Technical Evaluation Package

Advantages of Southwire ACSS and ACSS/HS285®
Overhead Conductor

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Report by: ____________________

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Summary

Southwire prides itself as the wire and cable "solutions provider", and we offer best-in-class conductors for every performance class. While our offerings cover the full performance range, this document focuses on the industry's first commercially-successful high temperature, low-sag (HTLS) conductor: Southwire ACSS/HS285.

ACSS/HS285 competes well in the advanced conductor market, with top ratings for capacity and low line loss. Conductors with advanced composite cores are available from Southwire and others. Composites offer unprecedented performance due to their low thermal expansion and light weight. Composite cores cannot match the ruggedness or the price of steel core. Southwire ACSS/HS285 combines the ruggedness and reliability of traditional steel-core conductors with several enhancements:

- All of Southwire's ACSS products are annealed after stranding. The conventional process is to strand pre-annealed aluminum strands. Pre-annealing problems include:
  - The back-tension brakes on the strander need to be set extremely low to avoid breaking the soft aluminum. This results in looser stranding, which can cause bird-caging. Most line crews prefer Southwire ACSS because of easier installation.
  - Pre-annealed aluminum is partly re-hardened during conductor manufacturing. Harder aluminum shifts the conductor behavior closer to ACSR behavior and removes some of the ACSS performance advantage. Objective test data (discussed later) is available to demonstrate:
    - Southwire ACSS/HS285 sag performance is in a class above conventional ACSS/MA5.
    - Southwire ACSS/MA3 (high strength) sag performance is comparable to conventional ACSS/MA5 (ultra-high-strength).
- Southwire ACSS, including ACSS/HS285 is best-in-class for line loss. Southwire-manufactured high-purity aluminum rod is used exclusively for Southwire ACSS production. Minimum aluminum conductivity is controlled at 63% IACS, and typically measures 64% IACS. Spot-market aluminum used by other manufacturers is required to meet only the ASTM minimum conductivity of 61.8% IACS.
- Ultra-high-strength (UHS) steel for the core is a Southwire innovation that raises the rated breaking strength (RBS) of ACSS to match the RBS of the same-size ACSR conductor.
- Mischmetal alloy coating for the steel core is also a Southwire innovation, and is standard on all Southwire ACSS, including ACSS/HS285. Mischmetal alloy coatings protect the steel core strands with unprecedented heat tolerance and corrosion resistance.
- Southwire requires that the steel core in ACSS/HS285 exceed ASTM B958 requirements after heat aging. Our steel core providers are required to verify "after aging" properties meet MA5 requirements, or else provide a strength margin above MA5 to compensate for known strength loss with heat exposure. Others use as-manufactured values which can decline during in-service heat exposure.

Fundamental Product Properties and Operating Performance Characteristics

Southwire is a vertically-integrated manufacturer. Southwire's high-conductivity aluminum rod is used exclusively for Southwire overhead conductor. Southwire's innovative trapezoidal-wire (TW) designs enhance conductor performance by increasing the aluminum area without increasing the conductor diameter. Southwire's manufacturing excellence, including considerable proprietary technology, is applied to ACSS/HS285 production.

The steel core chemistry, metallurgy and processing descend directly from improved plow steel (IPS) used in the first ACSR cores. Ultra-high-strength is achieved by higher purity steel for fewer and smaller metallurgical defects, combined with improved control over temperature and cold work. The result is a steel with consistently high strength combined with excellent ductility. ACSS/HS285 projects installed in 2004 are operating with no failures attributable to the ultra-high-strength core. Thousands of miles of ACSS/HS285 are in service around the world, including recent installations in Denmark, Finland, and New Zealand.

The mischmetal alloy coating for conductor steel cores was introduced by Southwire in 1994. Hot-dip zinc coatings used for standard cores cannot withstand the heat exposure in the annealing oven, and also cannot withstand the maximum operating temperature in service. Mischmetal coatings are chemically stable up to 330 °C (626 °F), and thermally stable up to 380 °C (716 °F).

HS285 is by far the most tested steel core of the modern time. Stress corrosion, Charpy impact, and fatigue were evaluated in-depth before the material was considered for conductor applications. The completed ACSS/HS285 conductor was also exhaustively tested for creep, stress-strain, and tensile breaking strength. Connectors and fittings were likewise tested, in some cases by Southwire and in some cases by our fittings partners.

One early finding in the stress-strain testing was relatively poor agreement between Southwire ACSS data and the Reynolds-legacy ACSS data from SAG10®. The mystery was solved when legacy-method ACSS was tested on the same Southwire test equipment. Test data for Reynolds-process ACSS agreed very well with the Reynolds-legacy test data. The inescapable conclusion is that Southwire's batch-annealing process results in significantly different conductor mechanical properties. The differences are significant enough to put Southwire-process ACSS in a different class, and require different charts for Southwire ACSS conductors. See the complete discussion under "Sag and Tension Characteristics".

