCS
  - Company E 12 AWG high flex CCS
  - Company D 14 AWG super flex CCS
  - Company A 12 AWG full annealed CCS

- ***Group II: High Strength CCS Wires***

  Group II are the high strength CCS. These wires have high tensile break loads, but the break loads were significantly reduced when they were tested with a kink in the wire. Even though these wires are intentionally made stronger than high flex CCS and solid copper wires, their tensile properties are greatly reduced and their insulation jackets are more susceptible to damage when a kink or tangle occurs in the wire which may be encountered during an HDD installation (this was experienced during one of the field installations). These wires have higher "Y/T" than the solid copper and high flex CC wires.

  - Company D 12 AWG CCS (1245Y-EHS: Extra High Strength)
  - Company Q 12 AWG CCS (BT-1201: for HDD application)
  - Company E 12 AWG CCS (for HDD application)

- ***Group III: Stress Relieved CCS and Hard Drawn Solid Copper Wires***

  Group III includes the stress relieved CCS wires and the hard drawn solid copper wires. The parameters (Y/T) of these wires are close to "1" because the tensile loads did not significantly increase in the plastic deformation range after the wire yields (see Figure 26, Figure 34 and Figure 35). Therefore, the tensile break loads were not significantly reduced when they were tested with a kink due to the larger tolerance of these wires to plastic deformation. The tensile break loads of these wires are higher than the wires in Group I, but significantly lower than those in Group II.

- ***Group IV: Polymer Fiber Reinforced Solid Copper***

  The tensile test results from Company F wire exhibit a different behavior than solid copper and CCS wires. This wire consists of polymer fibers and a copper conductor. Its higher tensile break load is primarily due to the polyester fibers which take the majority of the tensile load during tensile testing. Since the conductor is a 19 AWG copper wire, the wire possesses the flexibility of a thin gauge copper wire but very high tensile properties attributed to the fibers.

  In addition, the tensile break load of the wires from Company F did not drop when they were tested with a kink. This indicates that this type of wire is not likely to fail by kinking during HDD installations.

Task 2.5 Corrosion Evaluation

Accelerated Cyclic Corrosion Test (CCT-1)

Laboratory corrosion test consisting of alternate wet-dry seawater and high humidity exposure was performed to evaluate the corrosion performance of the wires that contained damaged insulation jackets. The test specimens included the wires pulled from field installation containing anomalies and the wire specimens which were scrape tested and contained cut-through jackets at the test areas.

The CCT-1 is a very rigorous corrosion test and simulates humidity and temperature fluctuation effects. The tests were performed using the Q-Fog machine shown in Figure 9. The CCT-1 test includes the following cycles:

1. Salt Fog at 95ºF for 4 hrs
2. Dry off at 140ºF for 2 hrs
3. Dry off at 104ºF for 0.5 hr
4. Humidity at 122ºF (>95% relative humidity) for 2 hrs
5. Repeat step 1 to step 4.

The continuity of the above test specimens were tested with Fluke 87 III Multimeter before and after 2000 hour CCT-1. The tensile strength was also tested post 2000 hr corrosion exposure for the wires having holidays in the insulation jacket from field installation if approximate 10 ft tensile specimens could be prepared from the holidays to have the holidays in the center of the 10 ft specimen.

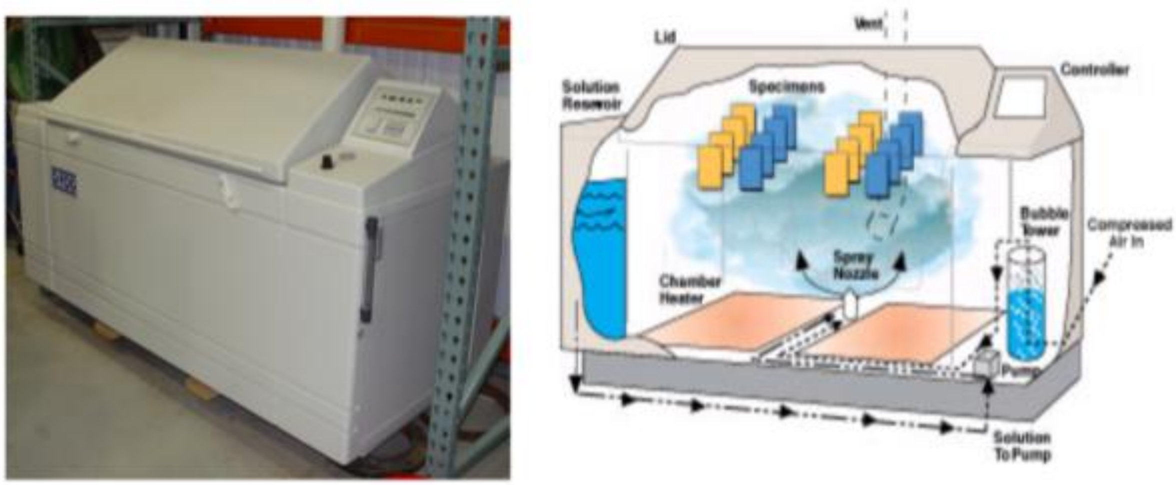


Figure 9. Cyclic Salt Fog Tester

Test Samples

- ***Wires Pulled out from Field Installations***

  Approximate 10 feet from each wire sample was prepared from the locations where the insulation jacket was found to be damaged during the two field installations. The samples were checked for continuity before placing them into the corrosion chamber. The samples include:

  1. Company F wire from the first field installation,

2. Company A 12 AWG solid copper from the first field installation (two wire samples prepared from the locations containing holidays in the jacket),
3. Company D 12 AWG CCS from the first field installation (two wire samples prepared from the locations containing holidays in the jacket),
4. Company E 12 AWG CCS high flex from the second field installation (one wire sample prepared from the location containing holidays in the jacket),
5. Company E 12 AWG CCS HDD from the second field installation (one wire sample prepared from the location containing holidays in the jacket), and
6. Company C 12 AWG solid copper from the second field installation (three wire samples prepared from the locations containing holidays in the jacket).

- ***Scrape Tested Wires***

The wire samples from the scrape tests were also included in the corrosion evaluation to compare the field performance of the insulation jackets with laboratory testing results. These wire samples contained three damaged locations where the insulation jackets were abraded through by the needle during the scrape test. The samples include:

1. Company A fully annealed CCS 30 mil HDPE
2. Company D super flex 30 mil HDPE
3. Company C 14 AWG solid copper 45 mil LDPE
4. Company B solid copper 45 mil LDPE
5. Company D extra high strength 45 mil HDPE
6. Company A HDD CCS 45 mil HDPE
7. Company E HDD CCS 45 mil HDPE
8. Company F 48 mil HDPE+Fiber

Corrosion Test and Results

Table 4 shows the results of continuity and the electrical resistance measured after the 2000 hour corrosion test. The CCS wire (Company E HDD-CCS-PE45) made for HDD application was severely corroded at the locations where the insulation jacket was damaged by scrape test or through field installation, see Figure 10. The wire lost continuity at the damaged insulation due to corrosion.

The wires containing holidays in their insulation jackets from the field installation were tested for tensile strength post corrosion test, the results are summarized in Table 5. The rating of the wire performance to corrosion exposure was calculated by the ratio of the break load measured after corrosion test to the break load measured on the as received specimens made from the same wire product, i.e.:

$$\boldsymbol{Rating} = \mathbf{100} \times \frac{\boldsymbol{T_{cor}}}{\boldsymbol{T}}$$

T_{cor}: tensile break load measured on the specimens after corrosion test

T: tensile break load measured on the as received specimens

The post corrosion tensile strength of the Company C 12 AWG solid copper wire did not change in comparison with the original tensile break load. However, the two CCS wires were both affected by corrosion exposure with Company E HDD CCS wire having the most reduction of the tensile break load (37% reduction from the tensile strength measured on the as received specimens), and 12% tensile break load reduction for Company D 12 AWG CCS wire.

It appears the CCS wires were more likely to be corroded in case their insulation jackets were damaged during the field installation. Because steel is anodic to copper, corrosion of steel core could be accelerated by the copper clad layer due to the galvanic effect between the two metals. The strength break load was reduced as a result of corrosion, and eventually the wire broke at the corroded areas causing lost of continuity.

Table 4. Continuity and Electrical Resistance Tests of Wire Specimens after 2000 Hour CCT-1

Specimens	Type of Wires	Continuity	Resistance	Comments
Scrape Tested	Company E, HDD-CCS-PE45-45 mil HDPE	NO	>1 Mohms	Break in Wire
	Company C, 14 AWG copper-45 mil HDPE	YES	0.2 Ohms	
	Company A, 12 AWG HDD CCS-45 mil HDPE	YES	0.1 Ohms	
	Company F-48 mil HDPE + Fiber	YES	0.3 Ohms	
	Company D, 14 AWG super flex CCS-45 mil HDPE	YES	0.4 Ohms	
	Company D, 12 AWG extra high strength CCS 45 mil HDPE	YES	0.3 Ohms	
	Company A, 12 AWG super flex CCS-30 mil HDPE	YES	0.4 Ohms	
	Company B, solid copper-45 mil HDPE	YES	0.3 Ohms	
Field Tested (at detected holidays)	Company D, 12AWG CCS (Holiday #1)	YES	0.3 Ohms	
	Company D 12AWG CCS (Holiday #2)	YES	0.1 Ohms	
	Company A, 12 AWG Copper (Holiday #1)	YES	0.3 Ohms	
	Company A, 12 AWG Copper (Holiday #2)	YES	0.3 Ohms	
	Company E, 12 AWG high flex CCS-45 mil HDPE (Holiday)	YES	0.4 Ohms	
	Company E, 12 AWG HDD CCS-45mil HDPE (Holiday)	NO	>1 Mohms	Break in Wire
	Company C, 12 AWG copper-45 mil HDPE (Holiday #1)	YES	0.3 Ohms	
	Company C, 12 AWG copper-45 mil HDPE (Holiday #2)	YES	0.3 Ohms	
	Company C, 12 AWG copper-45 mil HDPE (Holiday #3)	YES	0.3 Ohms	

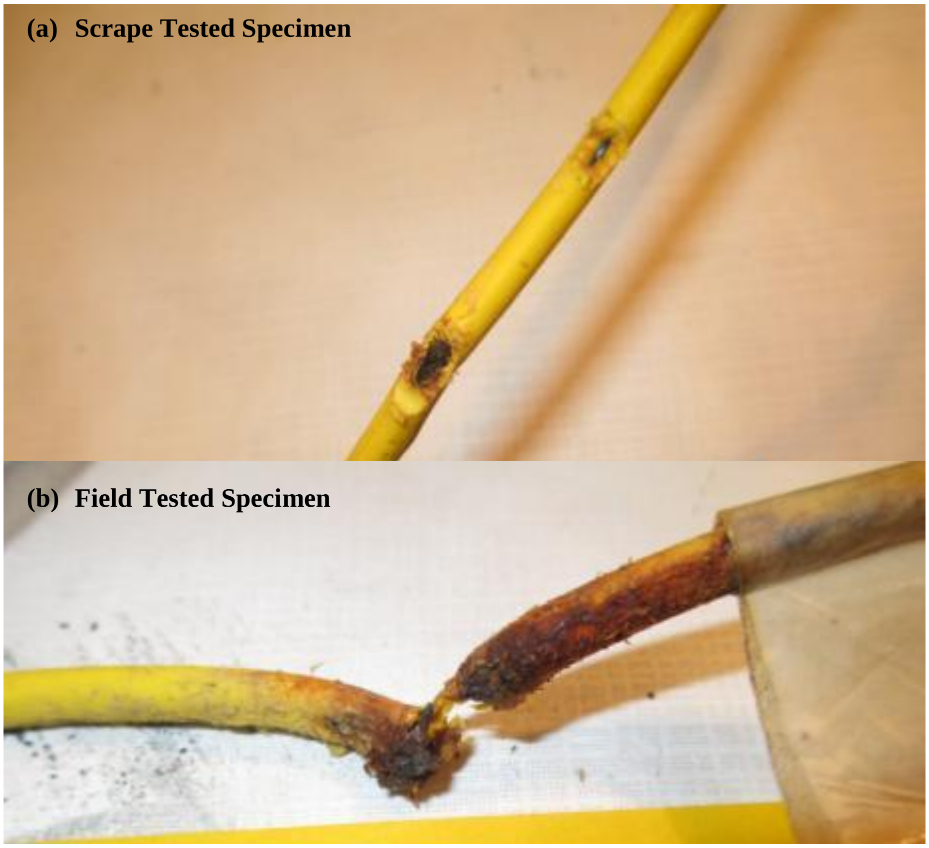


Figure 10. The Corroded Company E-HDD-CCS Test Specimens after 2000 hr CCT-1 Test

Table 5. Tensile Test Results of the Field Tested Wires after 2000 Hour CCT-1 Test

Tracer Wire	Break Load (lbs)	Minimum Yield (lbs)	(Y/T)	Rating [a]
Company D 12 AWG CCS	265.1	NA	NA	88
Company A, 12 AWG Solid Copper (#1)	199.1	150.4	0.755	-
Company A, 12 AWG Solid Copper (#2)	193.4	151.2	0.782	-
Company E,12 AWG CCS	676.7	NA	NA	63
Company C, 2 AWG Solid Copper (#1)	204.7	147.5	0.721	99
Company C,12 AWG Solid Copper (#2)	205.4	146.9	0.716	100

Note:

a: the rating was calculated by the ratio of the break load measured on the specimens after corrosion test to the break load measured on the as received specimens:

$$\boldsymbol{Rating} = \mathbf{100} \times \frac{\boldsymbol{T_{cor}}}{\boldsymbol{T}}$$

T_{cor}: tensile break load measured on the specimens after corrosion test

T: tensile break load measured on the as received specimens

NA: the sample failed before yield.

Summary

Tensile Properties

Tensile strength is one of the important characteristics of tracer wire to be considered for HDD applications. The traditional copper tracer wire is made of soft drawn copper and exhibits good flexibility that allows the wire to be easily handled during typical open trench field installations.

Copper clad steel (CCS) wires improve the tensile strength compared to the traditional solid copper tracer wire. The high flex CCS wires are made of low carbon steel through a special annealing process to make the wires flexible. The high flex CCS wires have a higher tensile break load, but also have the similar elongation property as the traditional soft drawn copper wire, see Figure 11. They all have larger plastic deformation region in the tensile plots between the yield and ultimate tensile load.

Extra high strength (EHS) CCS wires are designed for HDD application with very high tensile break load. These wires are made of high carbon steel and are hard drawn to achieve an optimum tensile strength which is normally around 1,000 lb for 12 AWG wires. The EHS-CCS wires are more rigid and brittle than the other tracer wires tested. Their tensile loads are significantly reduced when they were tested with a kink in the wire. The EHS-CCS wires manufactured by Company E for HDD possesses a higher tensile break load (~800 lbs) even with a kink in the wire, while the tensile break loads of the EHS-CCS wires from Company D and Company A demonstrated reduced tensile values (similar level as the high strength or stress relieved CCS wires) when they are tested with a kink in the wire.

The stress relieved CCS wires are made of high carbon steel or low carbon steel. They are annealed to improve flexibility but the tensile break load is significantly reduced as a result.

Hard drawn copper wire improves the tensile break load versus soft drawn copper, but it also makes the wire more hard and brittle.

Trace wire from Company F exhibits a significantly high tensile load (~1,800 lb) due to the polymer fibers used to give the product its strength. This wire also exhibits the similar high tensile load when it was tested with a kink in the wire. In addition, this wire is very flexible compared to the other types of tracer wires because a thin gauge (19 AWG) copper conductor is used.

Abrasion and Scrape Resistance of Wire Insulation Jackets

The abrasion resistance of the HDPE jackets from Company E and Company A outperformed the other tested PE jackets (LDPE and HDPE). The HDPE jacket from Company D has the similar abrasion resistance as the LDPE from Company B and Company C.

HDPE insulation jackets have higher scrape resistance than LDPE insulation jackets at the same coating thickness. The increase of insulation thickness from 30 mils to 45 mils significantly increases the scrape resistance of the wires. The scrape resistance of Company F insulation material (containing polymer fiber and HDPE coating) are significantly higher than the traditional HDPE or LDPE coating.

Corrosion Evaluation

The Company E CCS wires for HDD application were severely corroded at the locations where the insulation jacket was damaged by scrape test or through field installation. The wire lost continuity at the damaged insulation due to corrosion.

The corrosion evaluation results suggest that the wire manufacturers should take into account the selection of high performance insulation materials that have higher abrasion and scrape resistance in order to prevent wire insulation damage during HDD installation. Corrosion of CCS wire at the jacket defect could result in reduction of tensile break load and loss of wire continuity during the service.

