EVALUATION OF REGULAR STRENGTH AND HIGH STRENGTH STEEL WIRES FOR NOTCH FRACTURE TOUGHNESS AND STRESS CORROSION PROPERTIES

(Neetrac Project No. A 7727-000)
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I. INTRODUCTION

A project was initiated to evaluate the 0.1493" and 0.136" diameter low strength and high strength steel wires for notch fracture toughness and stress corrosion tests. Steel wire samples received from Southwire Co. were tagged as follow;

Special 0.1493" diameter, 275ksi UTS
Regular 0.1493" diameter, 220ksi UTS
Special 0.136" diameter, 285ksi UTS
Regular 0.136" diameter, 225ksi UTS

Currently, Southwire is using "regular 0.1493" diameter and 0.136" diameter" wires in their aluminum conductors. Recently, Southwire has developed a special wire which has higher UTS and YTS than the regular strength wire for use in aluminum conductors to increase the overall strength of the conductors. It is important to know the fracture toughness and stress corrosion properties of the high strength steel core wires since the conductors will be exposed to outside environments.

II. BACKGROUND

Since it is expected the core wire loading will be increased on these special wires, it is important to evaluate their toughness and stress corrosion cracking (SCC) properties compared to the present core wires. In general, once steels exceed 160ksi tensile strength, it is susceptible to brittle fracture and/or stress corrosion fracture in an environment where Cl- is present (coastal areas). A number of metallurgical factors are involved so it is important to evaluate: a) the notch fracture toughness and b) stress corrosion resistance of steel in its final fabricated shape since there have been several documented failures of high strength steel wires due to one or both of the above mentioned causes, e.g. wire reinforced pressure vessels and pipes. Two tests, notch fracture toughness and stress corrosion, were designed to evaluate the high strength steel reinforcing wire for transmission overhead conductors. Notched impact test provides information on the wire toughness (vs brittle) characteristics while the accelerated stress corrosion bend test provide data on its resistance to stress corrosion, particularly in coastal environments

III. CHARPY IMPACT TESTING

Charpy impact testing tests the amount of energy absorbed during high strain rate fracture of a material and is a measure of a material's resistance to brittle fracture. The test specimens are notched, and the size of specimens set forth by ASTM standards. Charpy test specimens are 10mm x 10mm x 55mm with a V shaped notch 2 mm deep (Figure 1). The notch opening is 45°. The impact test has limitations, but is widely used as a screening test because of the simplicity and cost. The Charpy test is good for evaluating toughness changes between various composition and temperature effects on fracture toughness. In order to determine the ductile to brittle transition temperature (DBTT) for a material, Charpy tests are performed over a range of temperatures. A sharp change in impact strength for a small increase in temperature indicates a transition in fracture mechanism.

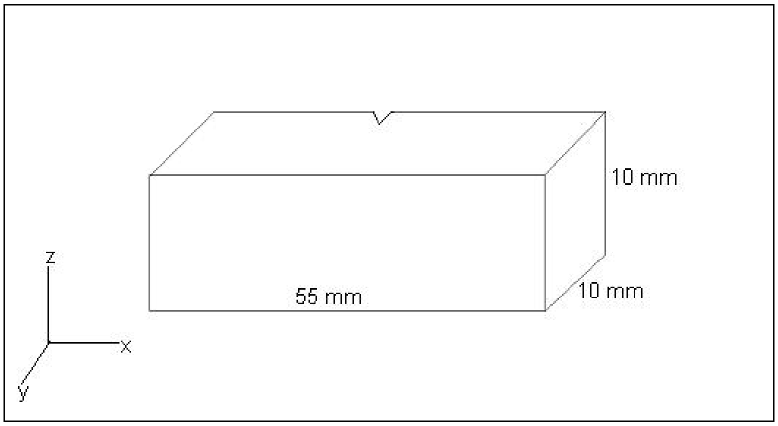

Figure 1: ASTM standard V-notch Charpy test specimen

The impact tester uses a pendulum hammer of specific weight dropped through a known distance. The pendulum hammer strikes the specimen on the flat surface opposite the notch at a specific velocity. The work done by the hammer in breaking the specimen is the impact energy required for fracture of the material.

Since the wires do not have the required geometry for Charpy impact testing, special holders were fabricated at GTRI. The sample holders were designed to keep the wire in a stable position, and so that the exposed portion of the wire would be impacted by the striker on the hammer pendulum. The dimensions of one sample holder are 10mm x 10mm x 24mm (Figure 2). One holder was placed on wither end of the wire samples, and the set screws were used to lock the sample into position.