Line Design using ACSS/HS285

The original concept for ACSS was to reconductor capacity-limited ACSR circuits with high-capacity conductors of the same size. Ampacity increases up to 80% are possible with no or limited structure changes. ACSS in its original form used the same core as ACSR. Conductor strength was significantly lower due to the loss of the strength contribution from extra hard-drawn aluminum. Stringing tension is limited by the reduced RBS, and quite often the existing structures have to be raised to accommodate greater sag. ACSS/HS285 solved the strength issue: the goal of HS285 development was to increase steel strength so that ACSS/HS285 could match the strength of conventional ACSR. This allowed full use of structures originally designed to support ACSR conductors. See

	ACSR	ACSS	ACSS/MA3	ACSS/HS285
795 kcmil Type 7 "Tern"	22,100	14,200	15,200	17,400
795 kcmil Type 13 "Cuckoo"	27,900	21,700	23,300	26,900
795 kcmil Type 16 "Drake"	**31,500***	25,900	28,000	**32,600***
795 kcmil Type 23 "Mallard"	38,400	34,300	37,900	44,300

Table 1 for breaking strength of ACSR compared with ACSS options.

* ACSR strength is exceeded by ACSS/HS285 for Type 16 conductors, and larger

Table 1: Conductor rated breaking strength for different steel grades

ACSS/HS285 has also become a popular choice for new lines. High capacity, low sag characteristics and favorable cost make the first commercially-successful HTLS conductor a compelling option for many line designs.

Stress-Strain Characteristics

Southwire's overhead conductor laboratory was extensively renovated in 2012, including the addition of new state-of-the-art stress-strain test and creep test machines. A priority for the new lab is to develop data for ACSS/HS285 to correct an issues when using the Reynolds-legacy data.

The Reynolds-legacy SAG10 chart caused an error if the ACSS/HS285 design included an ice load. The tension used by Reynolds Aluminum during their testing was tailored for standard-strength

ACSS. The higher load range required for ACSS/HS285 was not within the test range used by Reynolds. The fit equations for the available data did not extrapolate correctly as illustrated in Figure 1. Dashed lines labeled "Polynomial fits" are the stress-strain fit equations plotted beyond the range of the test data. The curve fit never reaches the stress required for ACSS/HS285 designs that include a 60% RBS allowable ice load.

In 2004, Alcoa created a temporary patch in SAG10 to accommodate ACSS/HS285: linear extrapolation of the stress-strain curve starting at a user-selectable strain (default is 0.5% strain). This patch is illustrated in Figure 1. A linear extrapolation from the stress-strain curve at 0.5% strain is extended to intersect the ACSS/HS285 60% RBS line. This provided an engineering estimate of the conductor strain for the ice load event. This point is labeled "Strain estimate" in Figure 1:

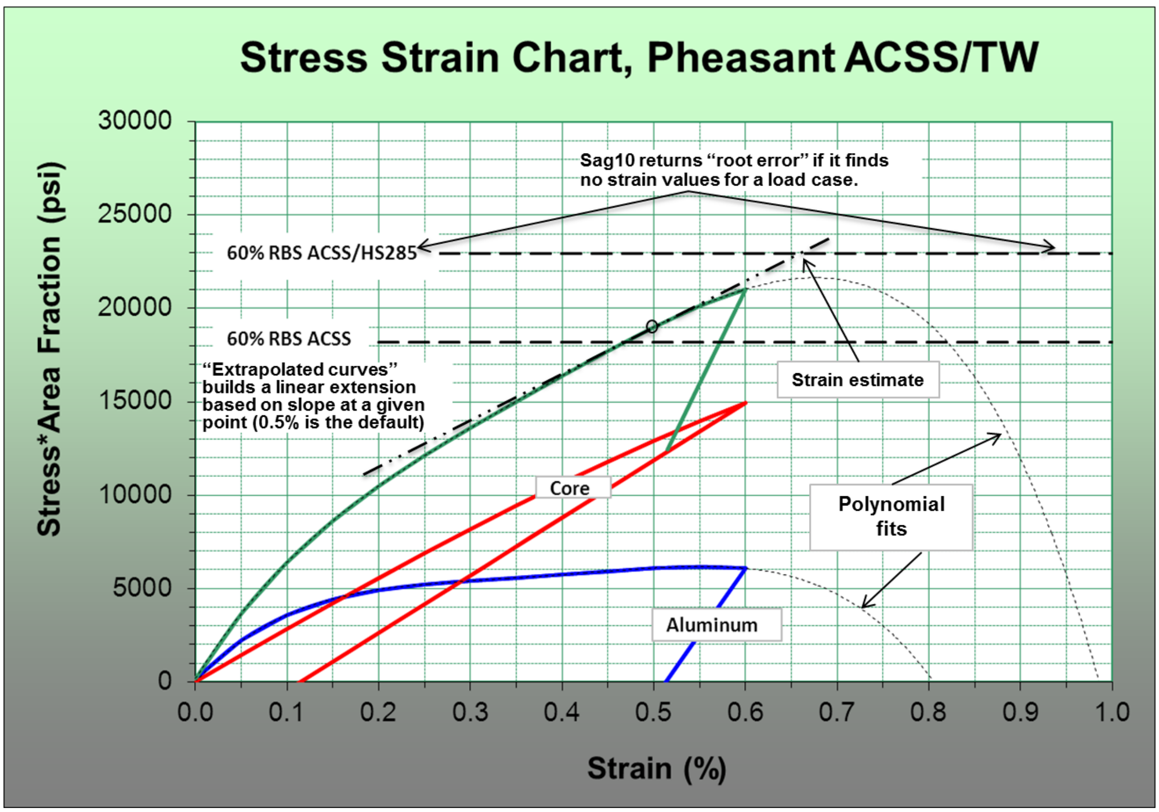

Figure 1: example Reynolds-legacy ACSS data, and illustration of "extrapolated curves"

Southwire's new ACSS and ACSS/HS285 stress-strain data was expected to be similar to the legacy Reynolds data, with the only expected improvement coming from extending the test range to accommodate higher allowable tensions for ACSS/HS285. There was a surprise:

Figure 2 compares the new Southwire ACSS data to the Reynolds-legacy data. The match for the steel core data (red line) is reasonable, but the aluminum data (blue lines) is different by a larger factor than can be accounted for as normal variation.