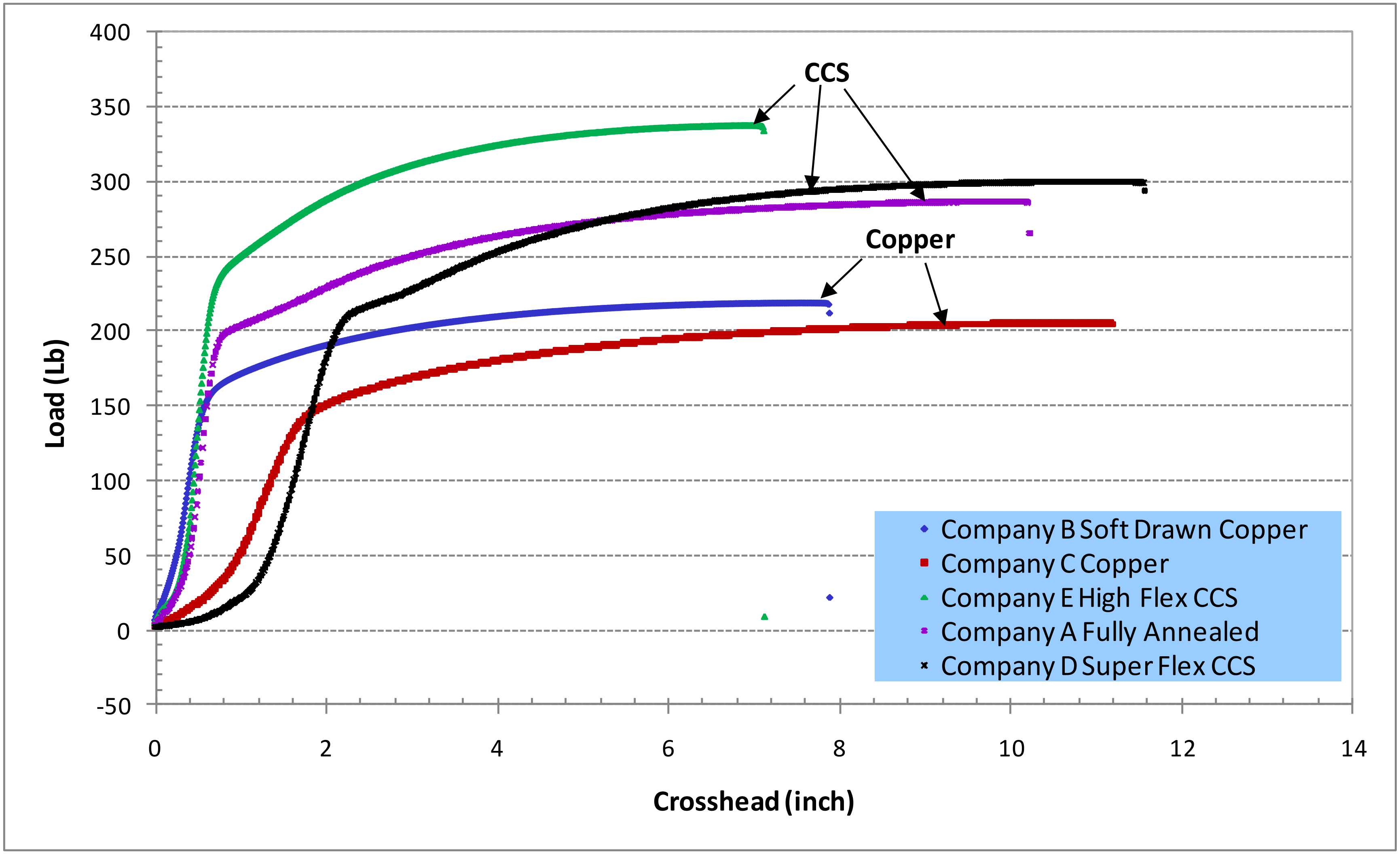


Figure 11. Tensile Plots of CCS vs. Soft Drawn Solid Copper Wires

Table 6. The Overall Performance Chart

Wire #	Manufacturers	Tracer Wires	Overall Performance Rating*							
			Tensile Break Load		Insulation Jacket		Corrosion Performance		Wire Flexibility	
			No Kink	Kinked	Abrasion	Scrape	Continuity	Break Load	Rigidity	Spring Back
1	A	Solid Copper (12 AWG)	NT	NT	NT	NT	Yes	NT		
2	B	Solid Copper (12 AWG)	12	12	51	34	Yes	NT		
3	B	Solid Copper (10 AWG)	18	NT	NT	NT	NT	NT		
4	B	Hard Drawn Solid Copper (10 AWG)	26	25	NT	NT	NT	NT		
5	C	Solid Copper (14 AWG)	8	8	65	18	Yes	NT		
6	C	Solid Copper (12 AWG)	12	12	NT	NT	Yes	100		
7	A	Fully Annealed CCS (12 AWG)	16	16	NT	9	Yes	NT		
8	A	Stress Relieved CCS (12 AWG)	32	24	NT	NT	NT	NT		
9	A	HDD CCS (12 AWG)	61	28	76	45	Yes	NT		
10	D	Super Flex CCS (14 AWG)	11	11	NT	10	Yes	NT		
11	D	Super Flex CCS (12 AWG)	17	17	NT	NT	NT	88		
12	D	High Strength CCS (12 AWG)	23	23	NT	NT	NT	NT		
13	D	Extra High Strength CCS (12 AWG)	63	25	53	44	Yes	NT		
14	B	Dead Soft Annealed CCS (12 AWG)	16	16	NT	NT	NT	NT		
15	B	Stress Relieved CCS (12 AWG)	30	29	NT	NT	NT	NT		
16	E	High Flex CCS (12 AWG)	19	19	NT	NT	Yes	NT		
17	E	HDD CCS (12 AWG)	61	45	100	56	No	63		
18	F	Fiber and Copper19 AWG	100	100	62	100	Yes	NT		

Overall Performance Rating

Table 6 shows the overall wire performance that was rated on the following properties investigated in this project:

- **Tensile Break Load with And without a Kink**

The rating of tensile break load (with and without a kink) was calculated using the laboratory tensile test results by the ratio of the break load of the evaluated wire to that of the best performed wire (tracer wire from Company F), i.e.:

$$\boldsymbol{Rating = 100 \times \frac{T}{T_F}}$$

T: tensile break load of the evaluated wire

T_F: tensile break load for Company F wire

- **Insulation Jacket Abrasion and Scrape Resistance**

a. The rating of abrasion resistance was calculated using the laboratory abrasion resistance test results by the ratio of the insulation thickness loss of the evaluated wire to that of the best performed wire (Pro-Trace CCS HDD having the lowest number of thickness loss), i.e.:

$$\boldsymbol{Rating = 100 \times \frac{\Delta t}{\Delta t_E}}$$

Δt: thickness loss of the evaluated wire

Δt_E: thickness loss of Company E HDD CCS wire

b. The rating of scrape resistance was calculated using the laboratory scrape resistance test results by the ratio of the scrape-through cycles of the evaluated wire to that of the best performed wire (Company F having the highest cycles that the insulation was scrape through), i.e.:

$$\boldsymbol{Rating = 100 \times \frac{Cycles}{Cycles_F}}$$

Cycles: the cycles needed for the needle to scrape through the insulation jacket on the evaluated wire

Δt_F: the cycles needed for the needle to scrape through the insulation jacket on Company F wire

- **Corrosion Performance at the Damaged Insulation Jacket by Field Installation**

a. The wire continuity with "Yes" means the wires remained continuity, and with "No" means the wires lost continuity after 2000 hr CCT-1.

b. The rating of the wire performance to corrosion exposure was calculated by the ratio of the break load measured after corrosion test to the break load measured on the as received specimens made from the same wire product, i.e.:

$$\boldsymbol{Rating = 100 \times \frac{T_{cor}}{T}}$$

T_{cor}: tensile break load measured on the specimens after corrosion test

T: tensile break load measured on the as received specimens

It appears Company F wire outperformed the other traditional wires based on its rating for the above properties. The Company F wire has the highest score on the tensile break load (with and without kink) and the scrape test. This wire was also tested in the two field test trials by HDD installation and did not show significant damage on the wire insulation. Furthermore, the continuity of this wire conductor was not affected after 2000 hr corrosion test.

The high strength CCS wires designed for HDD installation had the improved tensile break load compared to the traditional solid copper wire, however their tensile break loads significantly reduced when the wires were kinked. In addition, the scrape resistance of the wires needs to be improved in order to prevent insulation damage during HDD installation and wire corrosion during the service. The performance of the high strength HDD CCS wires made from the following three manufacturers was not significantly different with each other:

- Company E (CCS): Copperclad CCS conductor
- Company ~~E~~ (HDD CCS): CommScope conductor
- Company D (Extra High Strength): Copperweld CCS conductor

Task 3. Field Tests

First Field Test at Leaf River, IL

Location: Leaf River, IL

Date: July 26, 2011

Attendees: Dennis Jarnecke – GTI, Steve Cohen – Utility Sales, Gene Barney – Leaf River Telephone Co., Dave Salamone – Underground Services (installation contractor), Tom Catmen, Bob Hegan, and Steve Dumas – NEPTCO

Installation Photos: Appendix II

Review of First HDD Field Installation

Leaf River Independent Telephone Company installed 8-9 miles of 2-inch PE conduit for future fiber optic installation. The current installation is about 530 ft drilled parallel to a road and adjacent properties. The HDD project was installed by Underground Services (contractor from Rockford, IL).

Wire Samples

A total of four wires were installed and three wires were removed after the 2-inch PE conduit pipe was installed (one wire remained for future locating of the conduit):

- One 2 AWG Company A solid copper wire (PE coated): removed after pipe installed
- One 12 AWG Company D copper clad (PE Coated): removed after pipe installed
- Two Company F wires:
  - One was pulled out for evaluation
  - The other was left in as the locate mechanism for the PE conduit pipe

All four wires were taped to the pull head and front of the conduit pipe. One Company F wire was taped to the conduit pipe every 10 feet during the installation. This is the standard practice of the contractor installing the pipe. The other three wires were pulled d out from the bore hole simultaneously after the conduit pipe was installed. None of the wires broke during the installation. These wires were then washed and provided to GTI for further evaluation.

HDD Installation

- Ground Conditions:
  - 530ft total: 300ft rock/limestone shale and 200ft soil/clay
  - Soil Conditions: dry
- Other Job Characteristics:
  - Depth: 42 inch – 54 inch
  - Reamer: 6 inch
  - HDPE conduit: 2 inch
  - Severe grinding noise and ground vibrations noted during pull in/reaming in the limestone rock areas

- HDD Rotational PSI during Drilling:
  - Soil: 500 psi
  - Packed clay: 1000 psi
  - Rock: 1500: 2000 psi
- HDD Rotational PSI During Pipe Pull in: 250 psi
- Ambient Temperature: 85ºF

Inspection:

- The samples were cut into approximately 30 ft long specimens.
- The insulation jackets of the specimens were inspected by high voltage coating holiday detector per ASTM G-62 for voltage setting, i.e., 2.9kV for 30 mil coating.

Inspection Results:

- Company F wire: One break in the outer jacket coating was visible, see Figure 12. No holiday was detectable in this wire during the high voltage inspection. Although a breach in the outer jacket was detected the conducting wire still contained duel insulation to protect it; insulation on the copper plus the polyester fibers.
- Company A 12 AWG Solid Copper: Total of four holidays were detected, see Figure 13 through Figure 16.
- Company D 12 AWG Copper Clad Steel: Total of three holidays were detected, see Figure 17 through Figure 19.

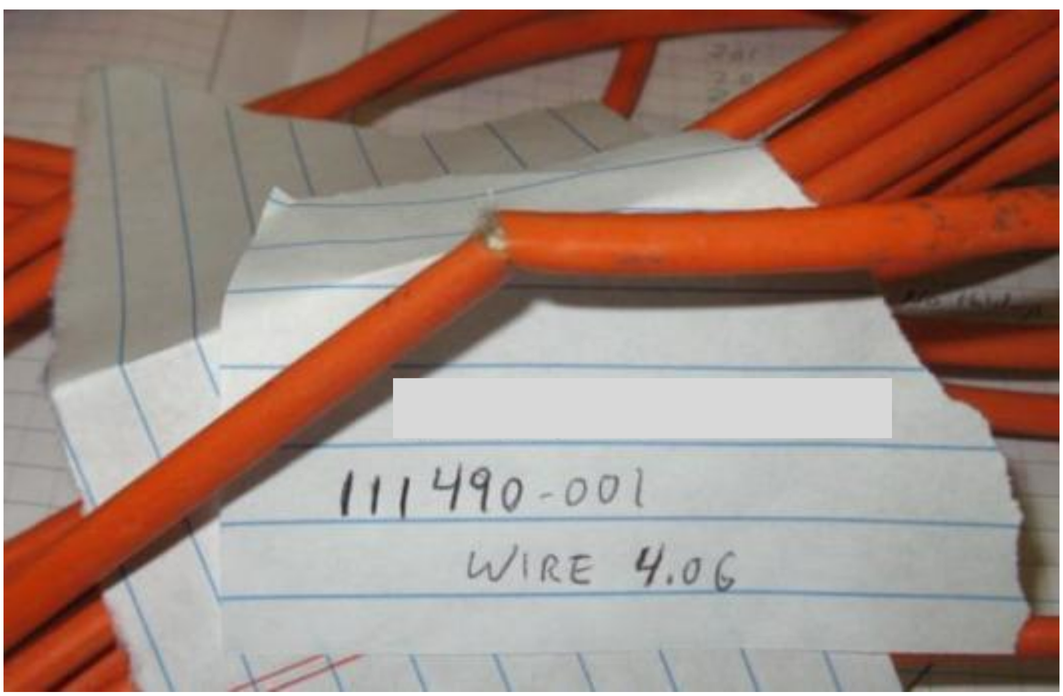


Figure 12. Break of Insulation Jacket on Field Tested Company F Wire

Figure 13. Break of Insulation Jacket (#1) on Field Tested Company A-12 AWG Solid Copper Wire

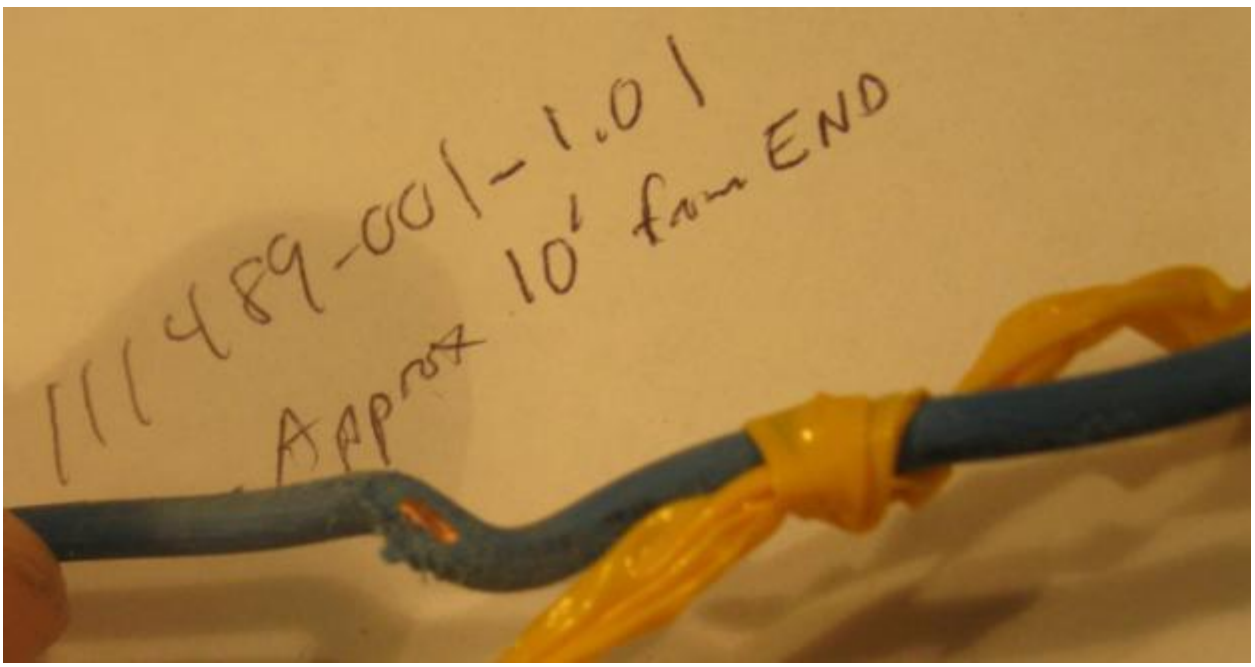


Figure 14. Break of Insulation Jacket (#2) on Field Tested Company A-12 AWG Solid Copper Wire