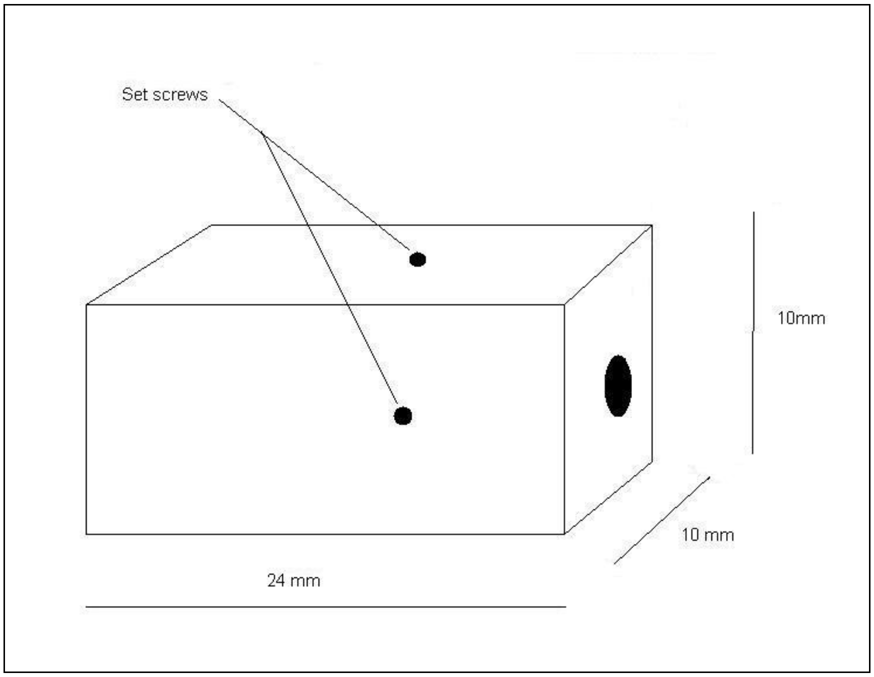

Figure 2: Specimen holder for Charpy impact testing of wire samples

Each wire was machined to have a V-shaped notch with a depth of 20% of sample diameter. The angle of the notch corresponded to ASTM standards. When placed in the sample holders and loaded into the Charpy tester, the center of the wire specimens was in the precise position of the center of a standard specimen.

Charpy Impact testing was performed on the wire samples at four temperatures: 8°F (-13°C), 32°F (0°C), 70°F (21°C) and 212°F (100°C). Four samples of each wire specimen were tested at each temperature. The 8°F (-13°C) temperature was achieved using a mixture of ice water and sodium chloride, and the 32°F (0°C) temperature was achieved using only an ice water bath. Samples were set in the sample holders and placed in the bath for 10 minutes to cool to testing temperature. The 212°F (100°C) temperature required a small precision furnace oven. Samples were set in the holders and left in the oven for 30 minutes prior to testing.

IV. RESULTS

Data for the samples is listed below in TABLE 1. A plot of the impact energy versus test temperature is shown in Figure 3.

TABLE 1
Charpy Impact Energy for Fracture Data for Wire Samples

Steel wire type	Temp	**Actual Force (Ft-Lb)** (after correction), avg values
Special, 0.1493"D 275kis	212F	3.4
	70F	2.1
	32F	1.4
	9F	1.3
Regular, 0.1493"D 220ksi	212F	1.5
	70F	1
	32F	0.72
	9F	0.75
Special, 0.136"D 285ksi	212F	1.75
	70F	1.5
	32F	1.4
	9F	1.25
Regular, 0.136"D 225ksi	212F	1.75
	70F	1.1
	32F	0.8
	9F	0.8