The conundrum was resolved when a sample of Reynolds-process ACSS was tested using the new Southwire equipment. There was a close match to the legacy Reynolds data. This confirmed that the Southwire batch-annealing process produced an ACSS with significantly different properties compared to Reynolds-process ACSS.

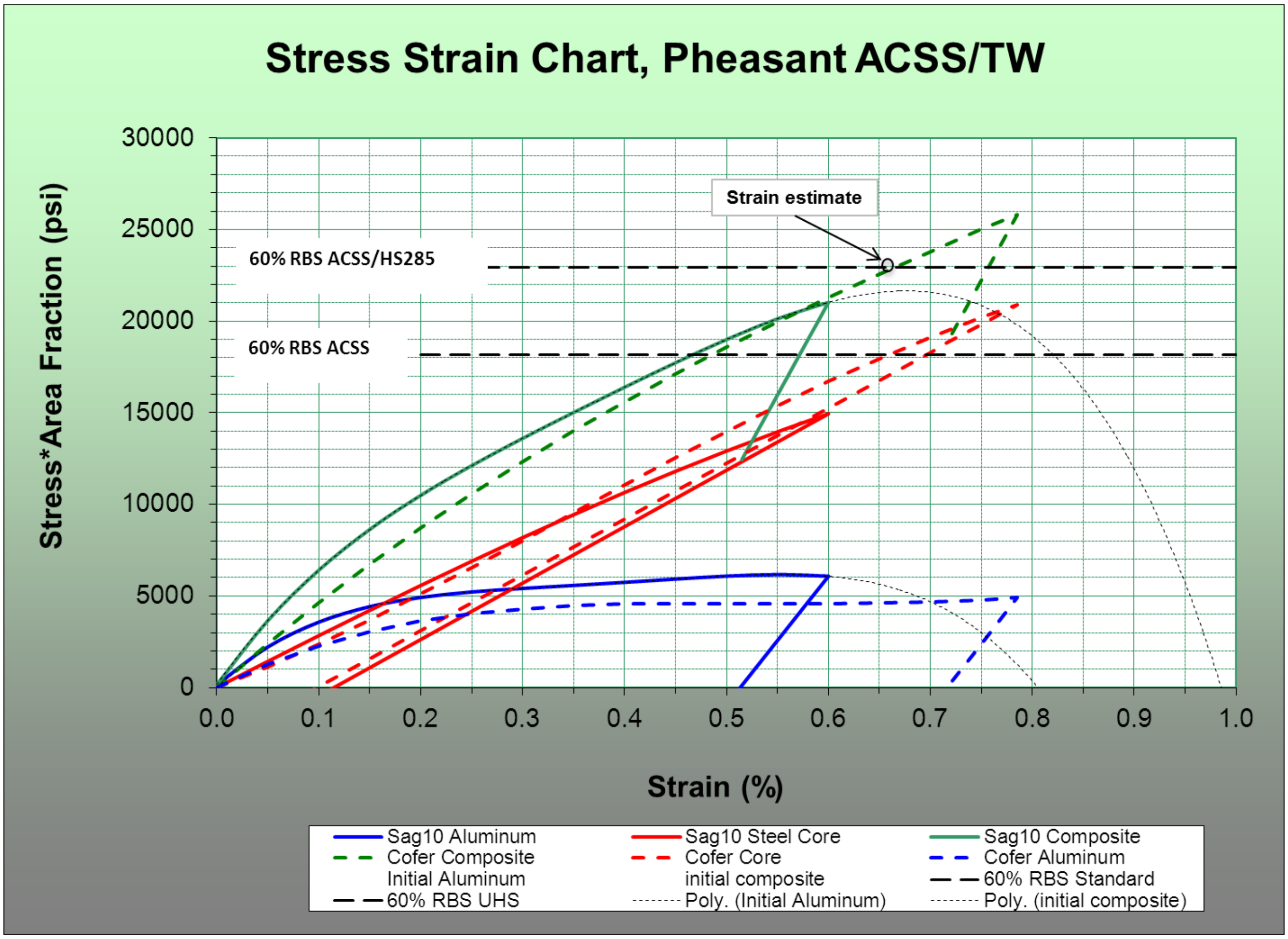

Figure 2: Southwire-Certified stress-strain test data (dashed lines) added to Reynolds graph (solid lines)

Figure 3 below shows the "virtual aluminum" (aluminum stress implied by the stress-strain data) for the aluminum shell for three conductors with identical core fraction. At the low strain range, Reynolds-process ACSS aluminum load share (red line) is comparable to ACSR (green line). The blue line shows the aluminum contribution in Southwire ACSS. There is no discernable linear elastic region, and it appears the aluminum begins yielding as soon as load is increased.