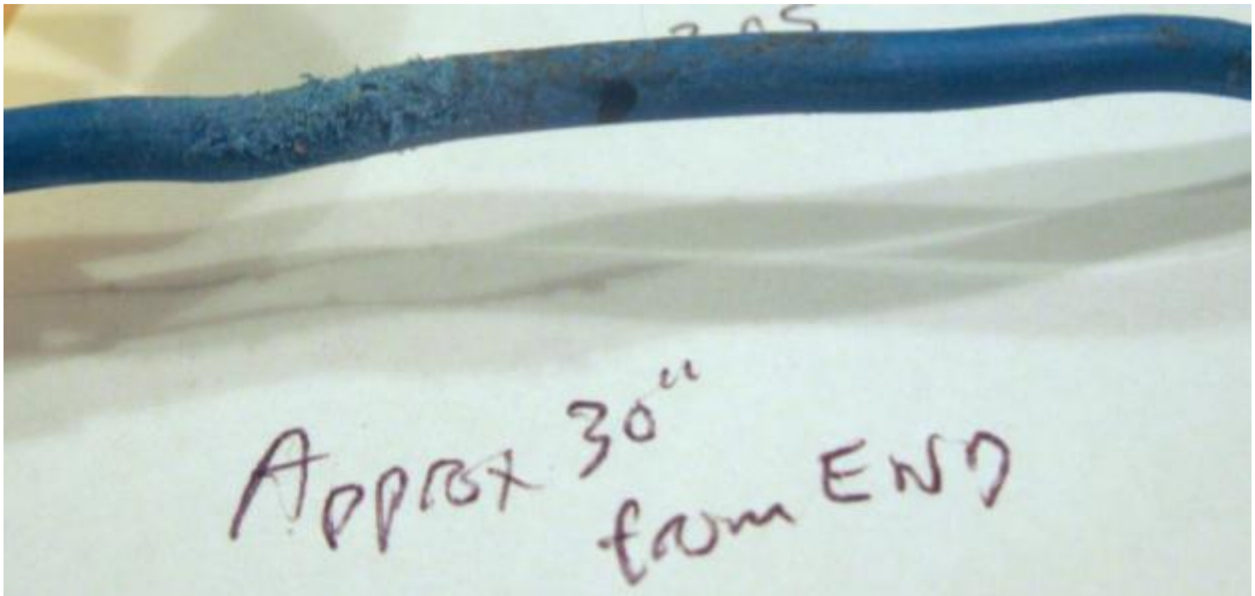


Figure 15. Break of Insulation Jacket (#3) on Field Tested Company A-12 AWG Solid Copper Wire

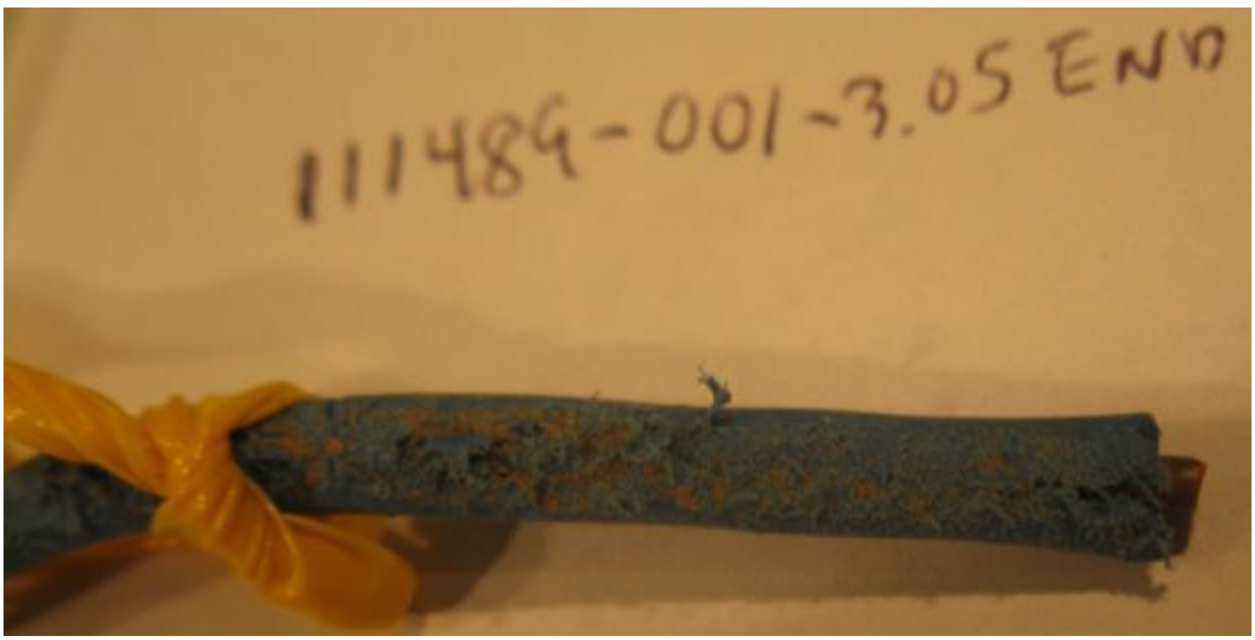


Figure 16. Break of Insulation Jacket (#4) on Field Tested Company A-12 AWG Solid Copper Wire

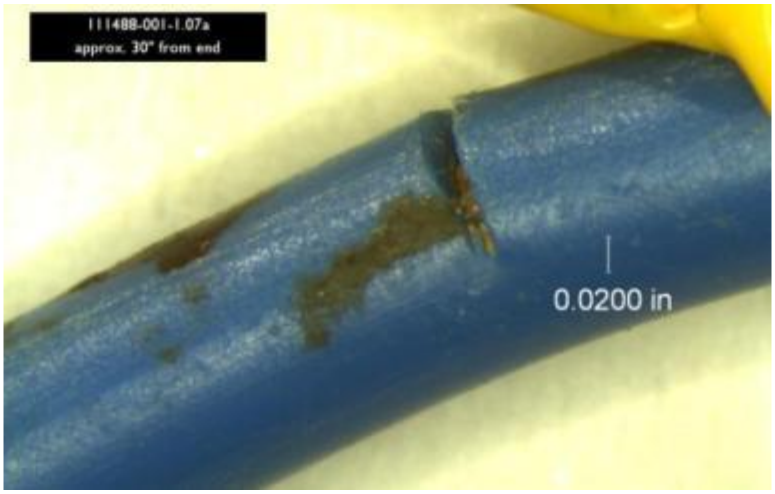


Figure 17. Break of Insulation Jacket (#1) on Field Tested Company D-12 AWG Copper Clad Steel Wire

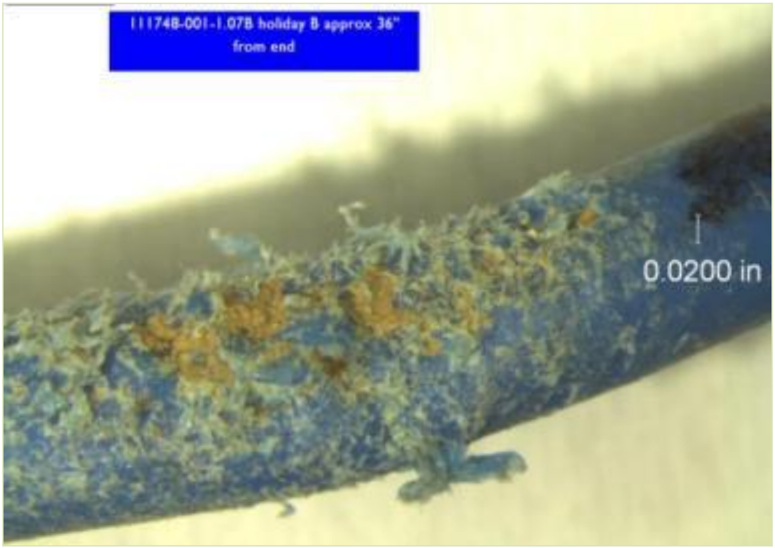


Figure 18. Break of Insulation Jacket (#2) on Field Tested Company D-12 AWG Copper Clad Steel Wire

Figure 19. Break of Insulation Jacket (#3) on Field Tested Company D-12 AWG Copper Clad Steel Wire

Second Field Test at Batavia, IL

Where: Batavia, IL

When: April 30, 2012

Attendees: Joe Baffoe – GTI, Steve Cohen – Utility Sales, Jim Sparks, Matt and Randy – Mid America Underground (installation contractors)

Installation Photos: Appendix III

Review of HDD project

The Batavia Park District 2-inch PE water service installation is about 340 ft drilled at Harold Hall Quarry Beach. The HDD project was installed by Mid America Underground (contractor from Aurora, IL).

Wire Samples

A total of five wires were installed. Four wires were pulled from the bore hole after the PE pipe installation. The pulled wires were then rinsed off and brought to GTI for further inspection and evaluations. One Company F wire was taped to the conduit pipe and remained for future locating purposes. Taping the wire on the conduit pipe is the standard practice of the contractor installing the pipe. The five installed wires include:

- One 12 AWG Company C solid copper wire (45 mil LDPE): removed after pipe installed
- One 12 AWG Company E HDD-CCS (45 mil HDPE): removed after pipe installed
- One 12 AWG Company E High Flex-CCS (45 mil HDPE): removed after pipe installed
- Two Company F wires:
  - One was pulled out for evaluation.
  - The other was left in as the locate mechanism for the project.

The three traditional tracer wires selected for the field evaluation represent the following attributes:

- Insulation jacket that has lower abrasion resistance: Company E 45 mil HDPE (Company E HDD CCS and Company E-HF-CCS)
- Insulation jacket that has lower scrape resistance: Company C 45 mil LDPE
- Higher tensile break load: Company E HDD CCS
- Improved tensile load with similar tensile property as solid copper: Company E-HF-CCS

HDD Installation

- Ground Conditions:
  - 340 ft total: 190ft Rock, 50 ft sand, 100 ft pea gravel and concrete
  - Soil Conditions: wet
- Other Job Characteristics:
  - Depth: 42" – 48"
  - Reamer: 6"

  - HDPE water pipe: 2"
  - Severe grinding noise and ground vibrations noted during pull in/reaming in the rock areas
- Ambient Temperature: 55ºF

Inspection:

- The samples were cut into approximately 30 ft long specimens for inspection purposes.
- The insulation jackets of the specimens were inspected by a high voltage coating holiday detector per ASTM G-62 for voltage setting, i.e., 2.9kV for 30 mil coating.

Inspection Results:

- 12 AWG Company E High Flex-CCS: one holiday detected 1 ft from borehead
- 12 AWG Company E HDD-CCS: three holidays detected at 1 ft, 15 ft, and 20 ft from borehead
- 12 AWG Company C Solid Copper: three holidays detected at 1 ft, 175 ft and 330 ft from borehead
- Company F: No holiday was detectable in this wire.

Summary and Recommendations

The traditional thin gauge soft drawn solid copper tracer wires are relatively easy to handle due to their good flexibility. However, the tensile strength of this type of solid copper wire is low and wire breakage by tensile load becomes the major concern when using soft drawn copper tracer wires for HDD pipe installations.

Copper clad steel (CCS) wires are designed to improve the tensile strength of the copper tracer wire by incorporating a stronger steel core. The steel is either made of high carbon or low carbon steel depending on the strength requirements.

The extra high strength copper clad steel wires designed for HDD application are made of high carbon steel core which significantly improves the wire tensile strength (~1,000 lb for 12 AWG wires). However, this type of wire is brittle and breaks without significant plastic deformation in the tensile test. Therefore, the tensile break load is significantly reduced when the wire is kinked.

The high flex copper clad steel wires are made of low carbon steel by special annealing process to make these CCS wires more flexible. The high flex copper clad steel wires also exhibit a higher tensile break load than the traditional soft drawn copper wire, but have similar elongation properties as the traditional soft drawn copper wire. They all have a larger plastic deformation region between the yield and ultimate tensile load (tensile break load) than the extra high strength CCS wires.

The break load of extra high strength copper clad wires (Company D and Company A) are significantly higher than the soft drawn copper and high flex copper clad steel wires. However, when the wires are kinked, the ultimate tensile strength are significantly reduced to a level similar to those of the high flex copper clad steel wires. The extra high strength copper clad wires may not outperform the high flex copper clad steel wires in terms of tensile break load if the wires are kinked when they are uncoiled during the field installation because the wires can’t take the higher tensile load as they are designed for.

The stress relieved CCS wires are made of high carbon steel or low carbon steel. They are annealed to improve flexibility, but the ultimate tensile strength is significantly reduced as a result. Hard drawn copper improves the tensile break load, but it is also hard and brittle.

The Company F product differs from traditional tracer wire products in construction. Traditional tracer wire construction employs a jacket of insulation placed over the conductive metallic core. The Company F wire utilizes a woven polyester core with an internal insulated wire. Such woven strip configurations have a very high strength-to-weight ratio, and larger sizes are commonly used in industrial lifting and towing applications which require very high levels of loading. The company F wire exhibits a significantly higher tensile load (~1,800 lbs) due to the polymer fibers. It also exhibits a similar high tensile load when it was tested when kinked. In addition, this wire is very flexible compared to the other types of tracer wires because a thin gauge (19 AWG) copper conductor is used.

The wear resistance of the PE jackets varied from the type of PE and also the manufacturer. The abrasion resistance of the HDPE jackets from Company E and Company A outperforms the other tested PE jackets (LDPE and HDPE). The HDPE jacket from Company D has the similar abrasion resistance as the LDPE from Company B and Company C.

HDPE insulation jackets have higher scrape resistance than LDPE insulation jackets with the same coating thickness. The increase of insulation thickness from 30 mils to 45 mils significantly increases the scrape resistance of the wires. The scrape resistance of Company F insulation (containing polymer fiber and HDPE coating) are significantly higher than the traditional HDPE and LDPE coating.

The wires that were tested in the field evaluations did not break, but did experience several damaged areas on their insulation jackets during the HDD installation. The Company E CCS wires for HDD application were heavily corroded at the locations where the insulation jacket was damaged by scrape test or through field installation. The wire lost continuity at the damaged insulation due to corrosion.

The corrosion evaluation results suggest that the wire manufacturers should take into account the selection of high performance insulation materials that have higher abrasion and scrape resistance in order to prevent the wire insulation damage during HDD installation. Corrosion of CCS wire at the damaged insulation jacket could result in loss of tensile strength and wire continuity during the service.

In all, Company F wire outperformed the other traditional wires based on its rating for the above properties. The Company F wire has the highest score on the tensile break load (with and without kink) and the scrape test. This wire was also tested in the two field test trials by HDD installation and did not show significant damage on the wire insulation. Furthermore, the continuity of this wire conductor was not affected after 2000 hr corrosion test.

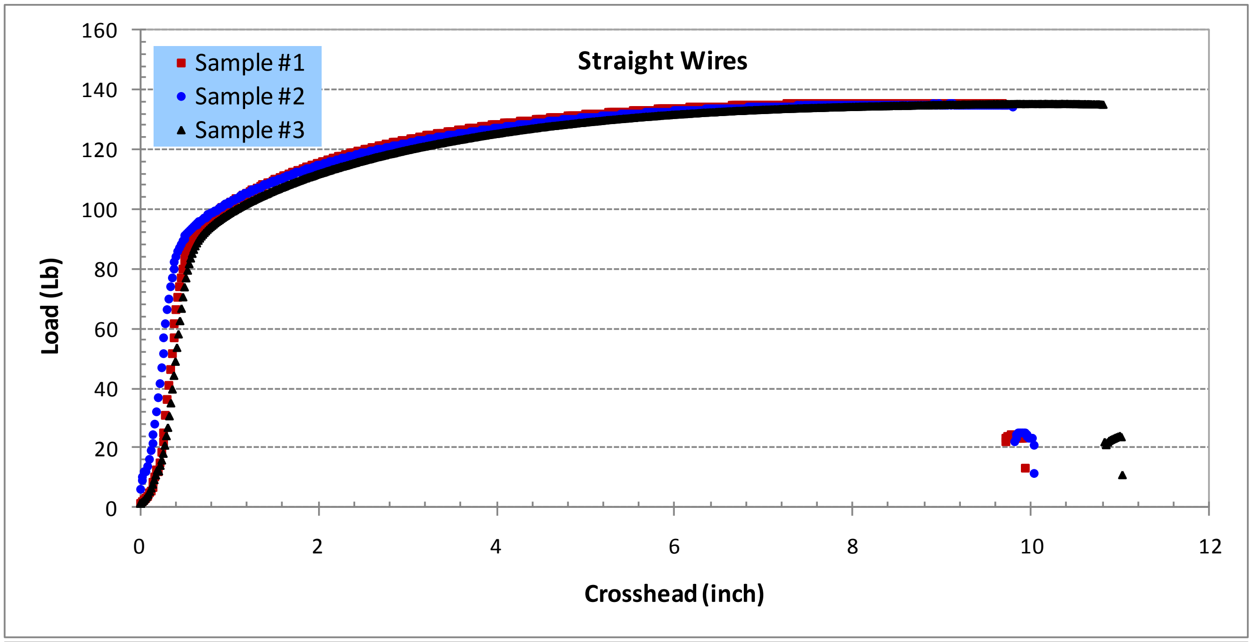
The high strength CCS wires designed for HDD installation had the improved tensile break load compared to the traditional solid copper wire, however their tensile break loads significantly reduced when the wires were kinked. In addition, the scrape resistance of the wires needs to be improved in order to prevent insulation damage during HDD installation and the resulted wire corrosion in service. The performance of the high strength HDD CCS wires made from the following three manufacturers (copperclad for Company E HDD CCS, CommScope for Company A HDD CCS, and Copperweld for Company D extra high strength CCS) was not significantly different with each other.