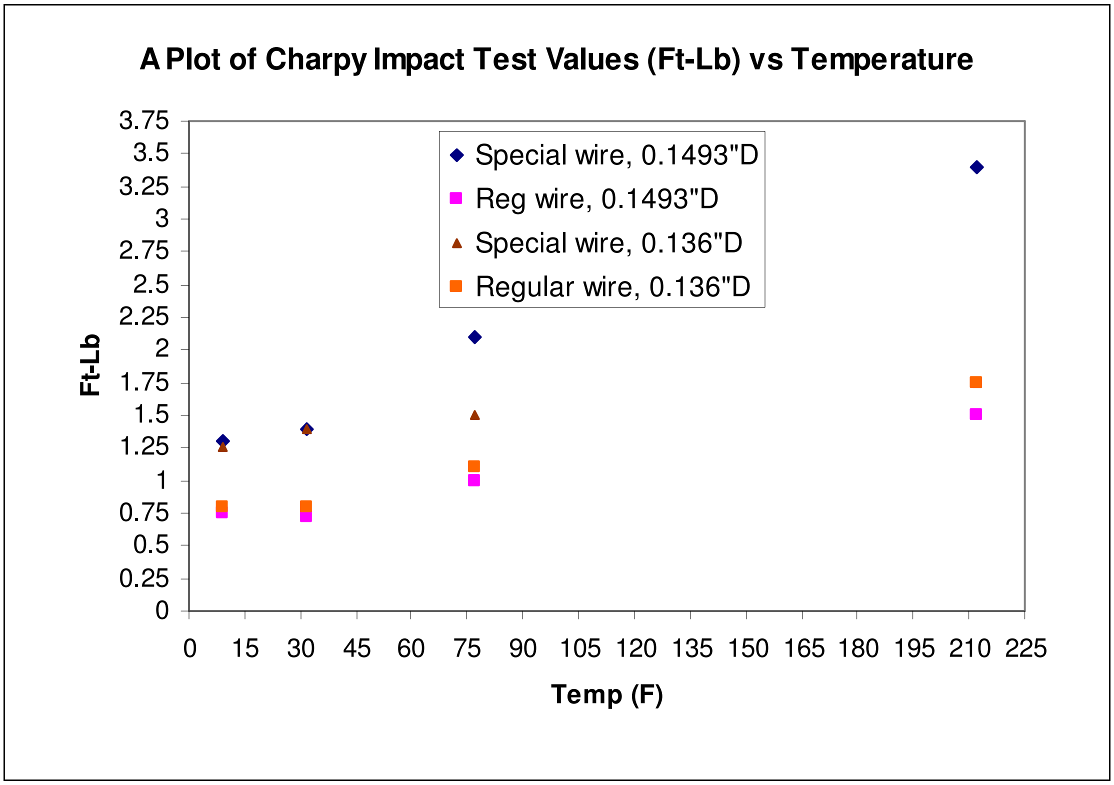

Figure 3: Charpy Impact Energy for Fracture Data for Wire Samples Versus Test Temperature

From the data it can be seen that a specific DBTT point cannot be easily ascertained. The transition of the impact strength over the temperature range is smooth rather than sharp. This may be related to the geometry of the sample compared to a standard impact specimen. In general, the fracture appears to have some ductility and the special wires have Charpy impact values higher than the presently used wires (Figure 4 - Figure 7). Analysis of fracture surfaces to determine the ratio of fracture mechanism (ductile or brittle) can be performed for a complete analysis.