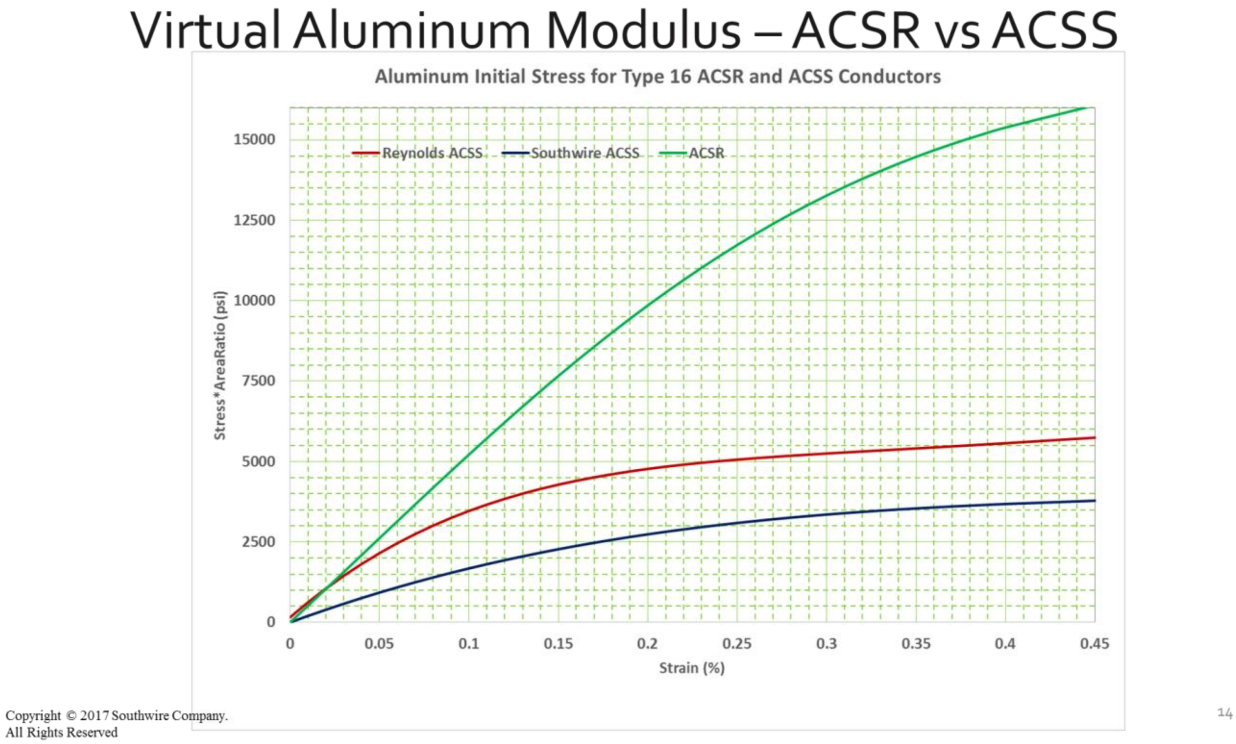

Figure 3: stress-strain data for aluminum stress in ACSR compared to two ACSS processes

These findings had implications for conductor stress-strain behavior, and required confirmation. Additional stress-strain samples for ACSS of different type numbers showed the same virtual aluminum characteristics.

As a cross-check on the conductor stress-strain testing, individual strands removed from ACSS conductors were tested at NEETRAC, a technical center of the Georgia Institute of Technology specializing in electric transmission and distribution technologies. Twenty samples of aluminum single-strands were removed from "as-manufactured" ACSS samples. Ten (10) samples were from bobbin-annealed ACSS, and ten samples were taken from Southwire batch-annealed ACSS. The results confirmed the batch-annealed ACSS are "dead soft", whereas the bobbin-annealed strands were closer to medium hard-drawn. A surprising result was the difference in yield strength: the bobbin-annealed strands had a yield point 2.4 times higher than the batch-annealed strands. Both are compliant with ASTM B609, which requires the tensile strength for 1350 O-temper to fall between 8.5 kpsi and 14 kpsi. There is no requirement for yield strength – despite the fact that yield strength is what accounts for the conductor performance differences identified in the Southwire research.