List of Acronyms

Acronym	Description
CCS	Copper Clad Steel
EHS	Extra High Strength
GTI	Gas Technology Institute
HDD	Horizontal Direct Drilling
HDPE	High Density Polyethylene
HF	High Flex
LDPE	Low Density Polyethylene
OTD	Operations Technology Development
PE	Polyetheylene

Appendix I: Tensile Test Results

Laboratory Test Data



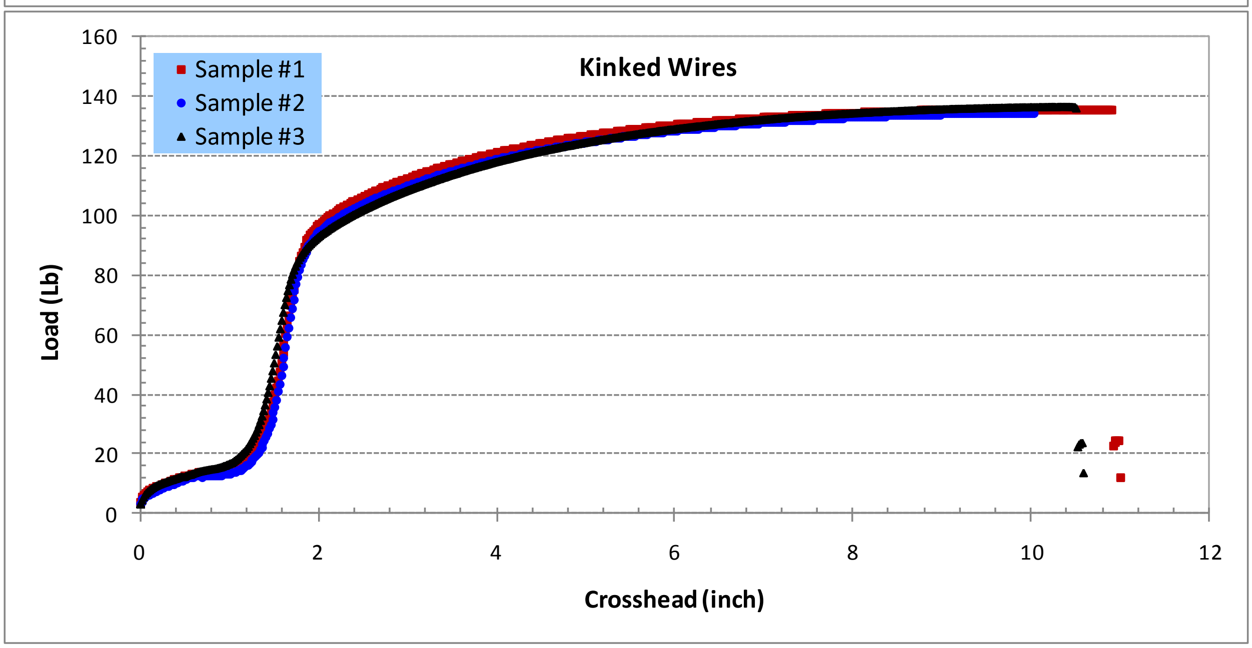


Figure 20. Tensile Plots for Straight and Kinked Company C 14 AWG Copper Wire

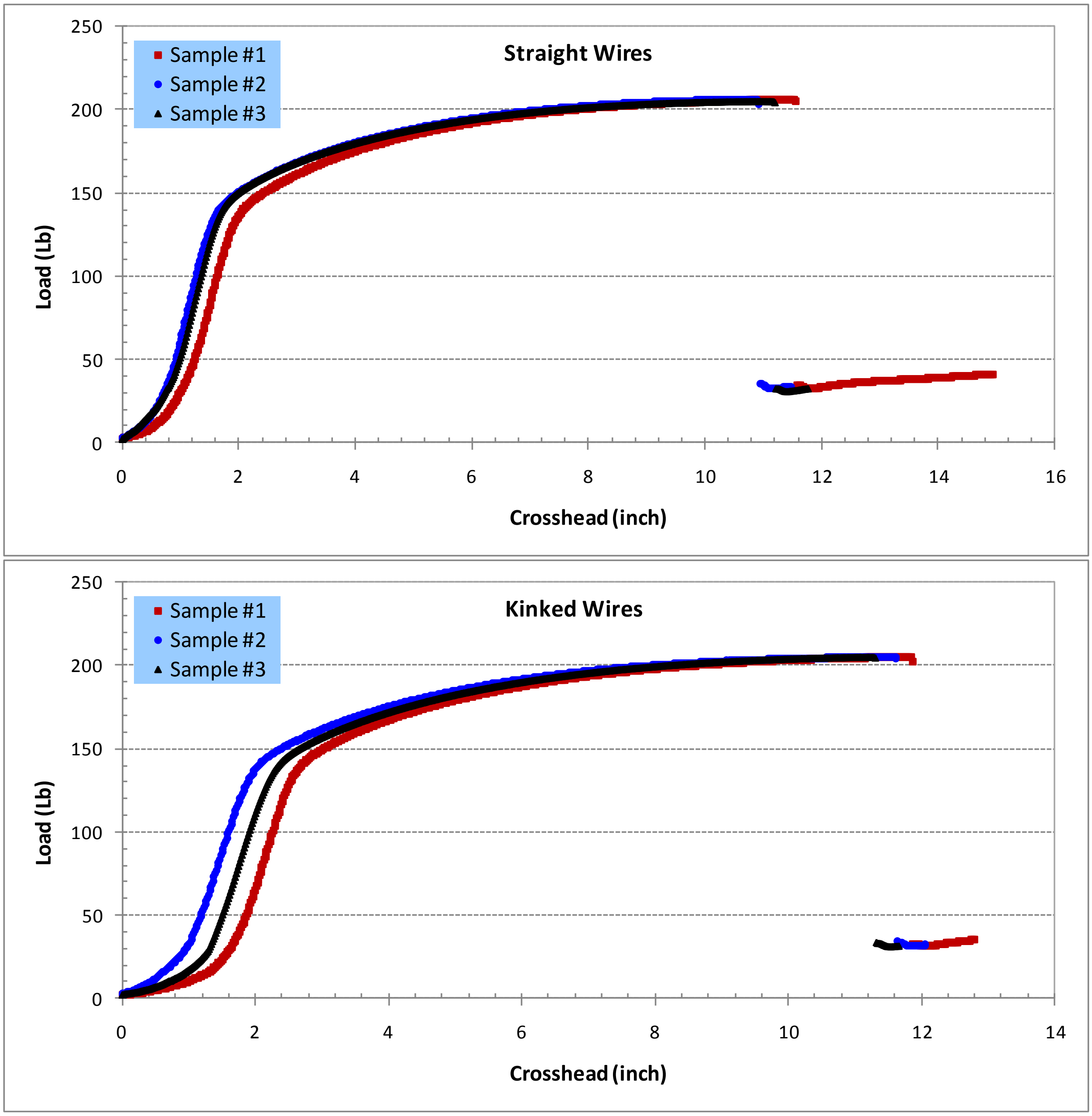


Figure 21.Tensile Plots for Straight and Kinked Company C 12 AWG Copper Wire

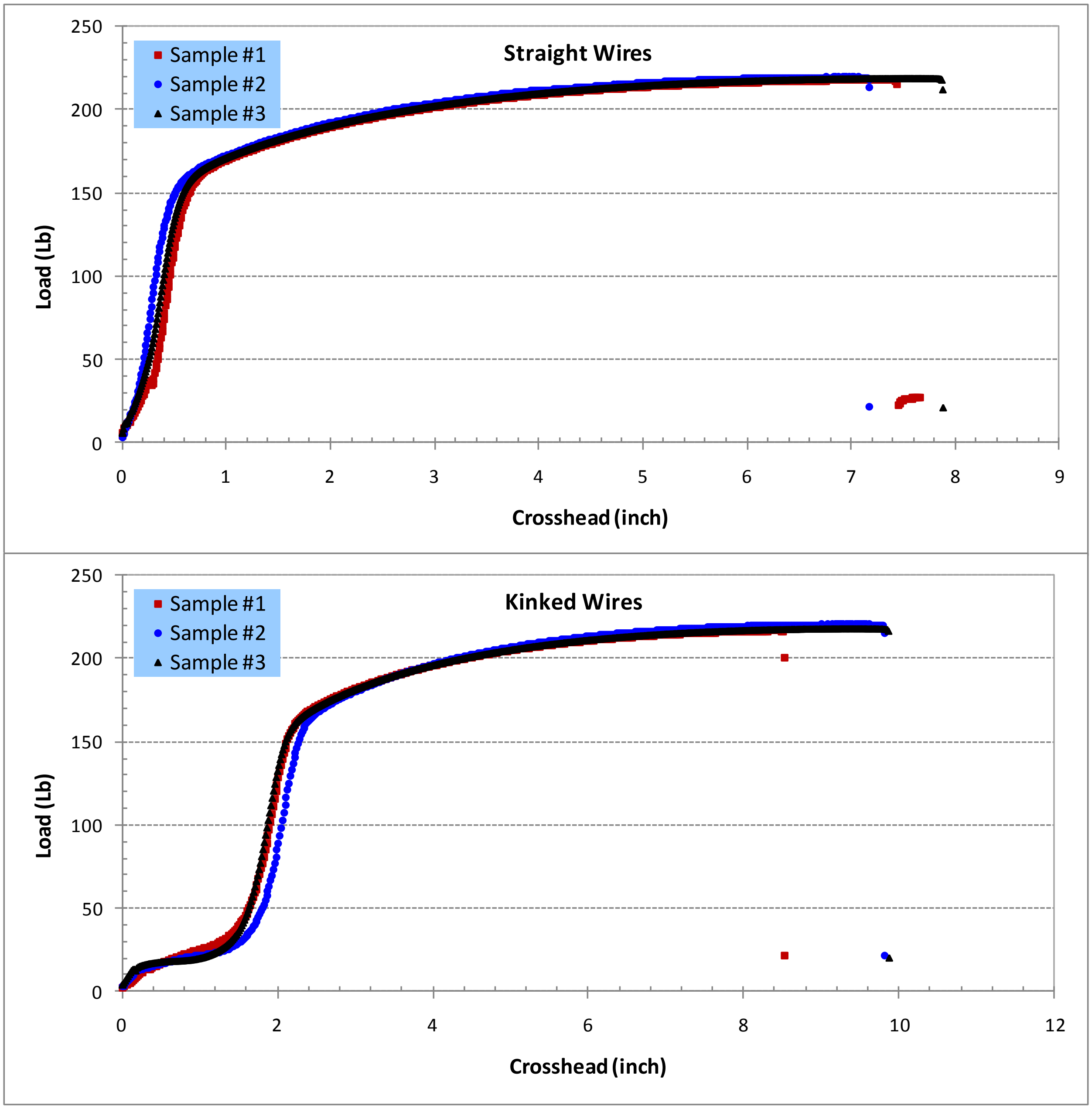


Figure 22. Tensile Plots for Straight and Kinked Company B 12 AWG Soft Drawn Copper Wire

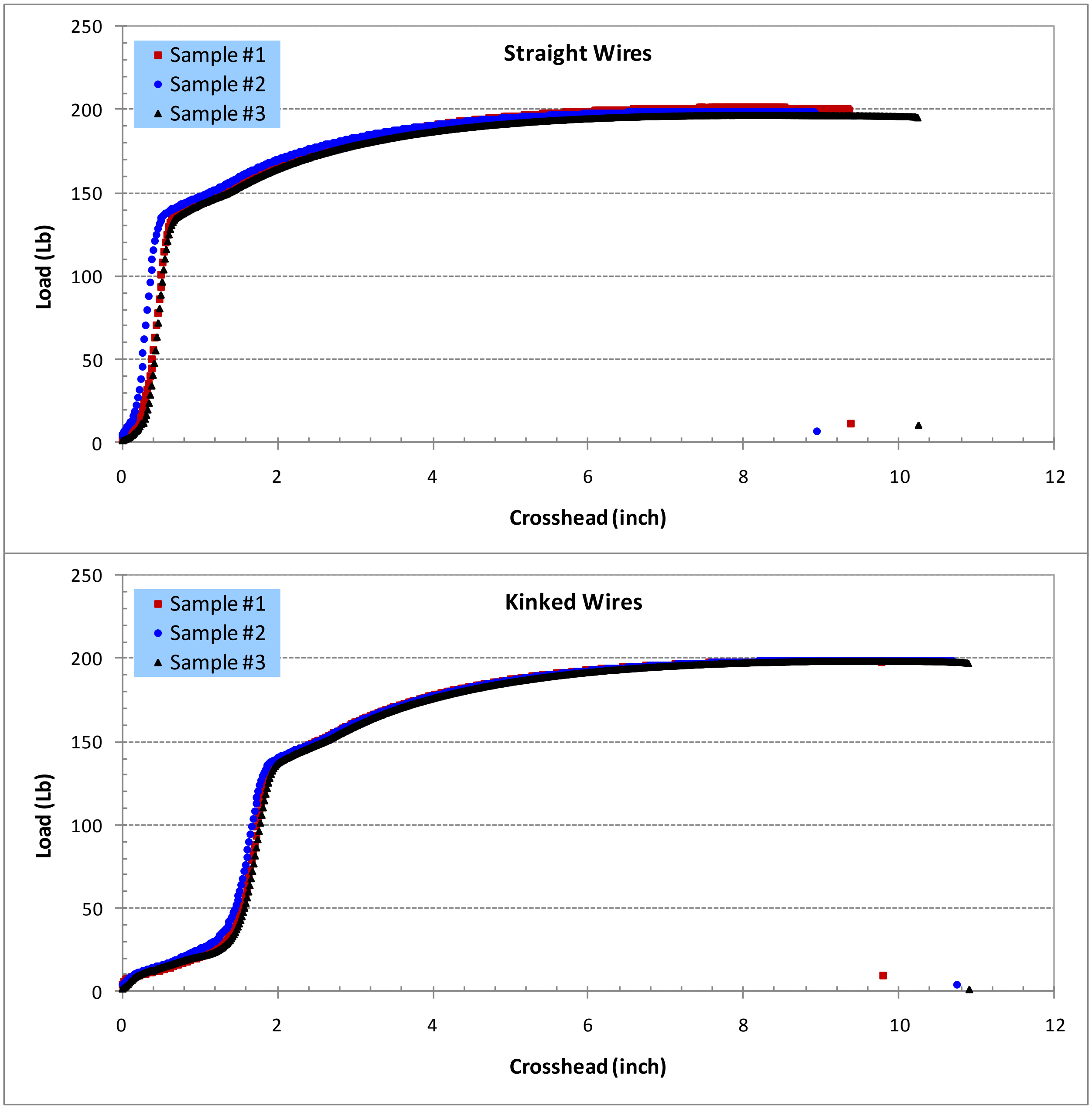
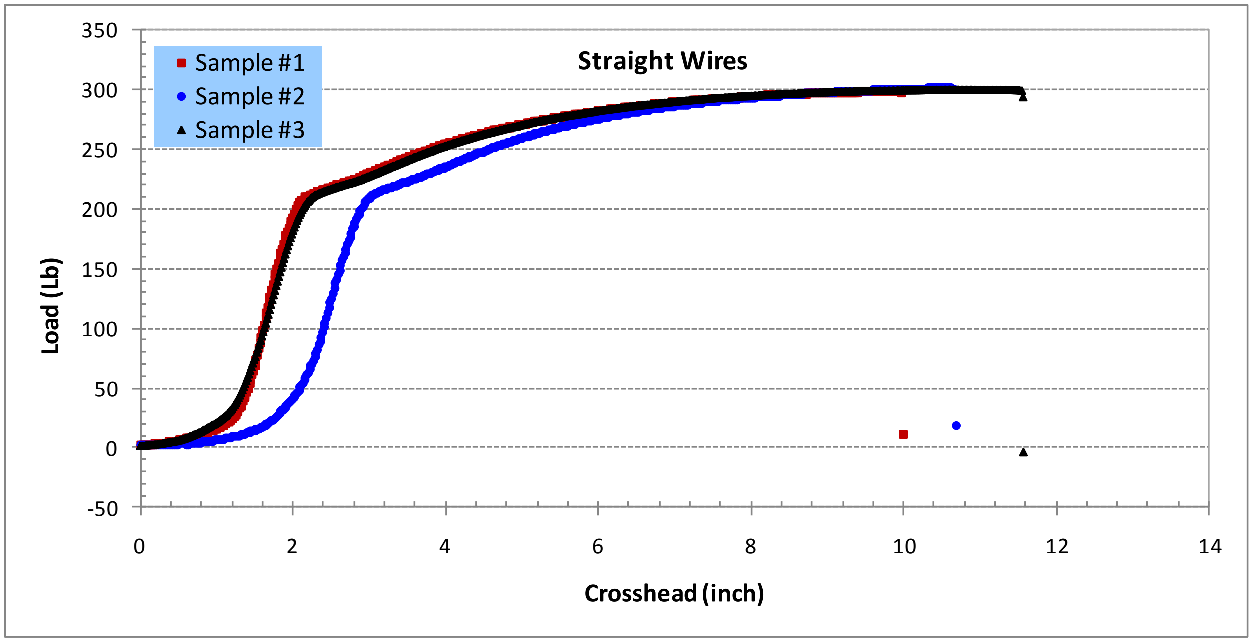


Figure 23. Tensile Plots for Straight and Kinked Company D 14 AWG Super Flex Soft Drawn Copper Clad Steel Wire