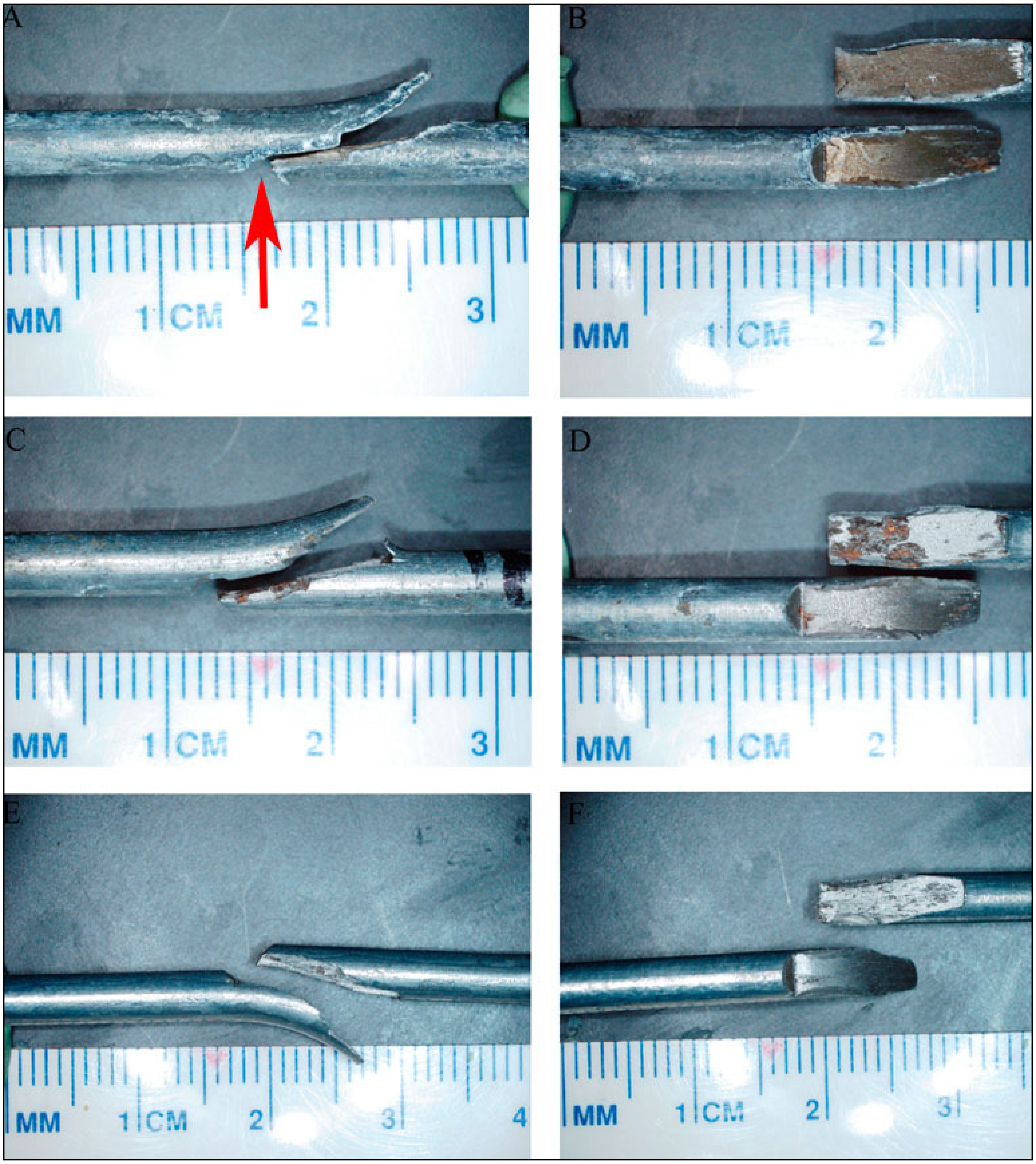

Figure 4: Micrograph of Special 0.1493" Diameter, 275ksi UTS Core Wire After Charpy Impact Testing. (A) and (B): 8°F, (C) and (D): 32°F, (E) and (F): 70°F. Arrow in (A) Indicates Notch Position.

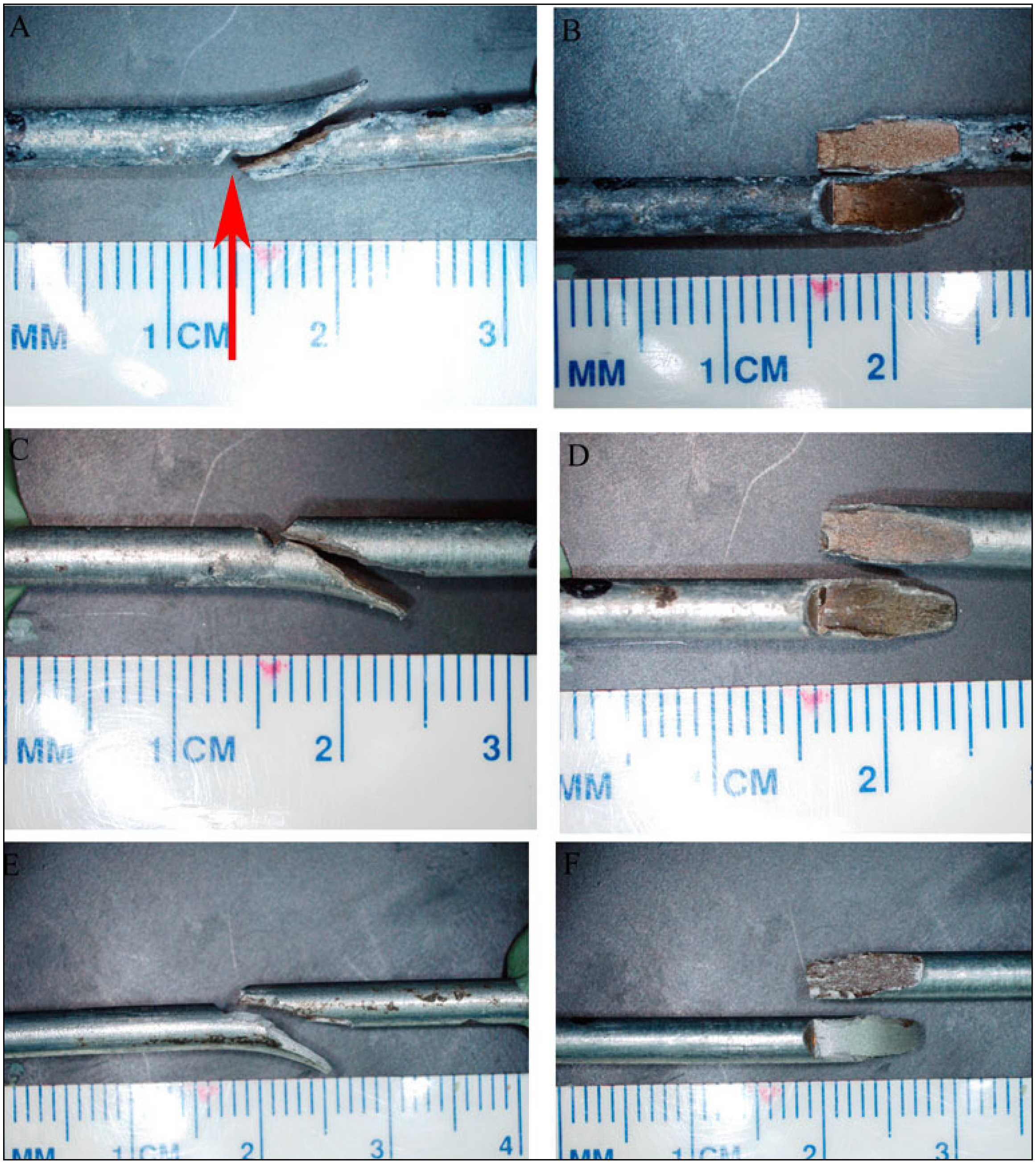

Figure 5: Micrograph of Regular 0.1493" diameter, 220ksi UTS Core Wire After Charpy Impact Testing. (A) and (B): 8°F, (C) and (D): 32°F, (E) and (F): 70°F. Arrow in (A) Indicates Notch Position.