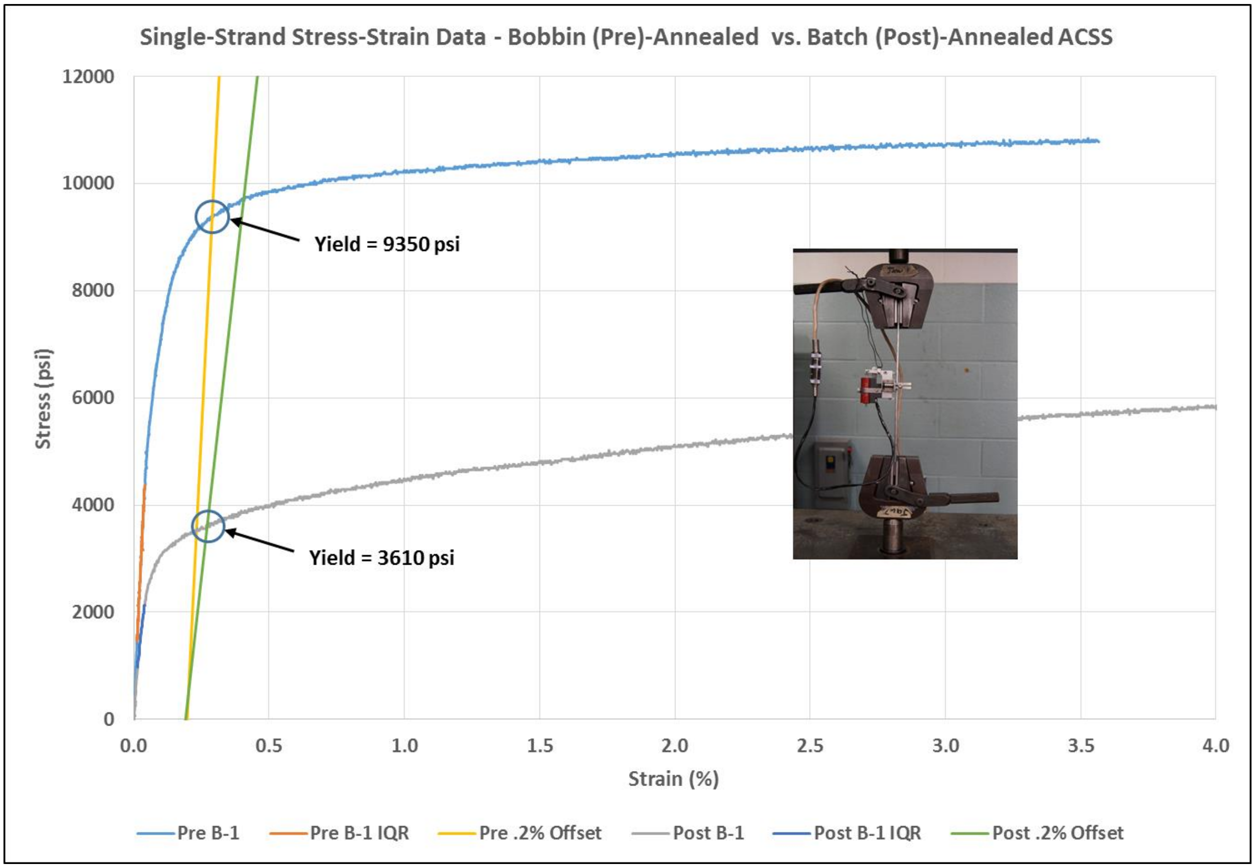

Figure 4 shows a typical example of NEETRAC data comparing bobbin-annealed and batch annealed single-strands.

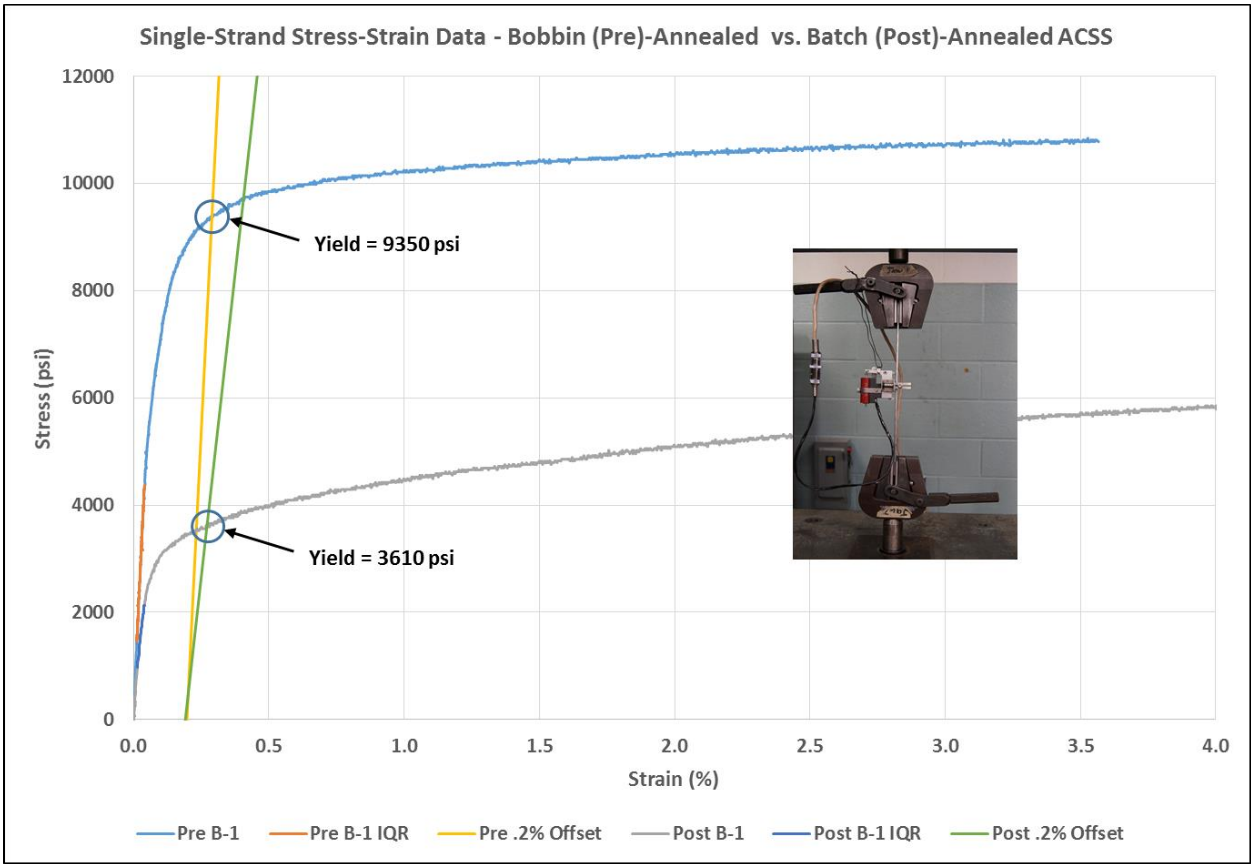

Figure 4: Stress-strain data for single-strand 1350 O-temper aluminum strands

On first reflection, stronger is better, but follow that logic and you are back at ACSR and its larger thermal sag increases. While it is correct that stronger aluminum helps to control sag under heavy ice load, in most applications it is the thermal sag that governs the required structure height required to maintain electrical clearances. Having softer aluminum provides significant advantages for thermal sag, as discussed in the next section.