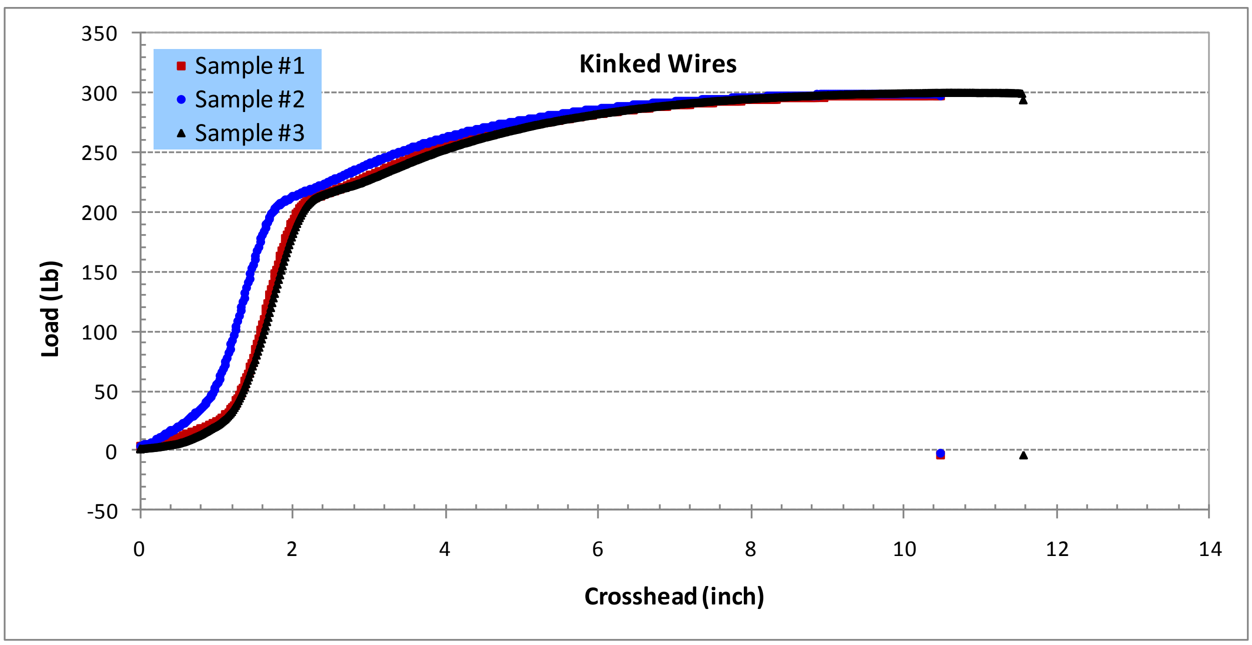


Figure 24. Tensile Plots for Straight and Kinked Company D 12 AWG Super Flex Copper Clad Steel Wire

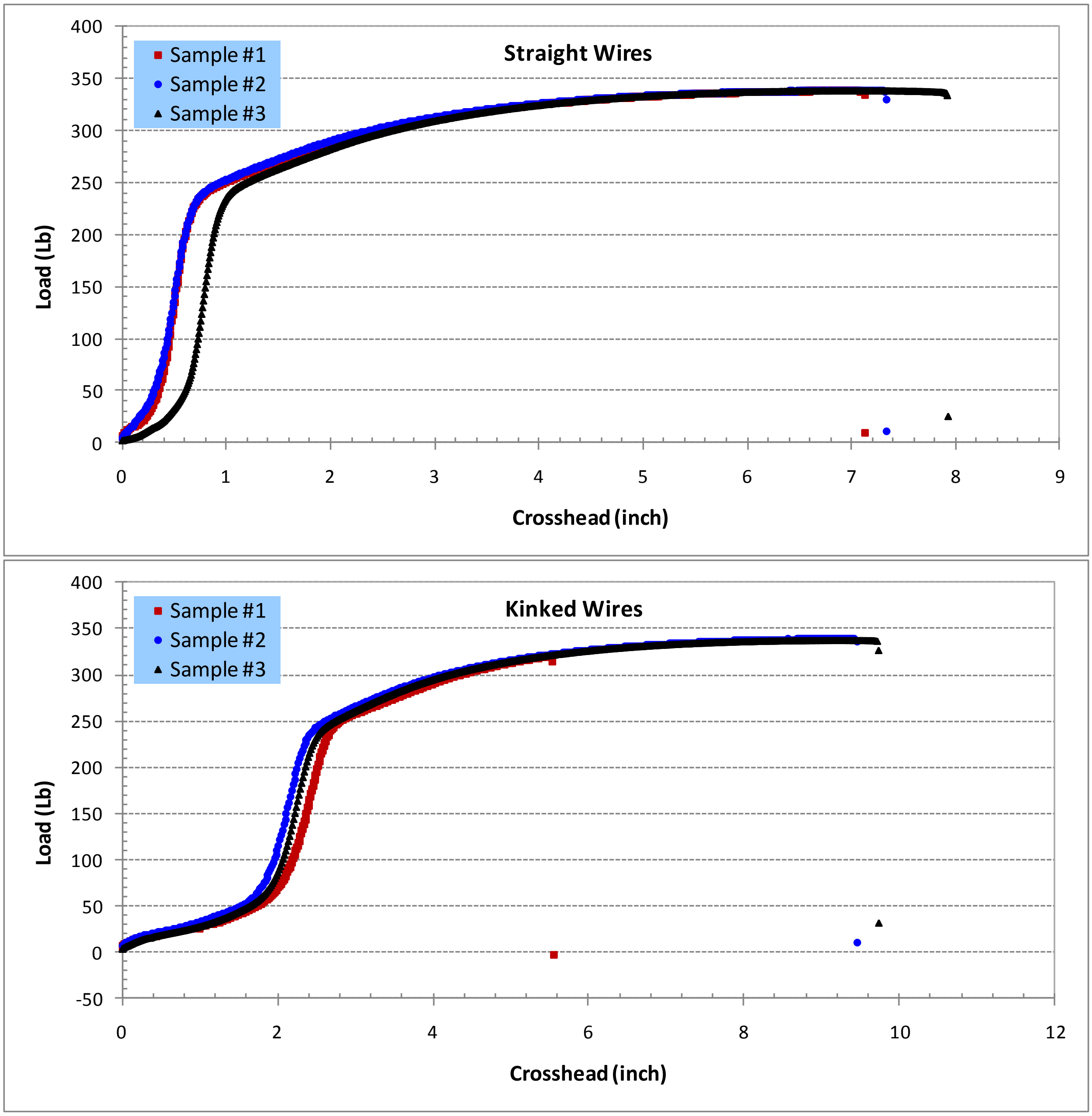
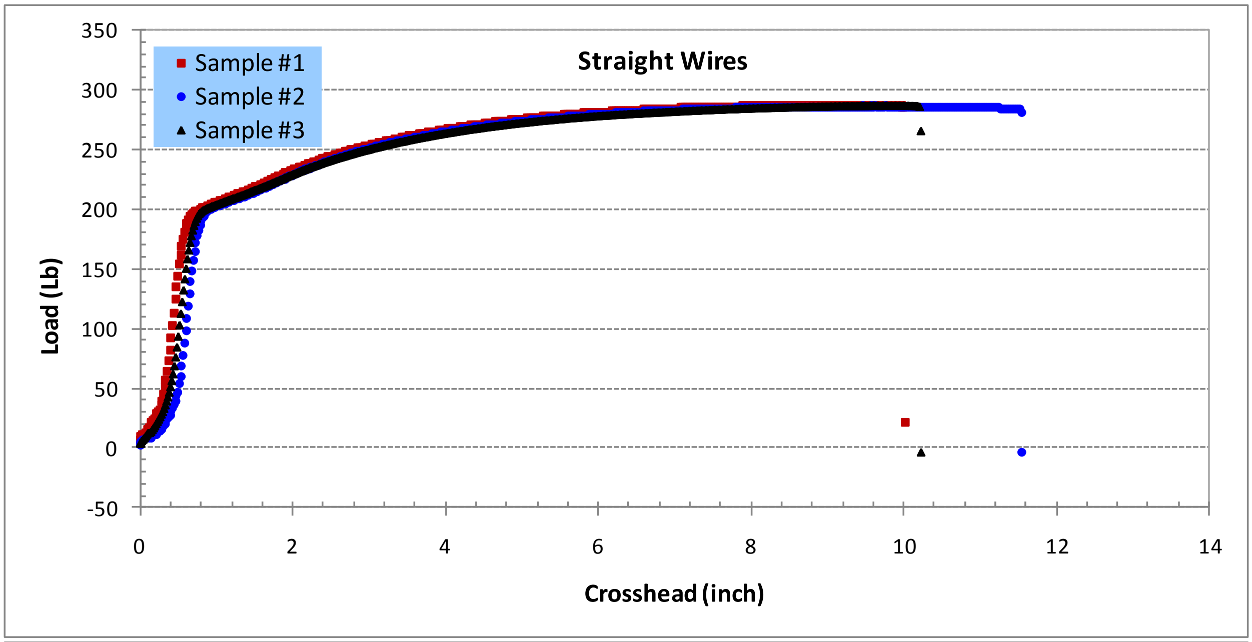


Figure 25. Tensile Plots for Straight and Kinked Company E High Flex 12 AWG Copper Clad Steel Wire



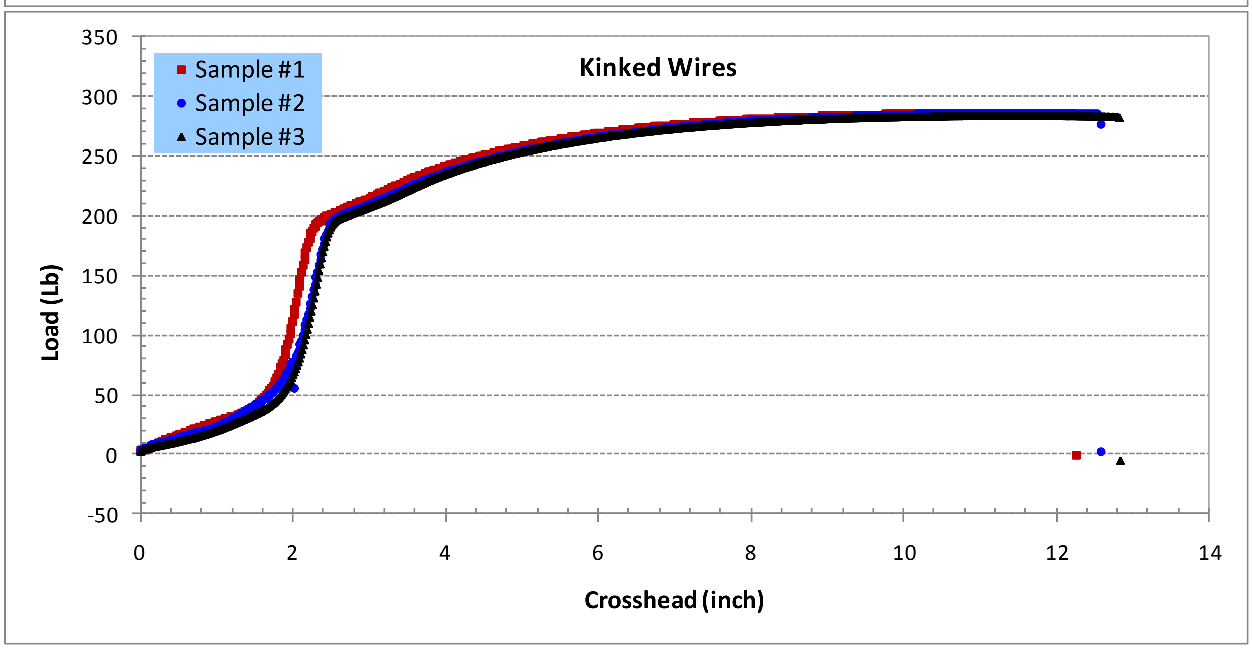


Figure 26. Tensile Plots for Straight and Kinked Company A 12 AWG Fully Annealed Copper Clad Steel Wire

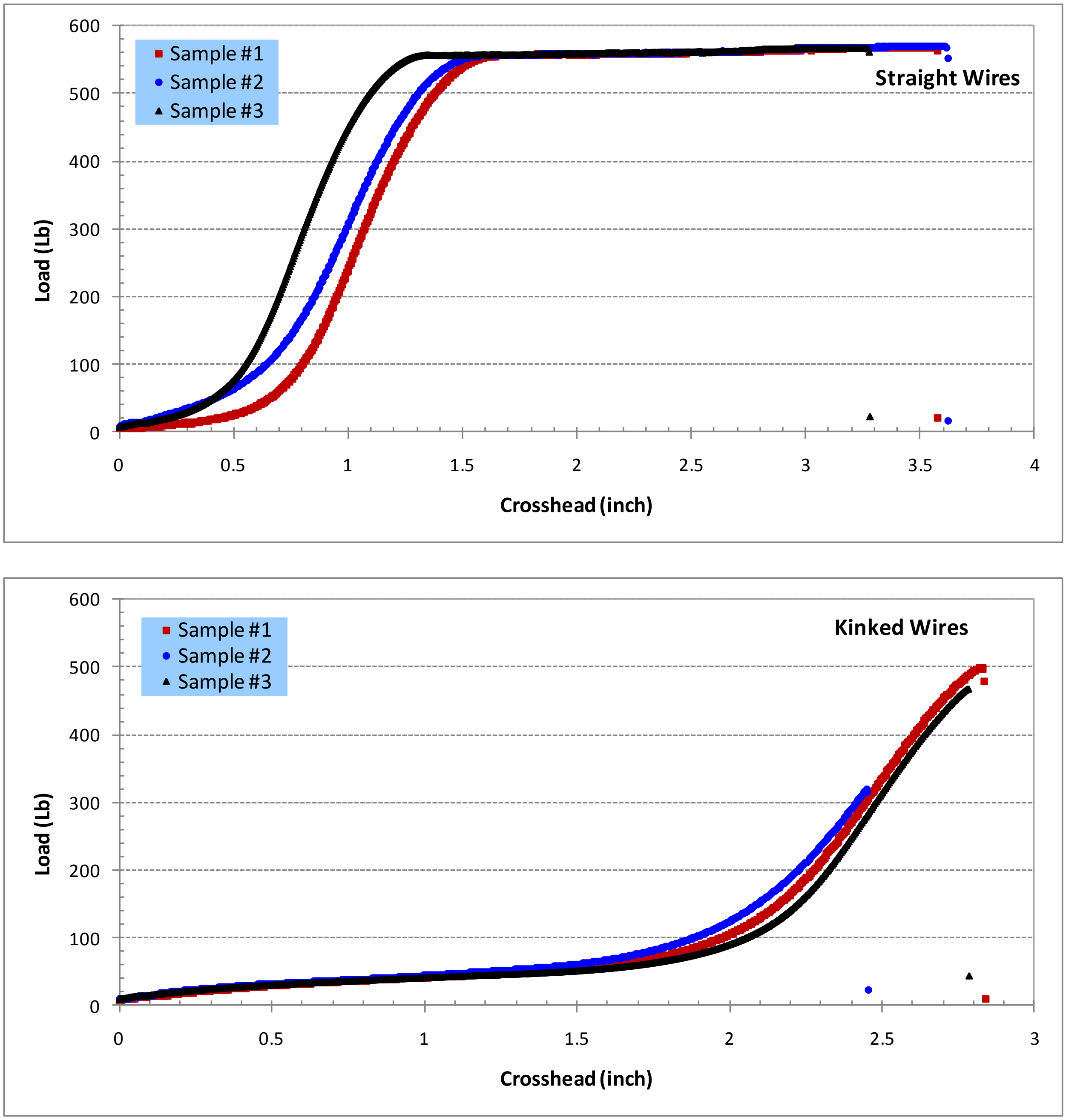
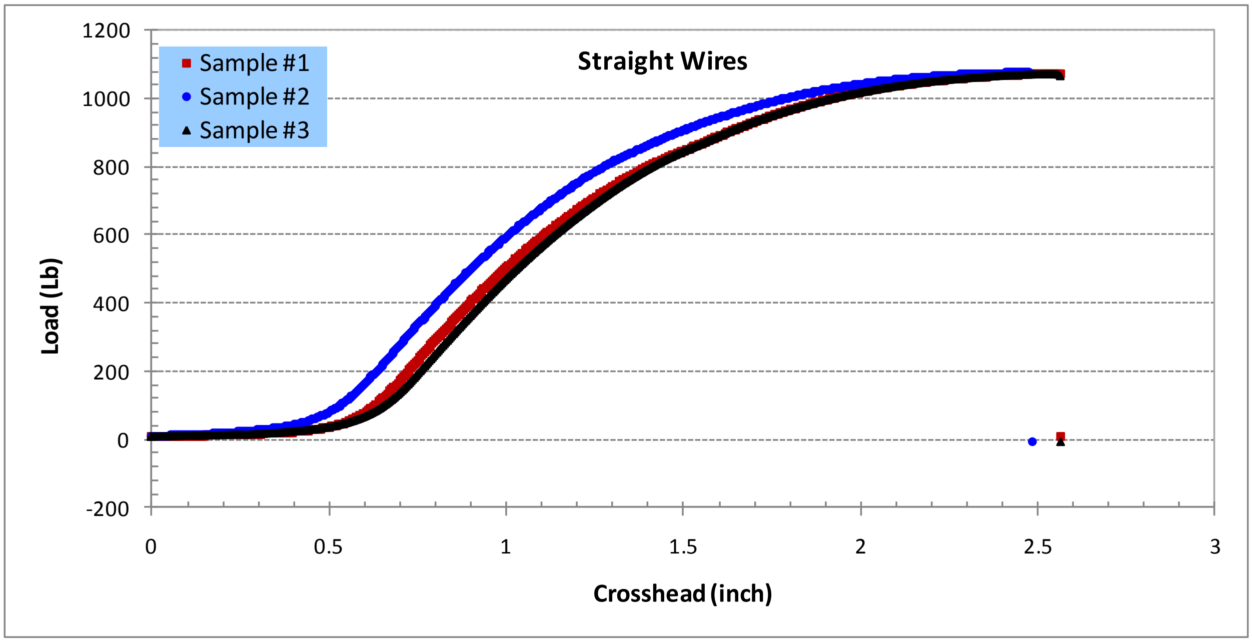