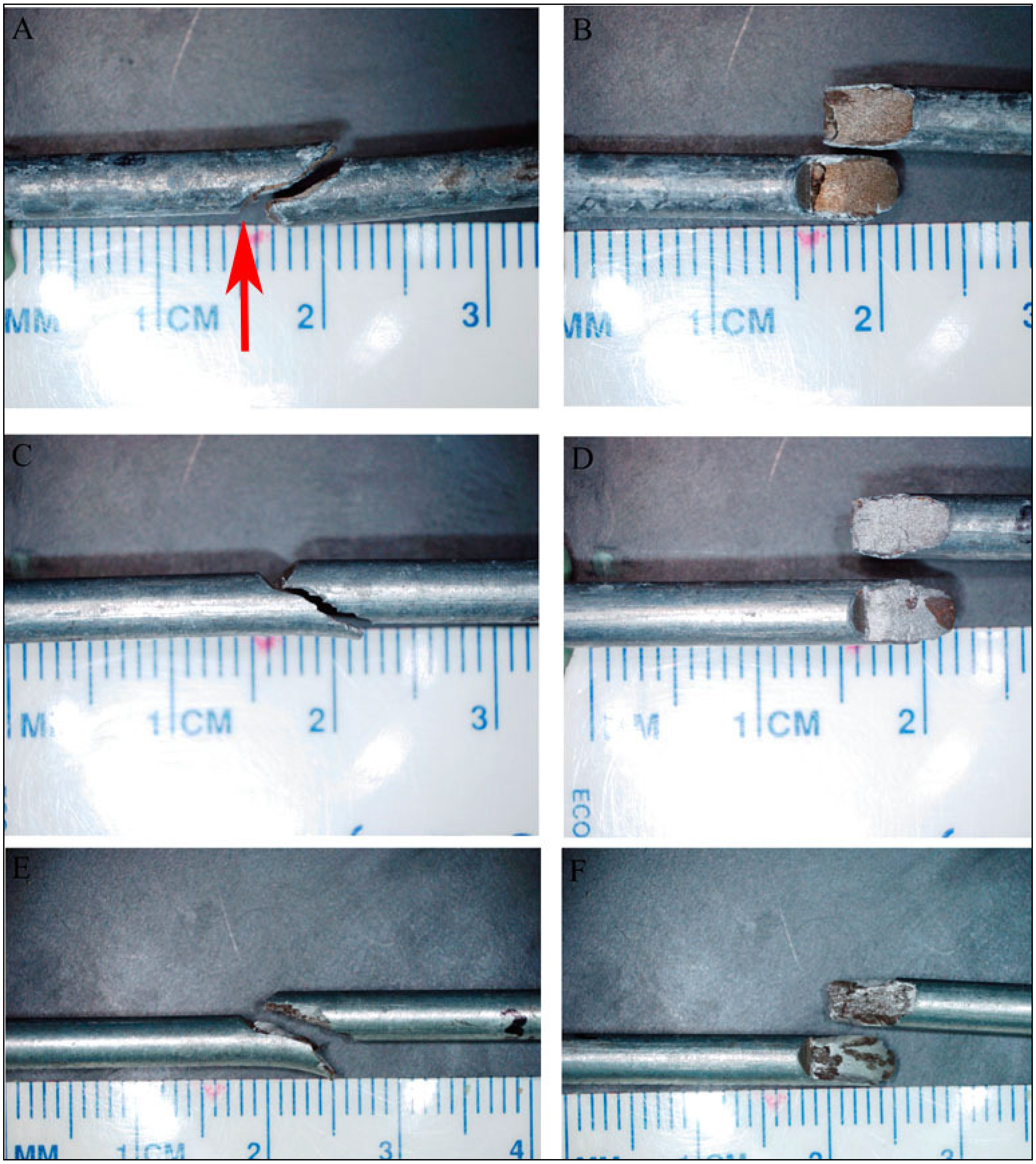

Figure 6: Micrograph of Special 0.136" diameter, 285ksi UTS Core Wire After Charpy Impact Testing. (A) and (B): 8°F, (C) and (D): 32°F, (E) and (F): 70°F. Arrow in (A) Indicates Notch Position.