The single-strand data can be compared to the conductor stress-strain data if the single-strand data is "normalized" by multiplying its stress value by the aluminum area fraction of a Type 16 conductor (0.86). This allows for direct comparison to the "virtual aluminum stress" from the stress-strain test, and the single strand stress-strain data. There are differences in the elastic modulus because conductor strands are in a helix and are therefore not as stiff as single-strands which are straightened prior to testing. The comparison does confirm the difference in the yield strength for aluminum strands. See Figure 5 for the single-end stress-strain data normalized to represent the virtual aluminum stress in a Type 16 conductor: the difference in the yield strength is confirmed. The solid lines represent data from conductor stress-strain tests. The dashed lines represent single strands removed from the same conductors. Friction effects in the stranded conductor account for the small difference in the apparent yield stress.

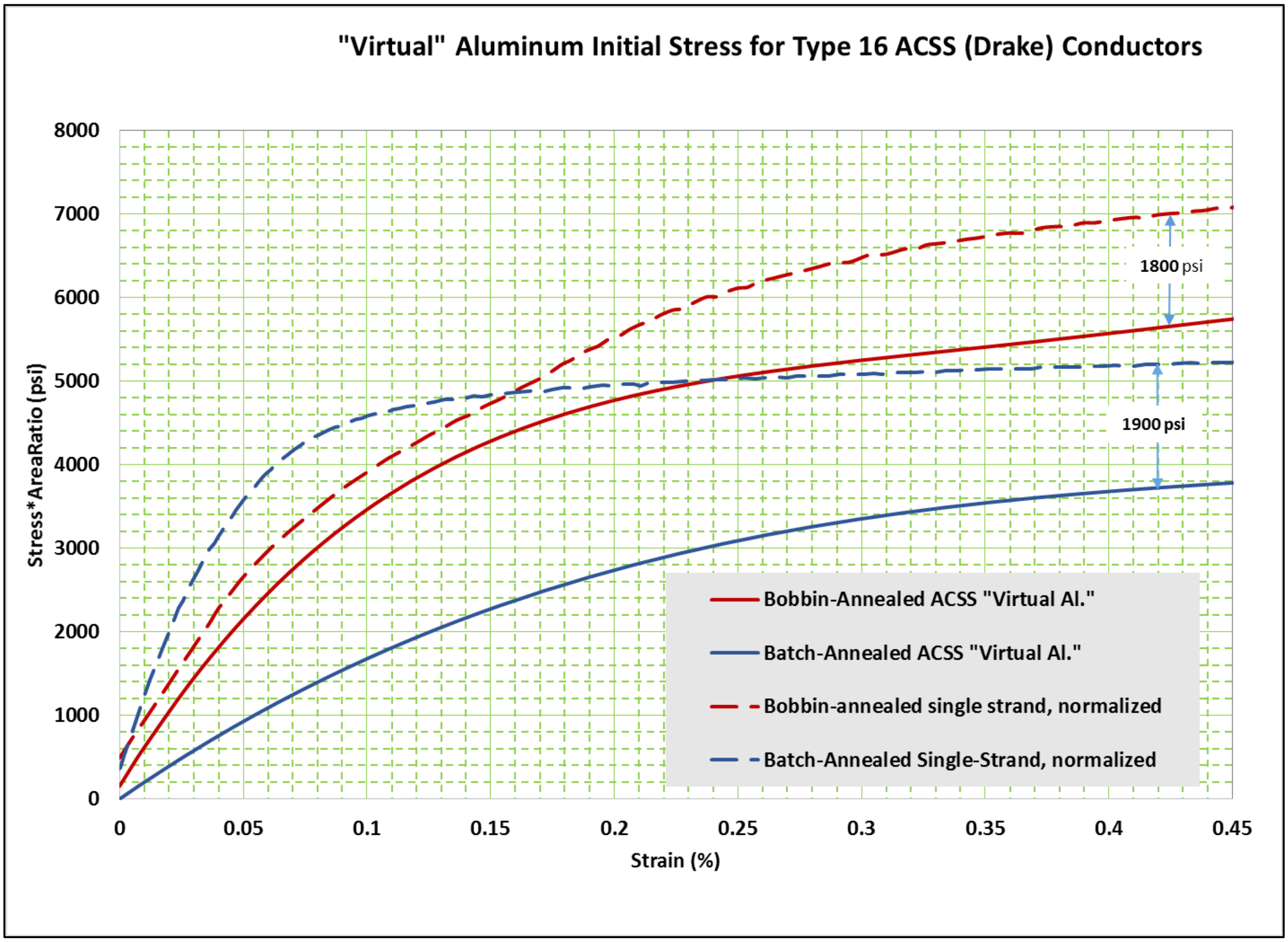

Figure 5: Comparison of "normalized" stress from tests on stranded conductor, and from tests on single strands removed from the same conductors

Sag and Tension Characteristics

The new Southwire stress-strain data is now available in Southwire SAG10 software, which can generate wir files for other line-design software packages. Performance comparisons in this report were modeled in SAG10 software, and can be easily verified by switching between "Legacy" charts and "Southwire Certified" charts for ACSS conductors. Line designs using Southwire conductor may use Southwire Certified charts with confidence. Southwire policy expressly forbids use of Southwire Certified data for line design if the conductor is from a different manufacturer.