Figure 27. Tensile Plots for Straight and Kinked Company A 12 AWG Stress Relieved Copper Clad Steel Wire



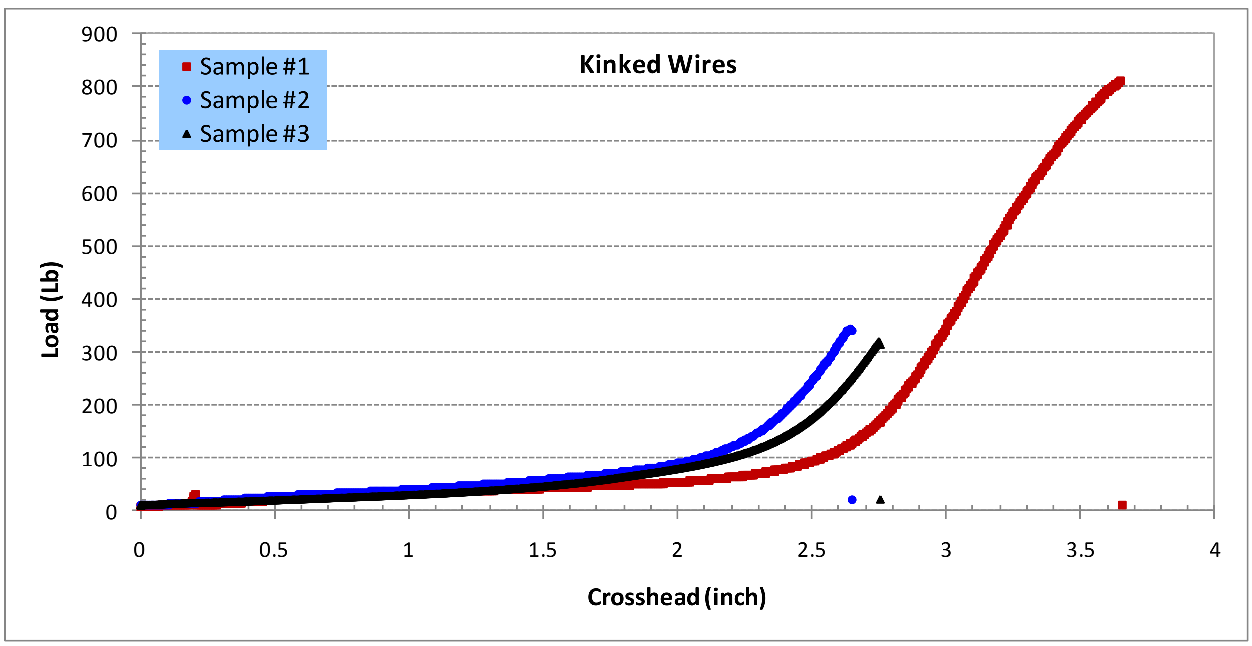


Figure 28. Tensile Plots for Straight and Kinked Company A HDD 12 AWG Copper Clad Steel Wire

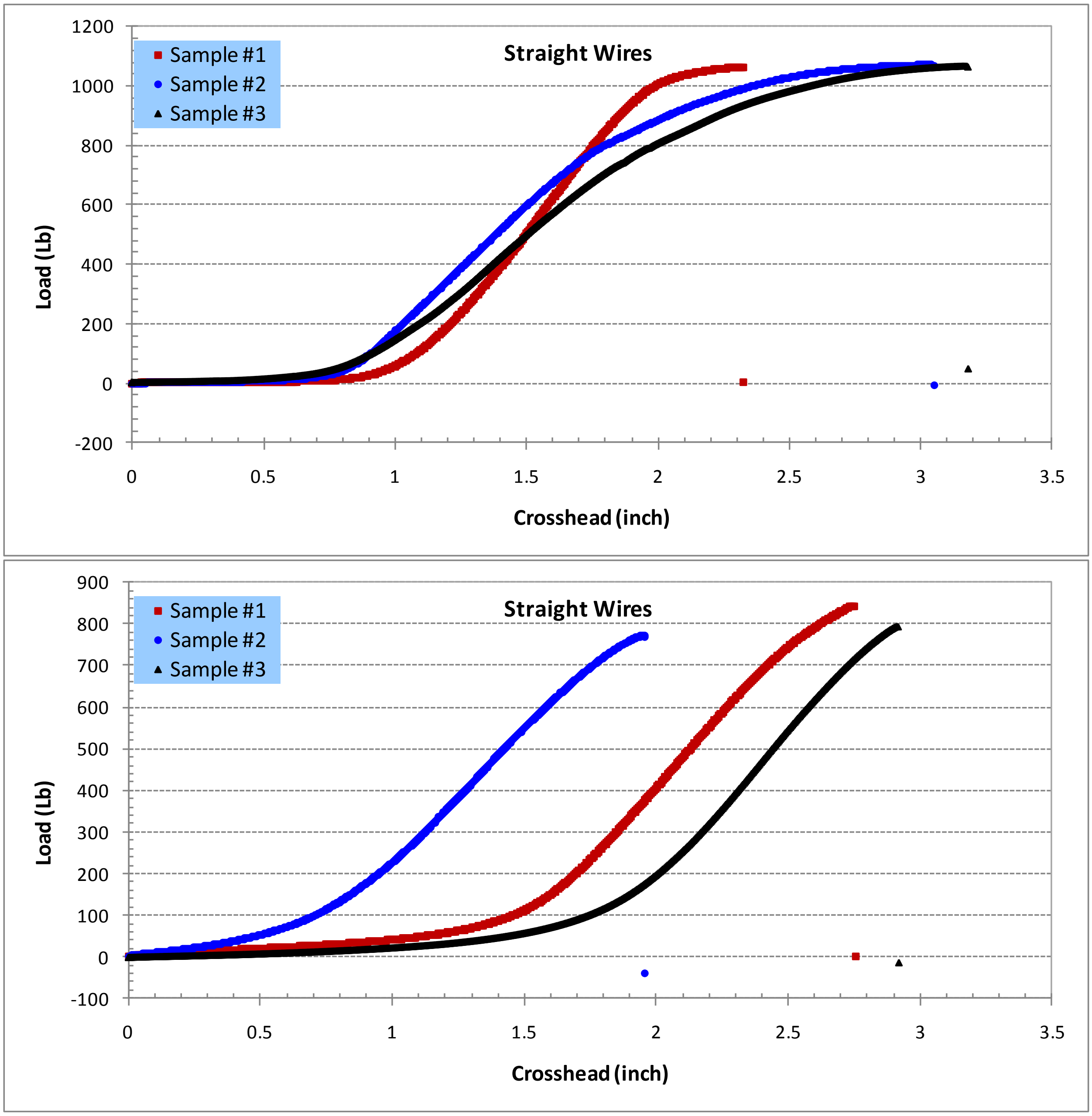


Figure 29. Tensile Plots for Straight and Kinked Company E HDD 12 AWG Copper Clad Steel Wire

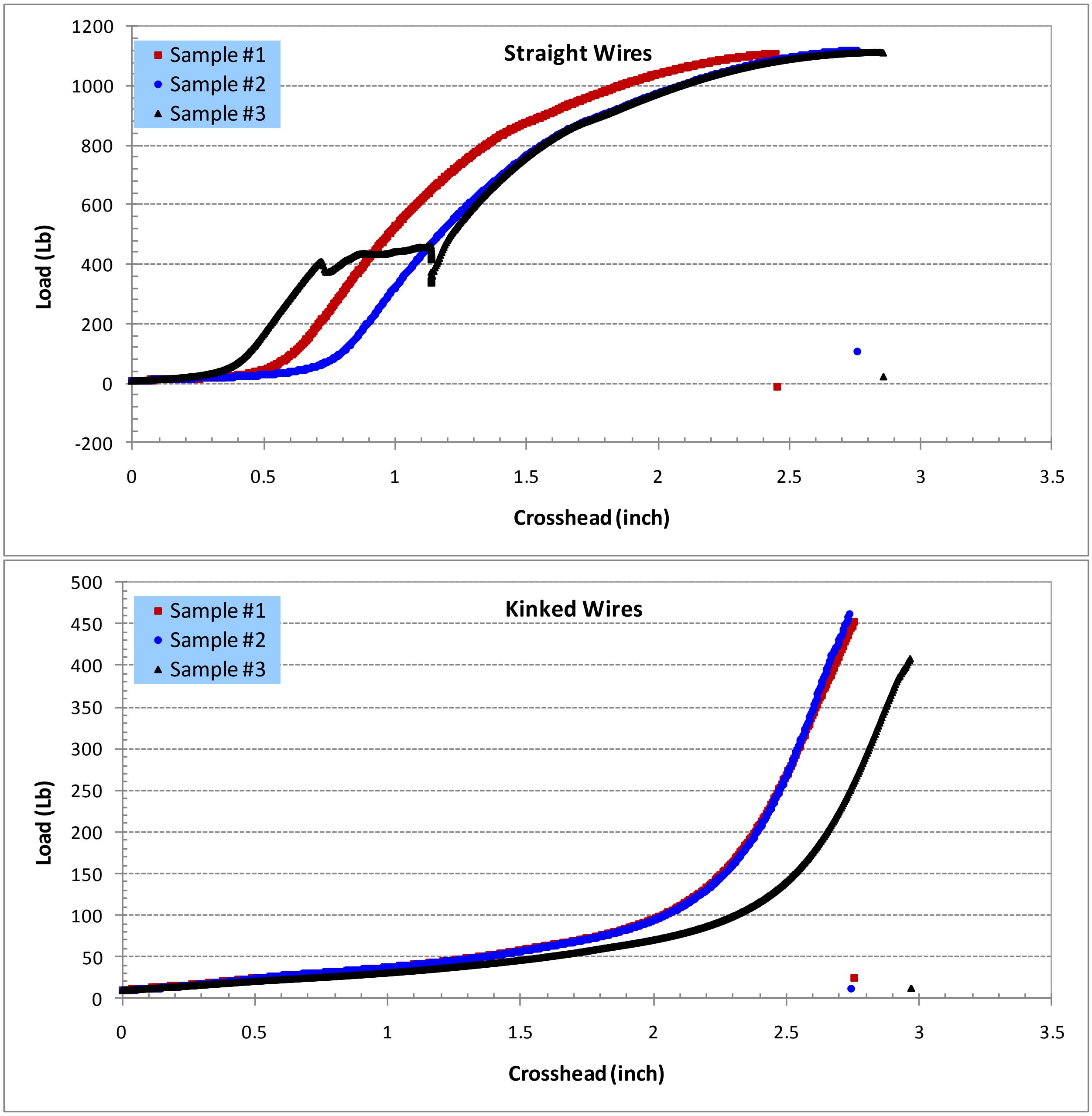


Figure 30. Tensile Plots for Straight and Kinked Company D Extra High Strength 12 AWG Copper Clad Steel Wire

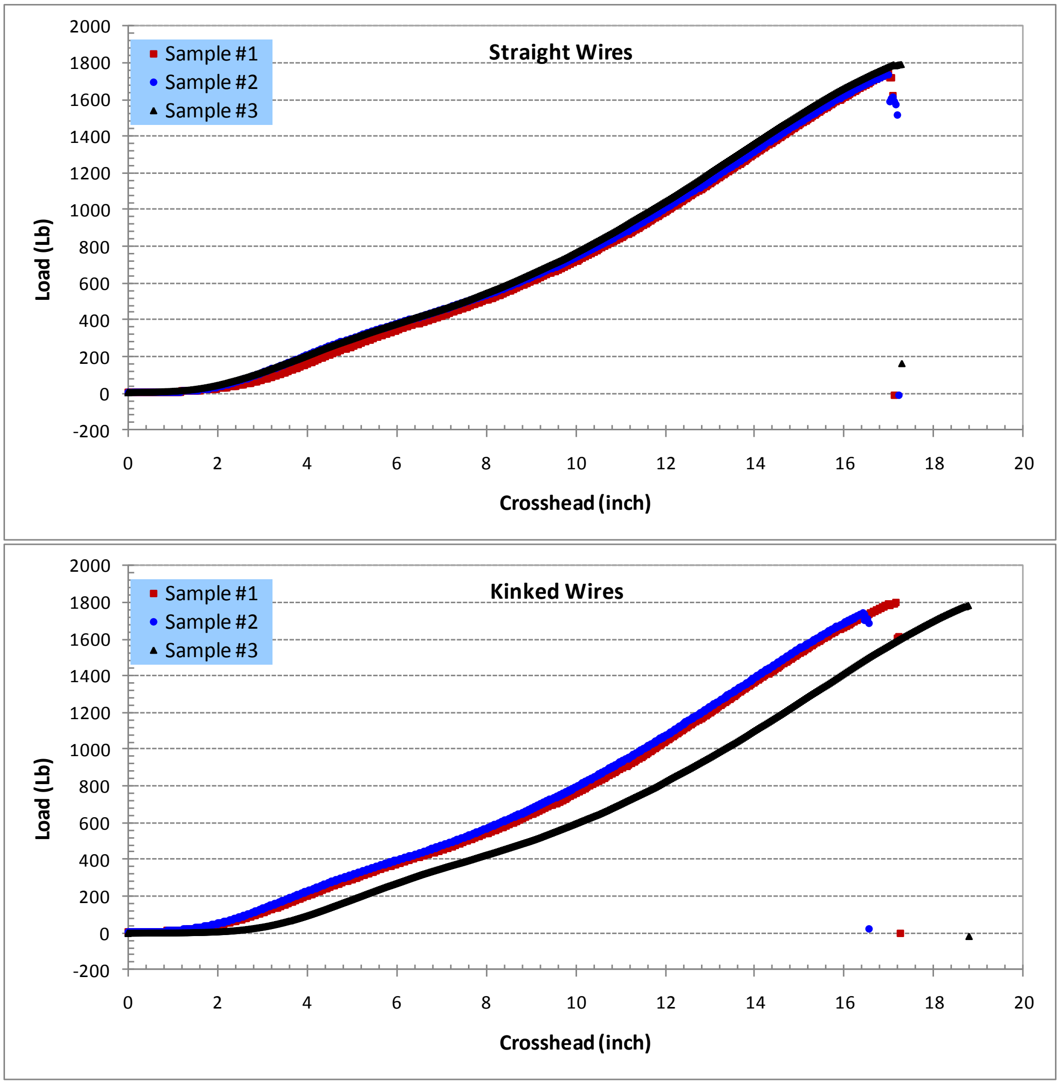


Figure 31. Tensile Plots for Company F Wire (Straight and Kinked)

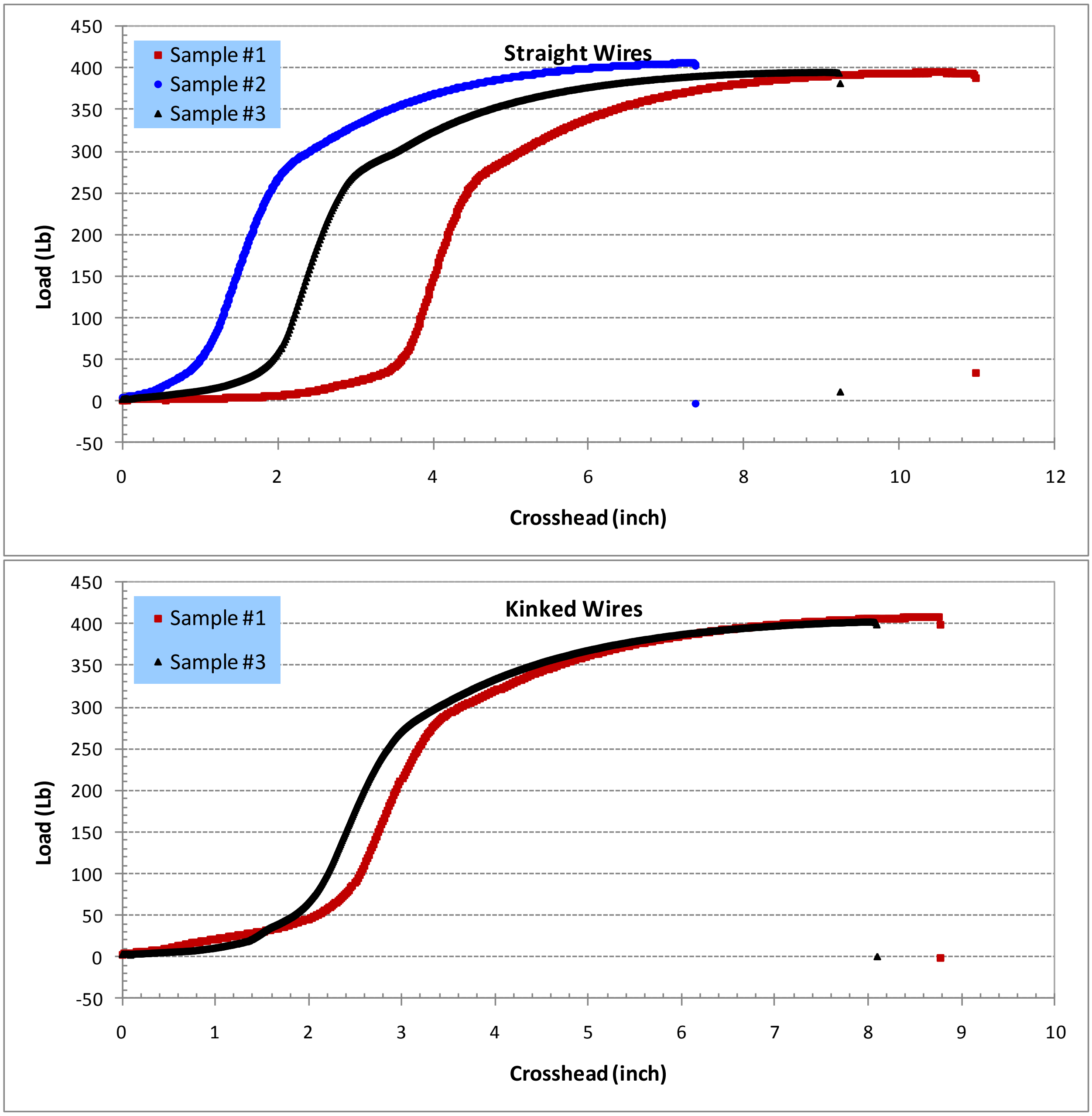


Figure 32. Tensile Plots for Straight and Kinked Company D 12 AWG High Strength Copper Clad Steel Wire