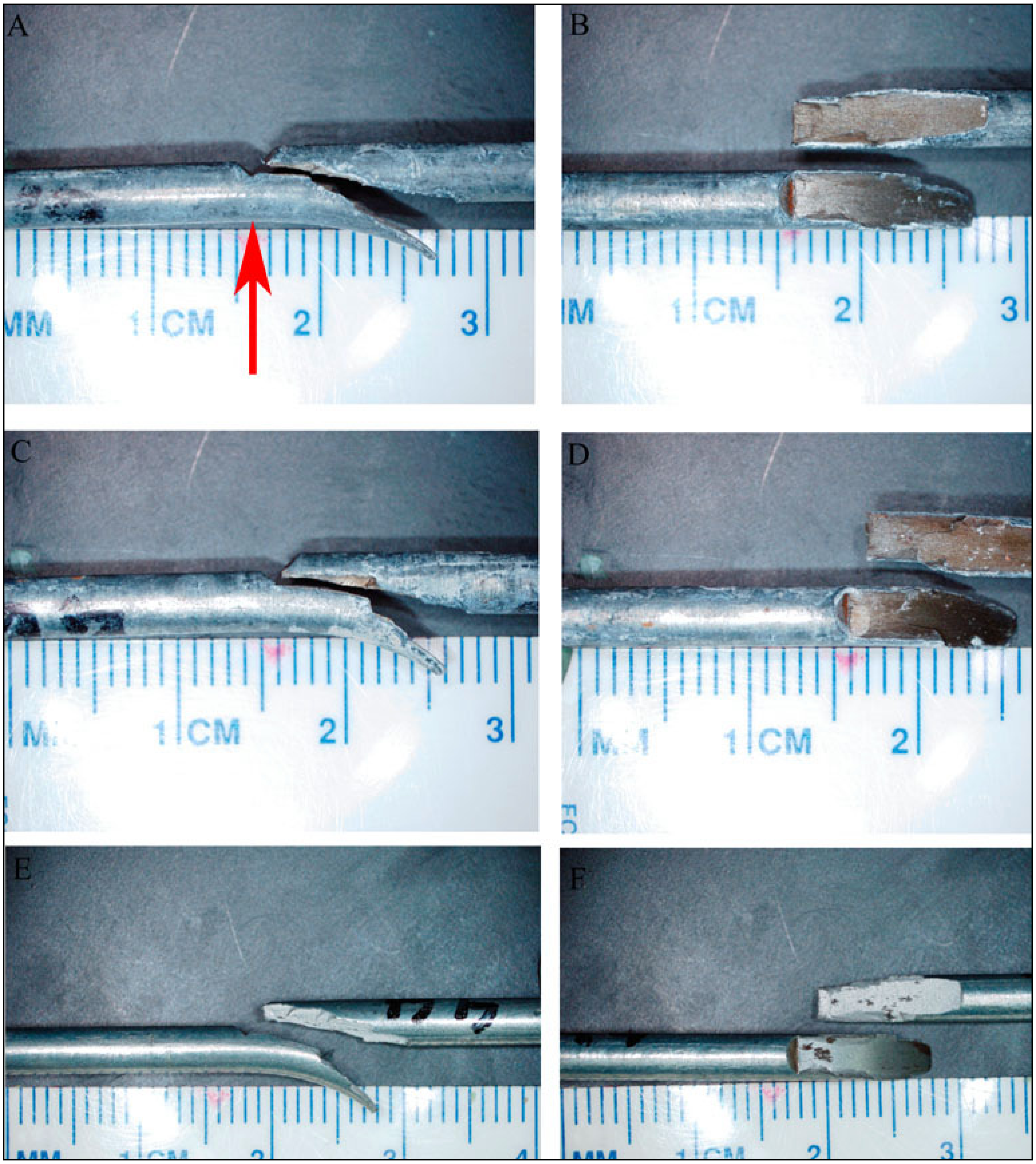

Figure 7: Micrograph of Regular 0.136" diameter, 225ksi UTS Core Wire After Charpy Impact Testing. (A) and (B): 8°F, (C) and (D): 32°F, (E) and (F): 70°F. Arrow in (A) Indicates Notch Position.

V. STRESS CORROSION CRACKING

Stress corrosion cracking (SCC) is cracking which results from both the influence of an applied stress and a corrosive environment. In order to test for SCC, a 3.5% sodium chloride/water solution was prepared with 7200 ml H_2O and 248.97g of NaCl. The solution was continuously circulated using a small electric pump. Four sample of each wire type were used in the salt solution to determine the effects of SCC.

The wires were bent with a 180° semi-circular bend with a diameter of 4 inches (Figure 8). Two samples of each wire type were scratched with a file at the peak of each bend. Images of some of the wire samples are available in Figure 9 -Figure 12. Each sample was submersed into the circulating salt water solution with only a small portion of the wire above the surface of the solution. The water was held at room temperature for the duration of the test period (ongoing). The accelerated test has been conducted for 5 weeks with no evidence of SCC.