Figure 6 shows the sag vs. temperature relationship computed for an 800-foot span in NESC medium loading district. The NESC tension limit is 25% RBS final at 15 °F (-9.4 °C). ACSS/HS285 and ACSS/MA5 have identical RBS, and therefore have identical NESC tension limits. The blue line reflects the Reynolds-process conductor performance. The green line shows the Southwire-process conductor performance.

ACSS/HS285 demonstrates a two-foot sag advantage because partly re-hardened aluminum strands in the Reynolds-process conductor carry a greater share of the tension, and contribute more to thermal sag increases. The Southwire process ensures the aluminum carries only minimal tension, and that allows the lower-expansion steel to limit the sag as the temperature increases. The thermal knee point at final condition is approximately 5 °C for ACSS/HS285, versus 30 °C for Reynolds-process ACSS/MA5.

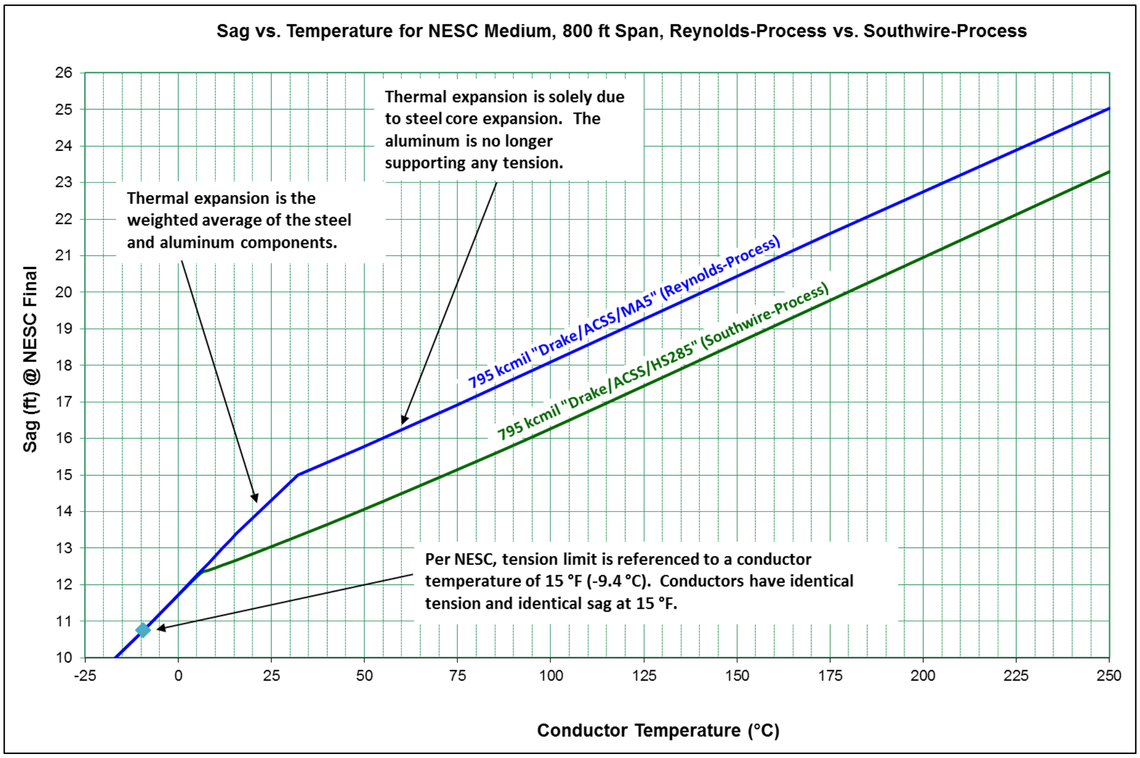

Figure 6: Sag vs. temperature chart for ACSS/HS285 and ACSS/MA5

Table 2 compares the sag performance for different span lengths. Regardless of span length, Southwire HS285 demonstrates less high-temperature sag. Table 2 also shows the sag under the medium ice load. It is identical in this case, but note that extreme ice loads and low-core-fraction conductors can show an advantage for Reynolds-process ACSS because the aluminum yields at higher tension, and therefore helps to support the ice weight. Note, however, that in all cases, the thermal sag far exceeds the loaded sag, and the structures must be sized for the greater thermal sag.

Figure 7 shows the Southwire-process ACSS/MA3 compared to Reynolds-process ACSS/MA5.

Despite a 16% difference in allowable stringing tension, Southwire ACSS/MA3 closely matches the thermal sag of Reynolds-process ACSS/MA5.