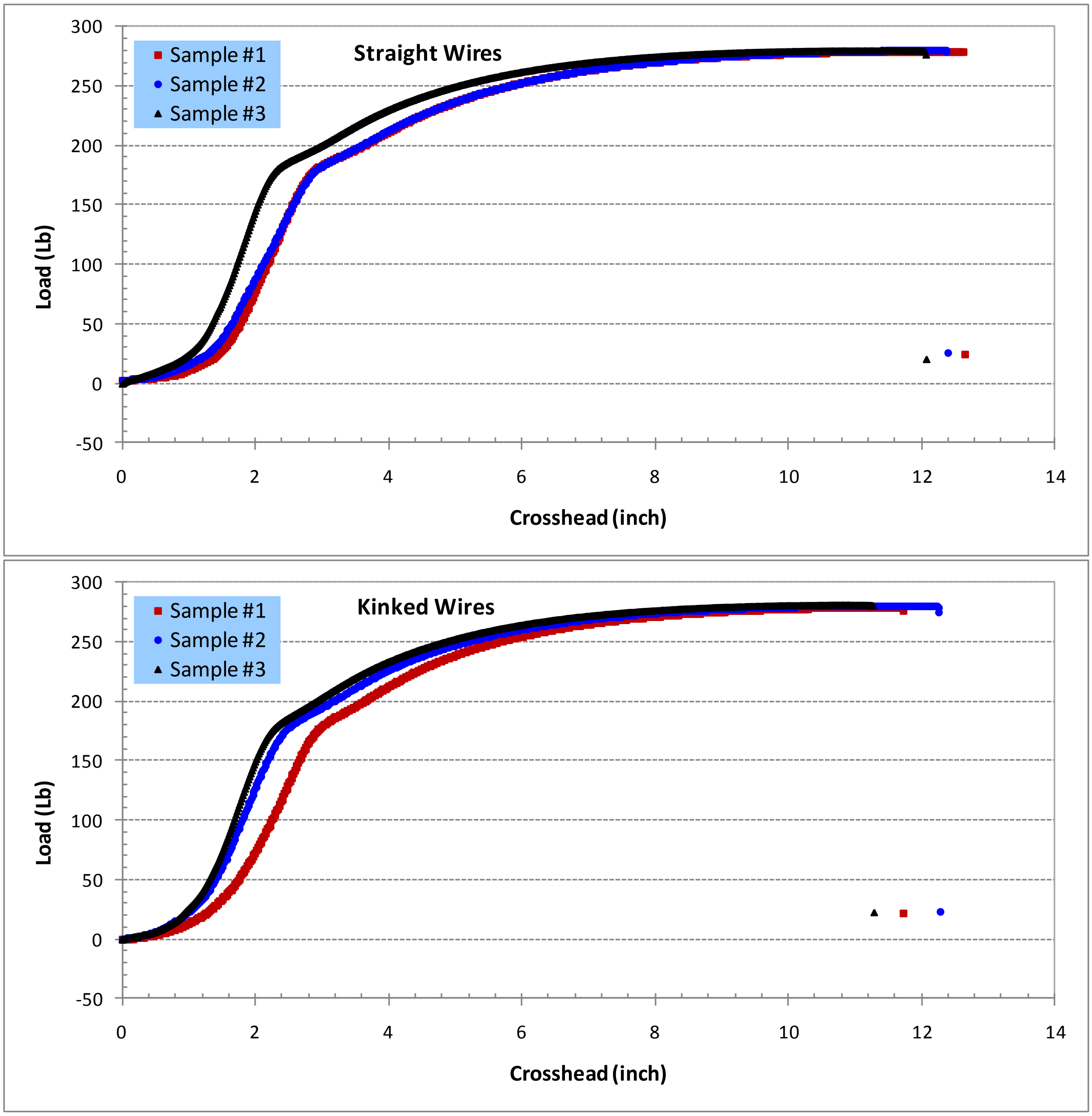


Figure 33. Tensile Plots for Straight and Kinked Company B Dead Soft Annealed 12 AWG CCS Wire

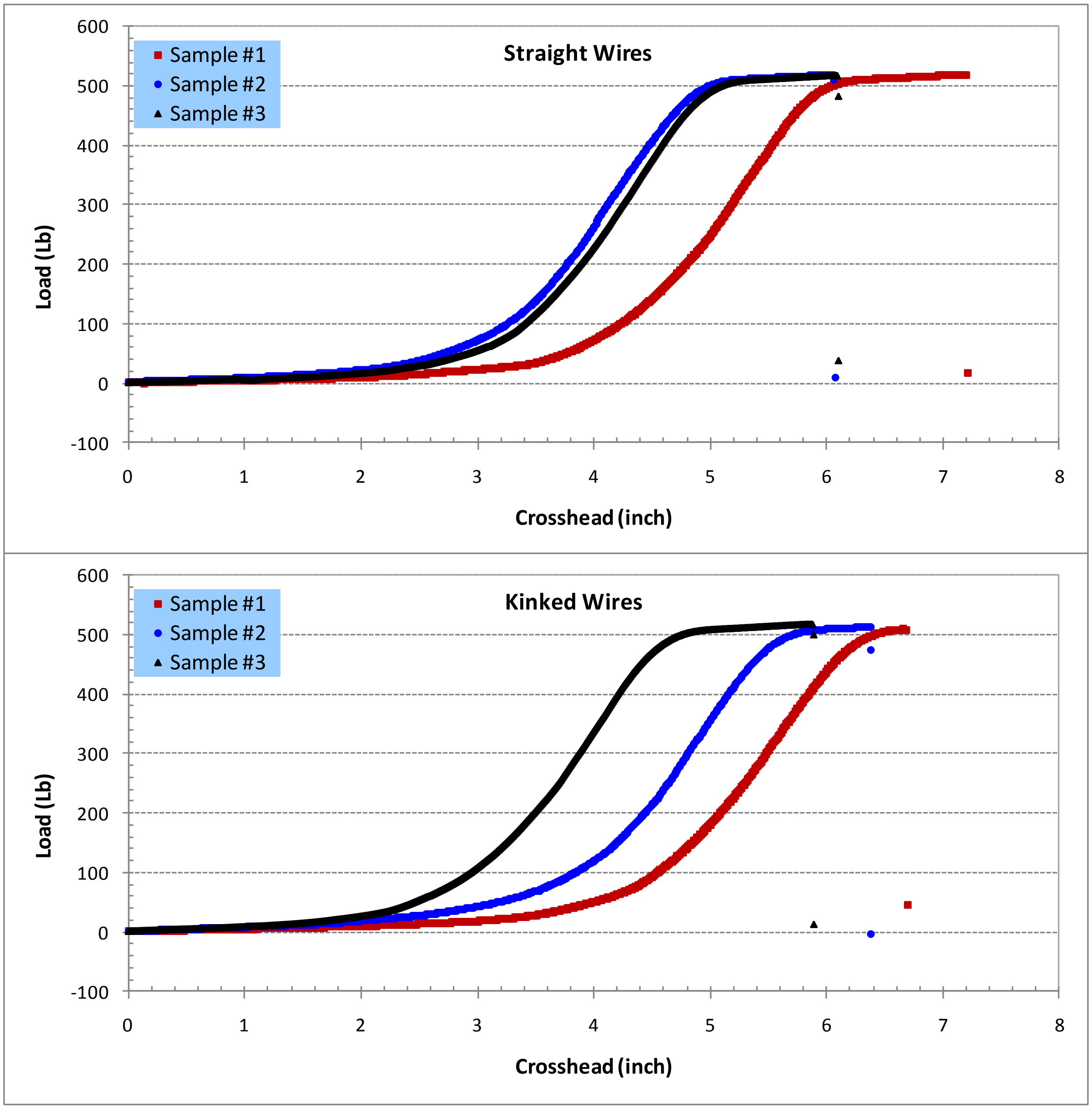
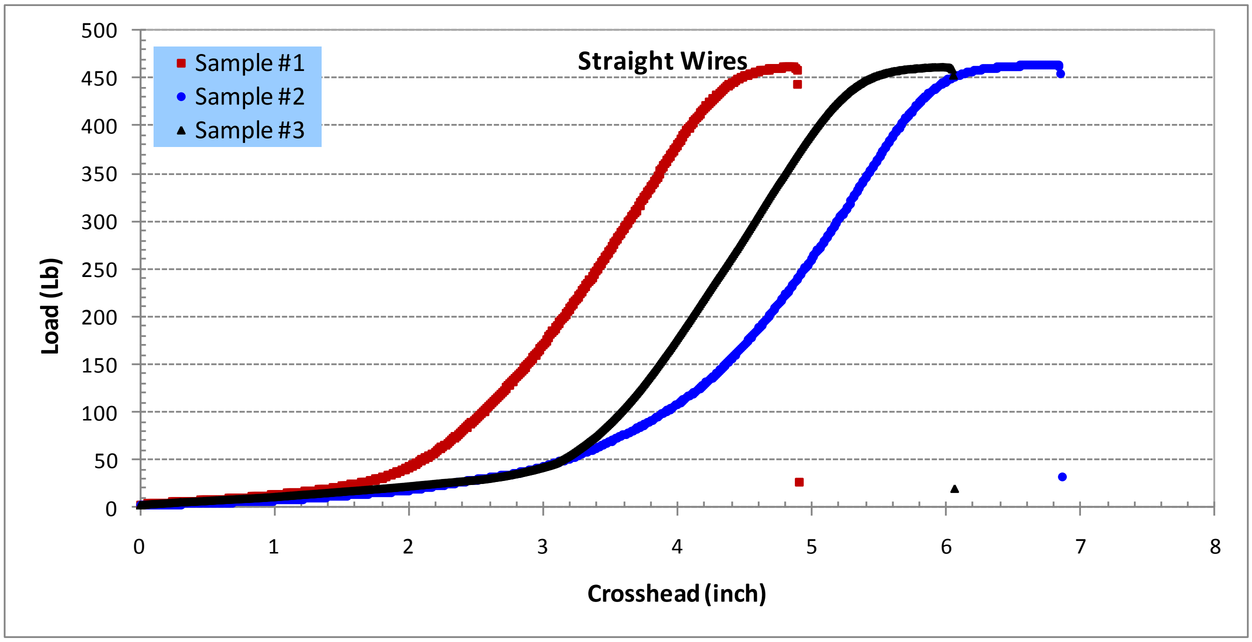


Figure 34. Tensile Plots for Straight and Kinked Company B Stress Relieved 12 AWG CCS Wire



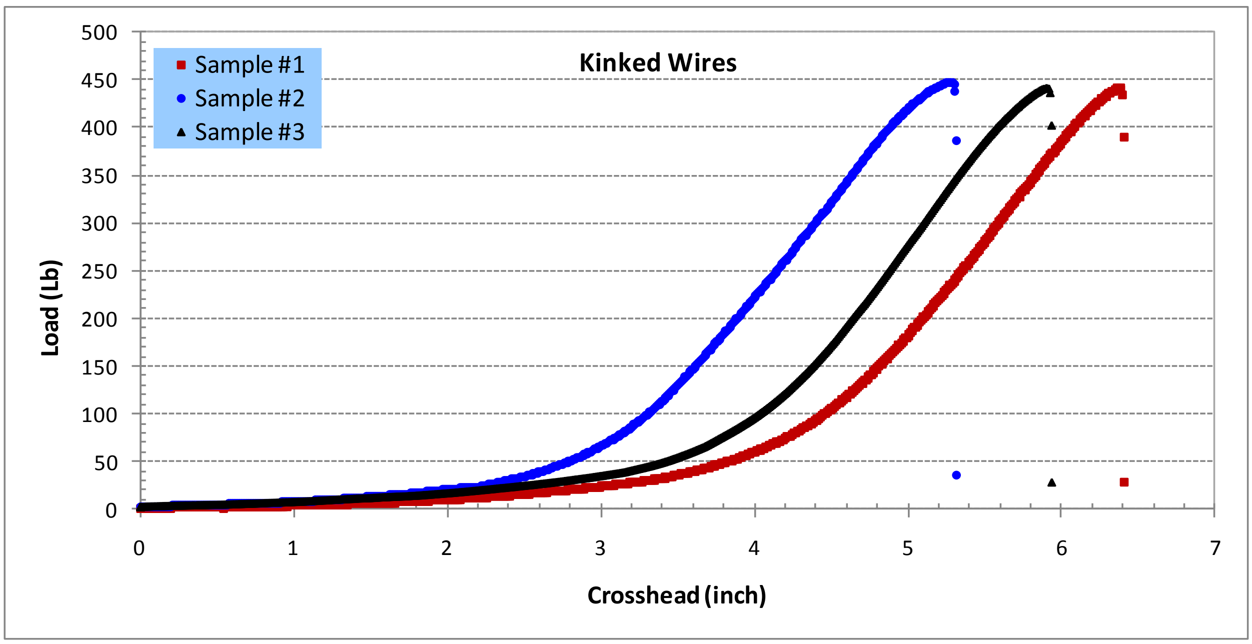


Figure 35. Tensile Plots for Straight and Company B 10 AWG Hard Drawn Copper Wire

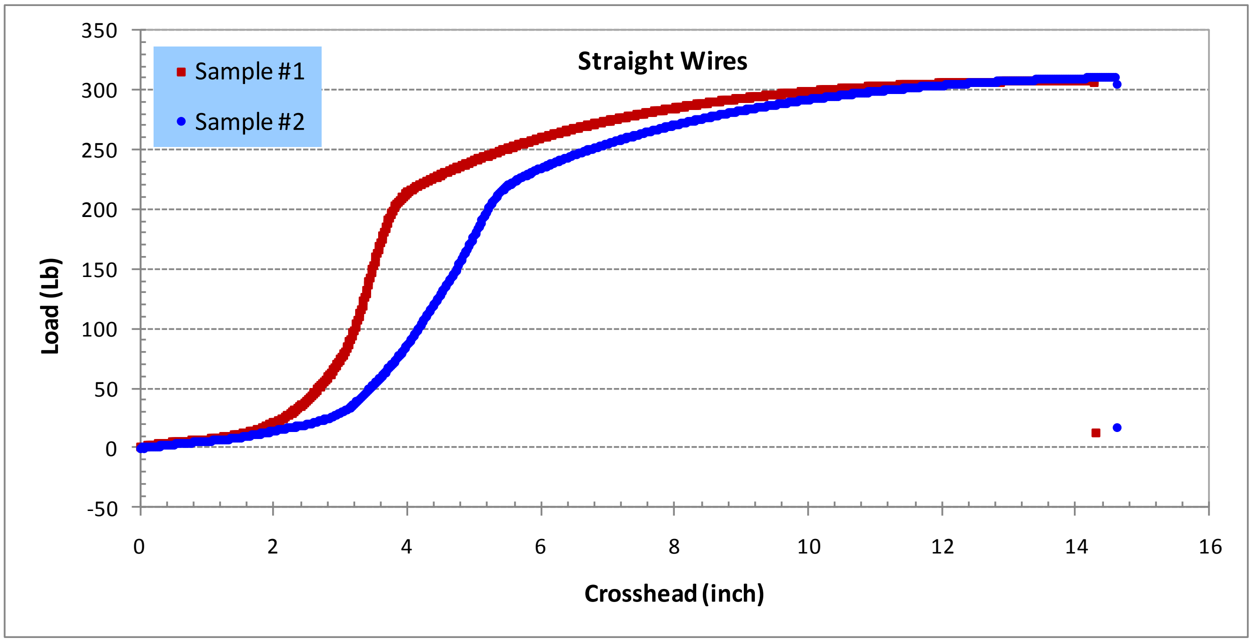


Figure 36. Tensile Plots for Company B 10 AWG Soft Drawn Copper Wire*

* This test is used to compare the tensile properties of 10 AWG soft drawn with hard drawn copper wire.