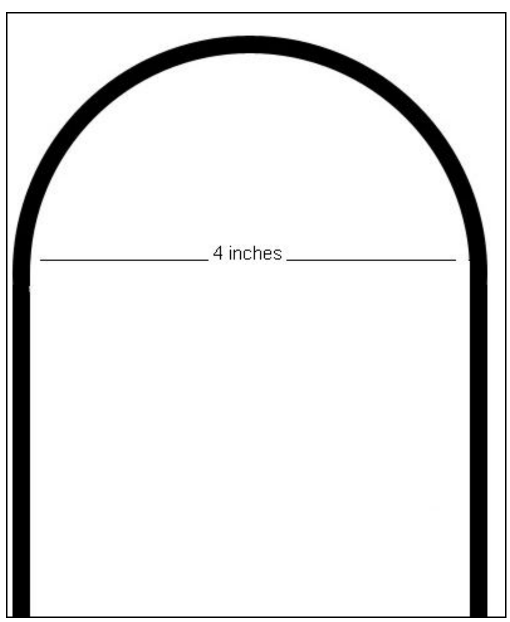

Figure 8: Sketch of Wire Samples Used in SCC Testing

Figure 9: Image of Special 0.1493" Wire Sample at 50X Before SCC Testing

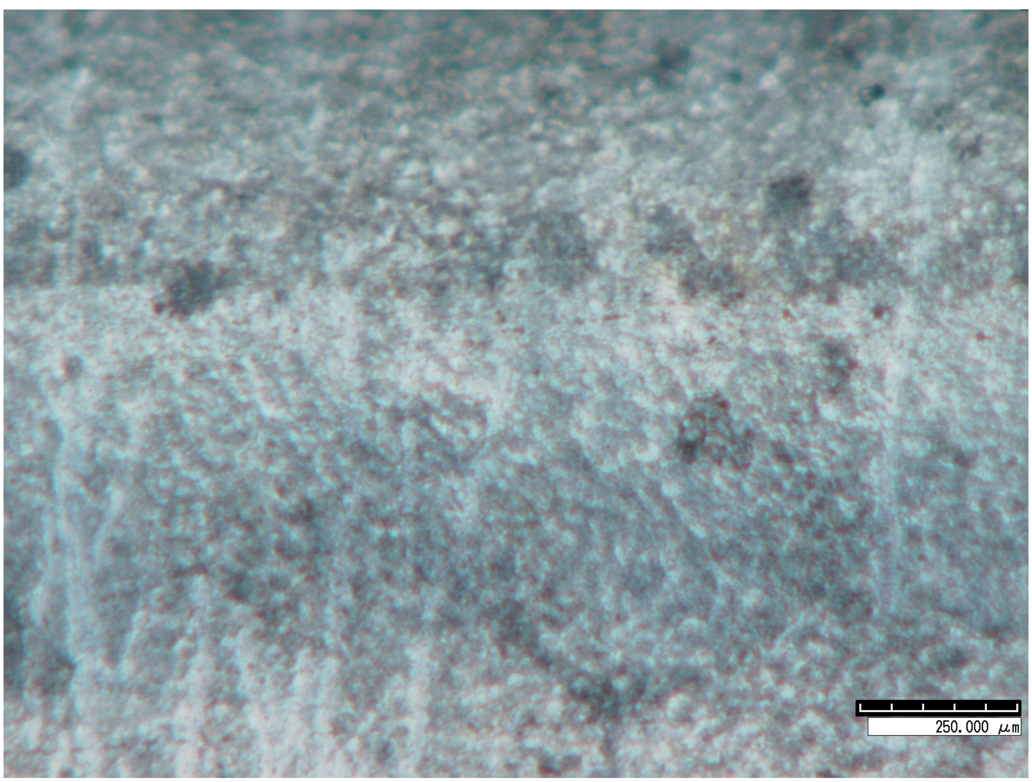

Figure 10: Image of Special 0.1493" Wire Sample at 200X Before SCC Testing

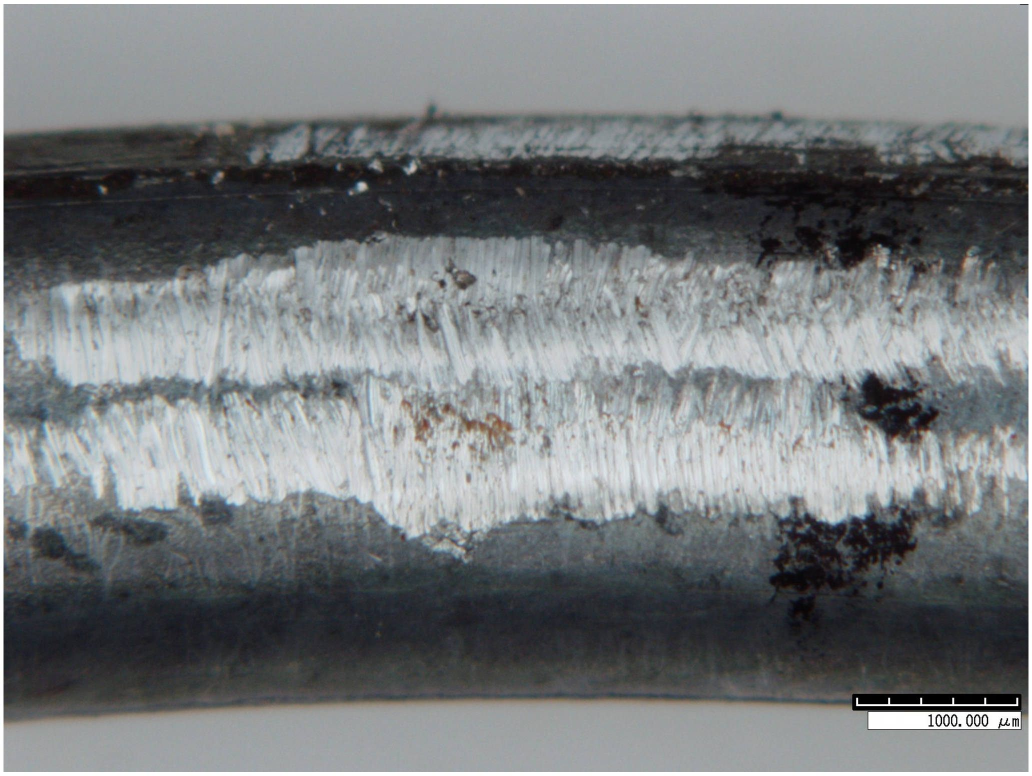

Figure 11: Image of Scratched Special 0.1493" Wire Sample at 50X Before SCC Testing

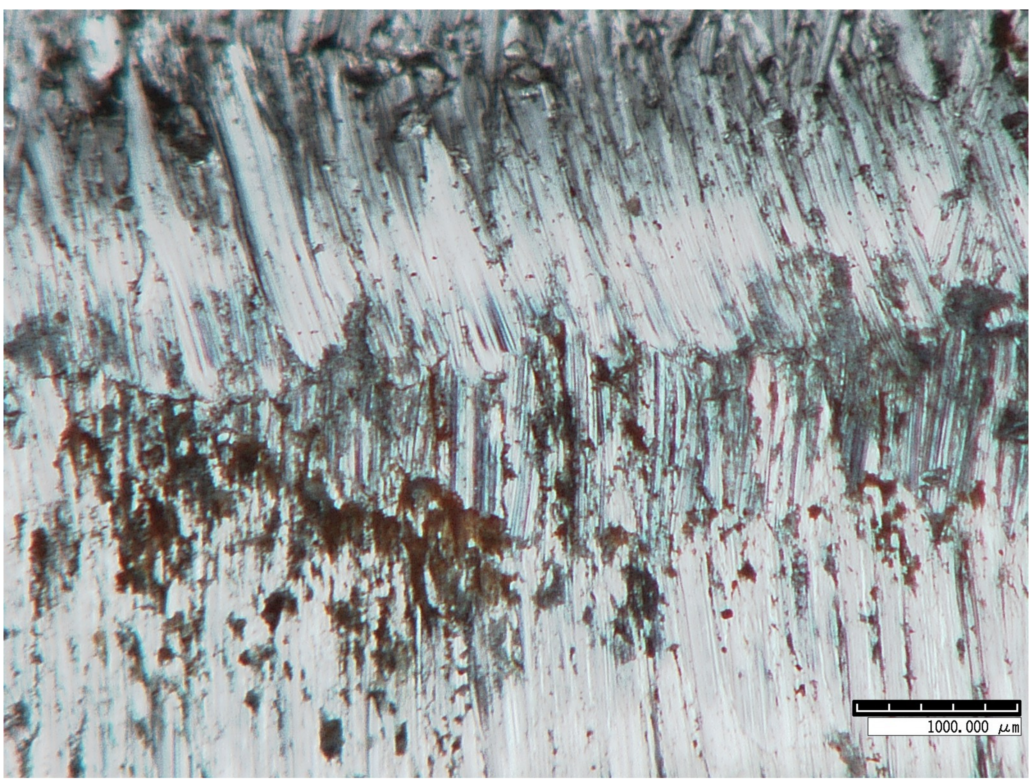

Figure 12: Image of Scratched Special 0.1493" Wire Sample at 200X Before SCC Testing

The surface conditions of the specimens after the test have not been examined since no failures have occurred after five weeks of exposure to corrosive environments.

VI. CHEMISTRY

2 includes the results of chemical analysis on typical samples of both the new special core wires and the presently used core wires.

TABLE II

	Elements, wt%								
Sample I.D.	C	Mn	P	S	Si	Ni	Cr	Cu	Al
regular, 225ksi	0.8	0.53	0.018	0.012	0.18	0.04	0.04	0.11	0.29
special, 275ksi	0.72	0.5	0.018	<0.005	0.22	0.08	0.08	0.04	0.38
Alloy or specification	0.72/0.85	0.3/0.6	0.04max	0.05max	0.15/0.35				

VII. CONCLUSIONS AND DISCUSSION

Although there is a drop in impact strength with temperature for the new special core wire, it has significantly higher impact strength across the entire range of test temperatures compared to the presently used core wires. The new higher strength core wires also appear to have some ductility across the entire testing range. We surmise that breakage of the present core wire has not been a significant problem, and if so, the new 'higher strength' special core wire should be satisfactory in the same applications. The same reasoning applies to SCC resistance. The new wire appears to have SCC equivalent to the present low strength core wire. However, we would caution that if any field failures occur that they be carefully evaluated for cause.