Specimens Prepared from Field Installed Wire Samples

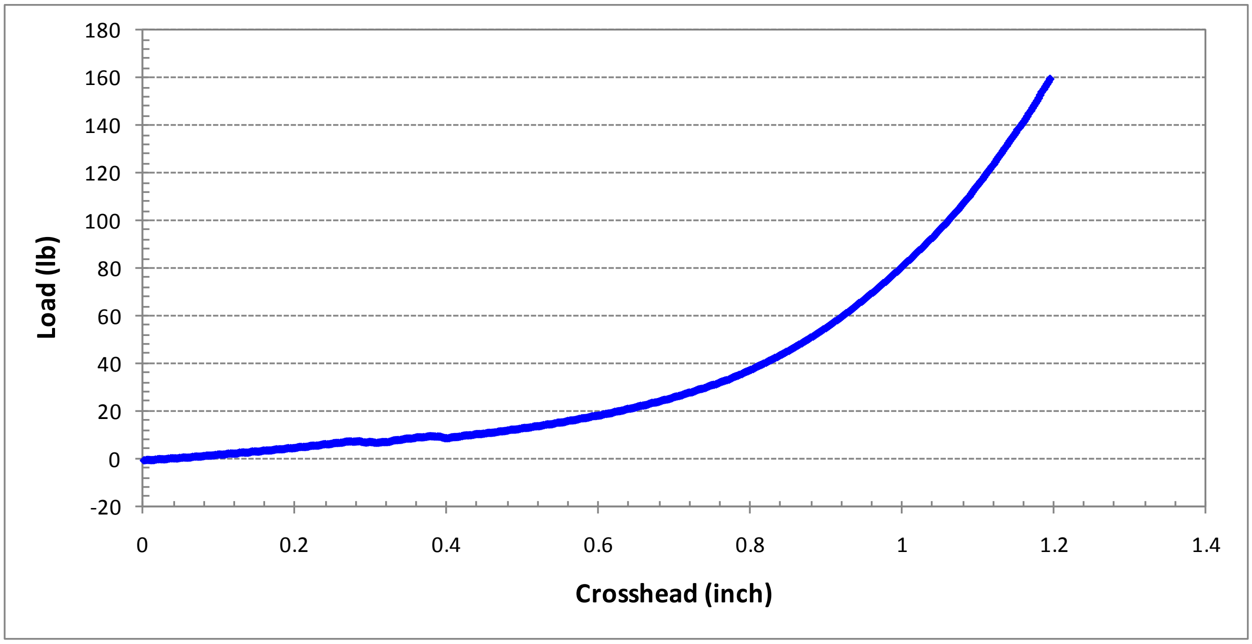


Figure 37. Tensile Plot for Field Tested Company D 12 AWG Copper Clad Steel Wire

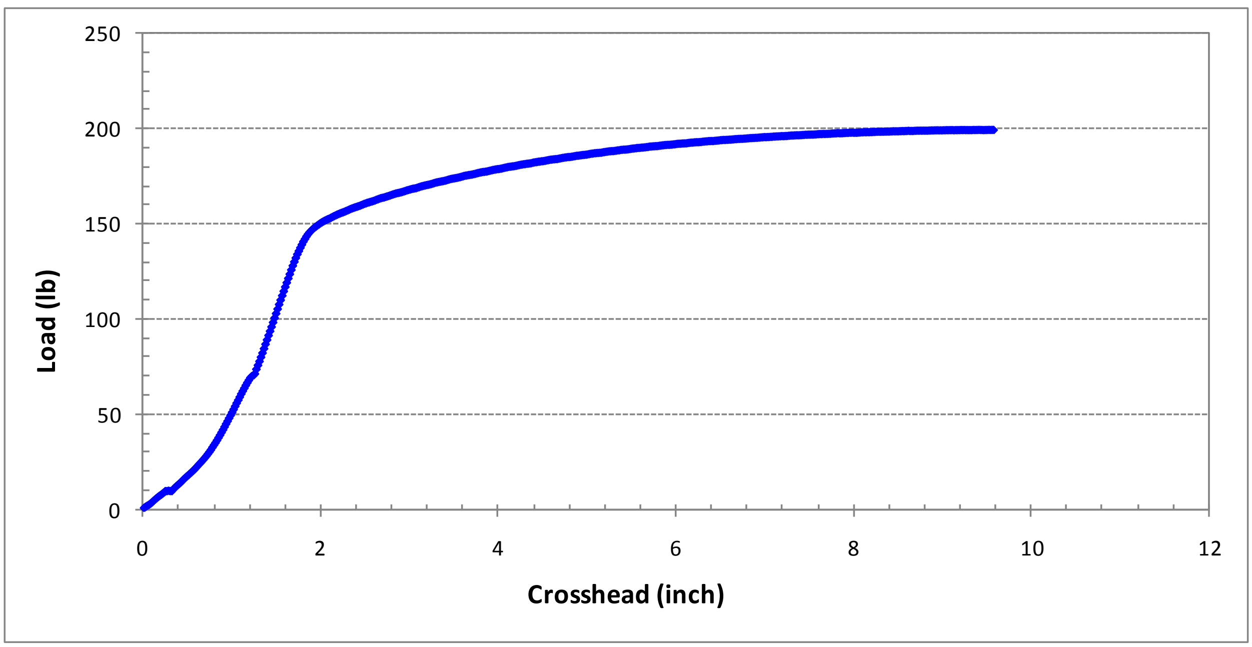


Figure 38. Tensile Plot for Field Tested Company A 12 AWG Copper Clad Steel Wire (Holiday #1)

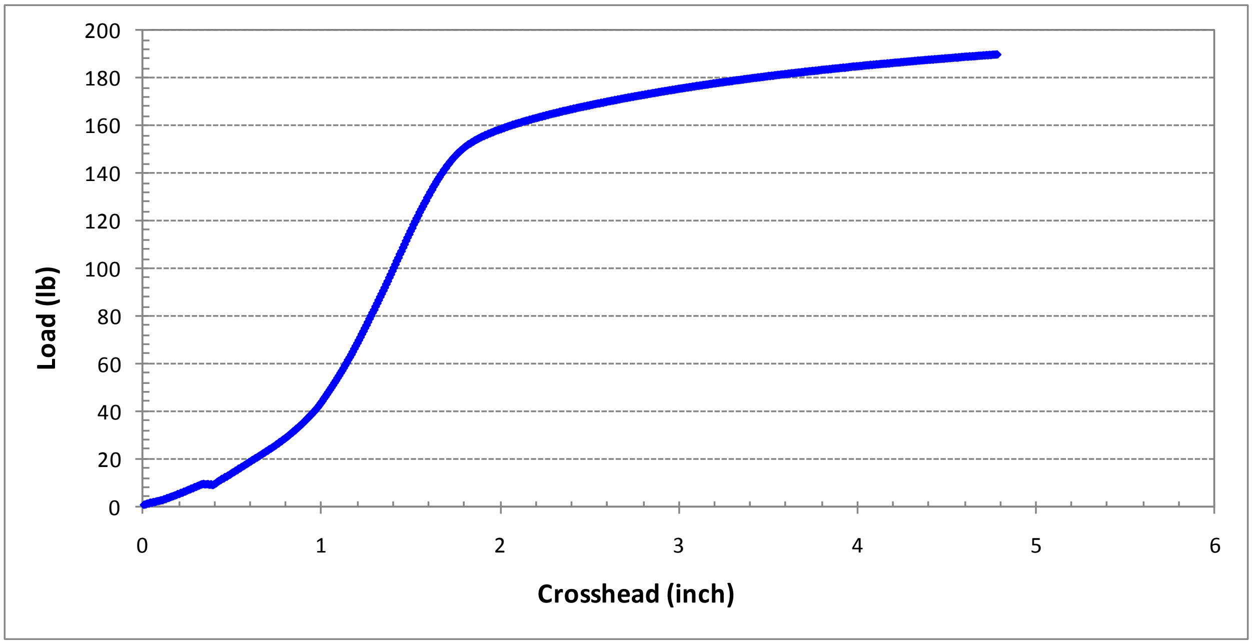


Figure 39. Tensile Plot for Field Tested Company A 12 AWG Copper Clad Steel Wire (Holiday #2)

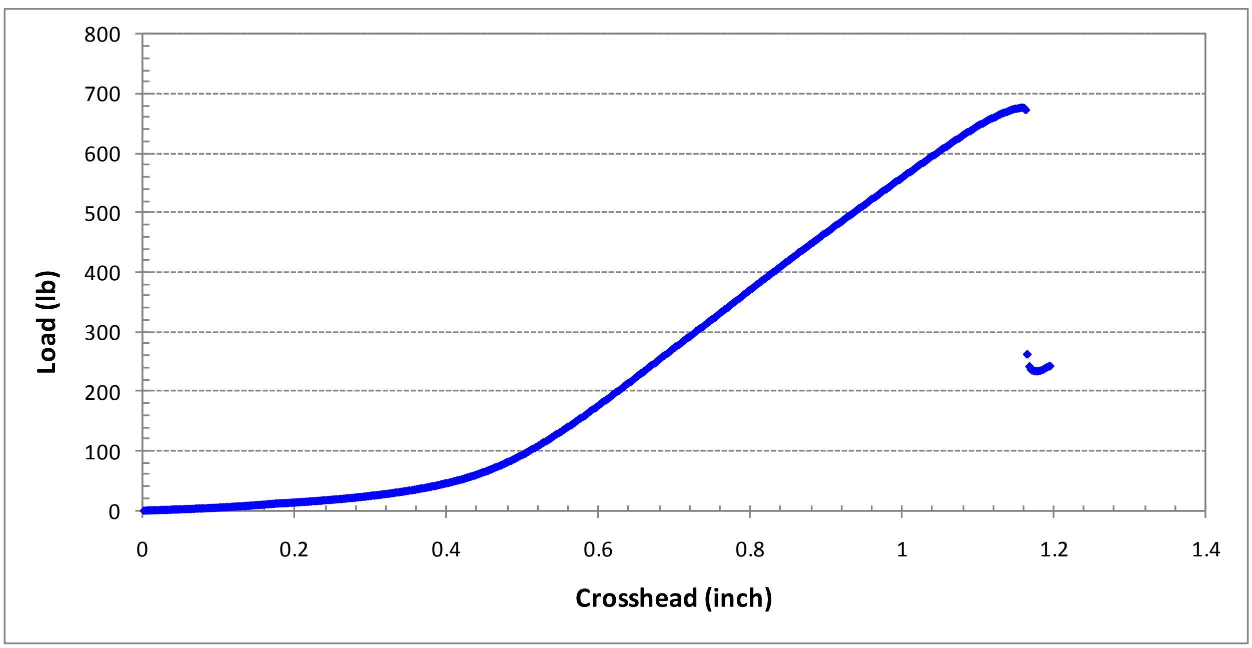


Figure 40. Tensile Plot for Field Tested Company E HDD 12 AWG Copper Clad Steel Wire

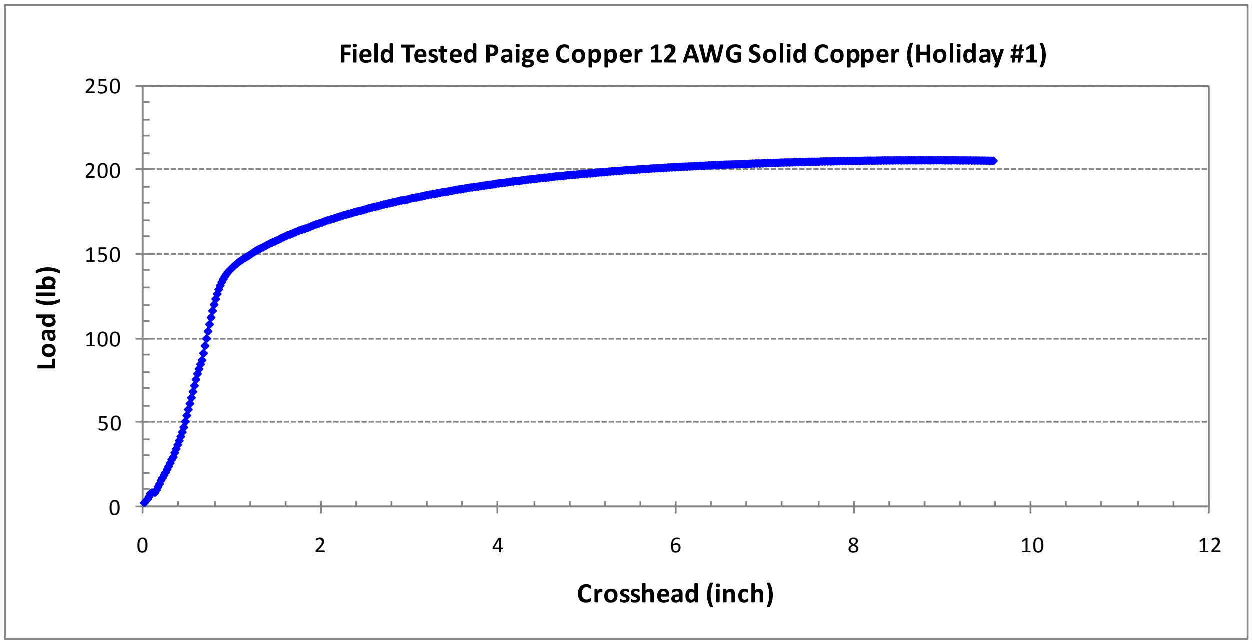


Figure 41. Tensile Plot for Field Tested Company C 12 AWG Solid Copper Wire (Holiday #1)

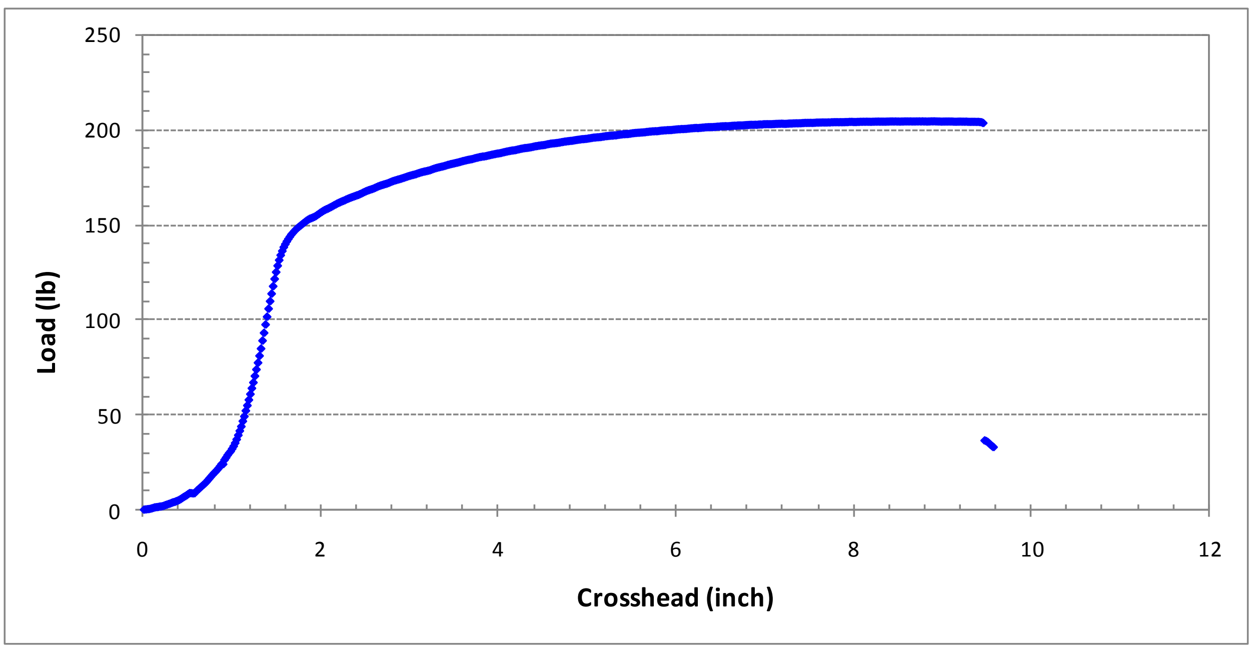


Figure 42. Tensile Plot for Field Tested Company C 12 AWG Copper Wire (Holiday #2)

Appendix II: Field Installation of Tracer Wires at Leaf River, IL

Figure 43. Four tracer wires used during HDD pipe installation


Figure 44. Tracer Wires being Pulled in with Pipe

Note: Permanent wire was taped to pipe.

Figure 45. Tracer Wires during Pull In


Figure 46. Pipe and Wires Crossing Another Existing Conduit

Note: limestone rock

Figure 47. Tracer Wires and Pipe at Exit Point (530’ away from Entry Point)

Figure 48. Three Tracer Wires being Pulled out of the Ground

Figure 49. Three Tracer Wires being Pulled out of the Ground

Appendix III: Field Installation of Tracer Wires at Batavia, IL

Figure 50. Vermeer HDD Machine at the Job Site

Figure 51.Tracer Wires before the Installation

Figure 52. Example of the Rocky Soil Areas

Figure 53. Example of the Pea Gravel Soil

Figure 54. Example of the Pea Gravel with Concrete

Figure 55. The Sand Area of the Pipe Installation

Figure 56. Five Tracer Wires Used during HDD Pipe Installation

Note permanent wire taped to the pipe.

Figure 57. Tracer Wires being Pulled through the Borehole along with the Pipe

Figure 58. Pipe and Wires being Pulled out by Backhoe

END OF REPORT