Conductor: 795 kcmil 26/7 "Drake/ACSS/MA5", NESC "Medium" (0.25 in ice plus 4 psf wind at 15 °F)								
	400 ft Ruling Span		600 ft Ruling Span		800 ft Ruling Span		1000 ft Ruling Span	
	Sag @ 250 °C (ft)	Sag@NESC Medium Ice (ft)	Sag @ 250 °C (ft)	Sag@NESC Medium Ice (ft)	Sag @ 250 °C (ft)	Sag@NESC Medium Ice (ft)	Sag @ 250 °C (ft)	Sag@NESC Medium Ice (ft)
Reynolds Process	10.9	3.9	17.5	8.2	25.0	13.7	33.5	20.5
Southwire Process	9.8	3.9	16.1	8.2	23.3	13.7	31.5	20.5
Difference (ft)	1.1	0.0	1.4	0.0	1.7	0.0	2.0	0.0
Difference (%)	-10%	0%	-8%	0%	-7%	0%	-6%	0%

Table 2: Comparison of the sag performance for Reynolds-process and Southwire-process ACSS

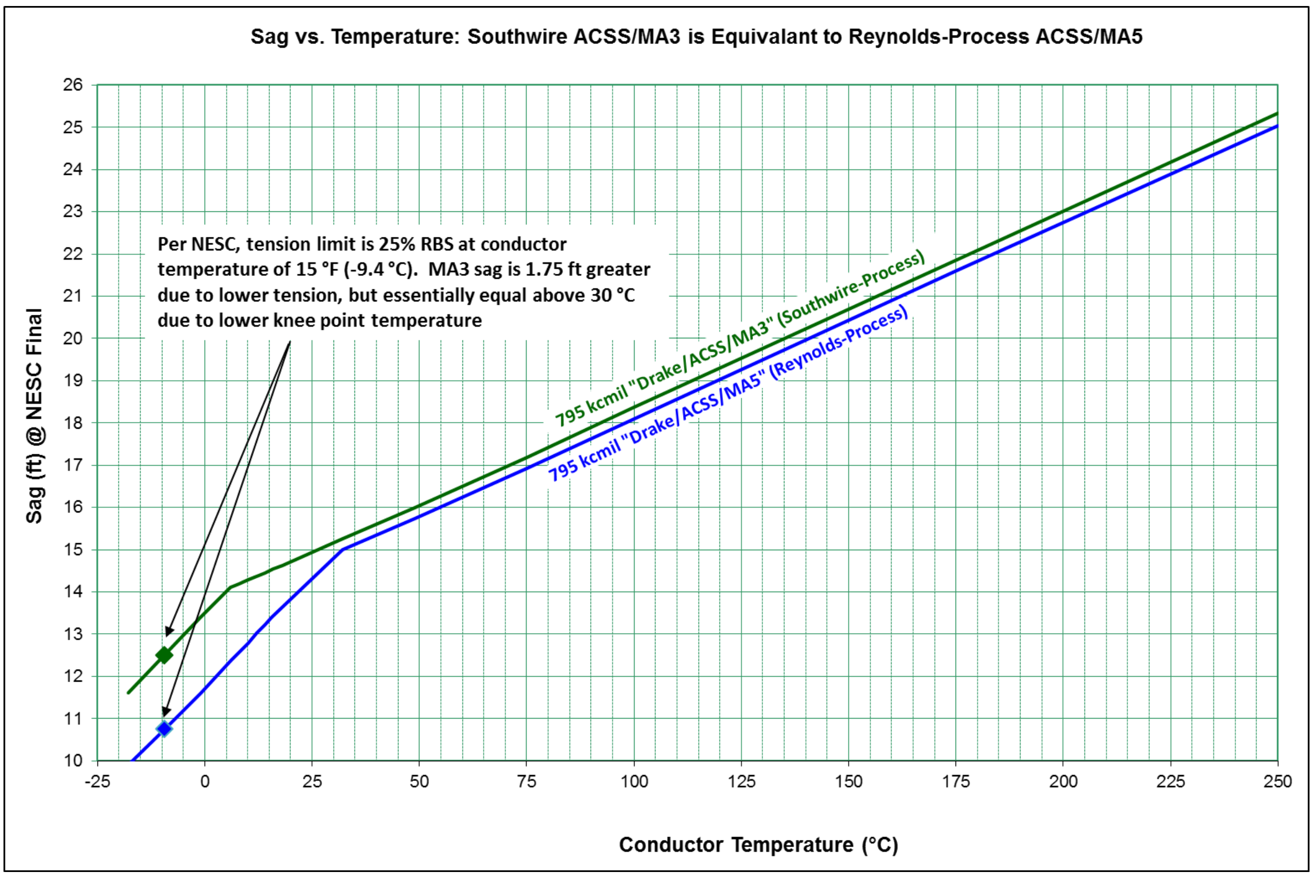

Figure 7: Sag vs. temperature chart for Southwire-process ACSS/MA3 and Reynolds-process ACSS/MA5

Data for SAG10 software and PLS-CADD software are shown below:

SAG10® Chart and Stress-Strain Plot:

Figure 8, SAG10 coefficients and plot of sag-tension data

PLS-CADD® wir file (from SAG10 wir file generator):

TYPE='CABLE FILE' VERSION='8' UNITS='US' SOURCE='Southwire's SAG10® Software' USER='Southwire' FILENAME='795.0 kcmil 26-7 ACSS Drake-ACSS-HS285.wir'

795.0 kcmil 26/7 ACSS "Drake/ACSS/HS285" - Data herein is to be considered confidential and proprietary to Southwire and is for the use in association with Southwire products only.

0 0
0.7263
1.108
1.093
32600
DATA ON THIS LINE IS NOT USED
0 20470 -40000 31605 -5100
0 20470 -40000 31605 -5100
68565
0.00128
0 38037 8235 -12025 0
0 38037 8235 -12025 0
38862
0.00064
71
0 ; num_pts
1 ; cable_file_type
0.1135 0.2150 77 482 0.5 0.5 173.9 39.9 0 0
1
0

Notes on Conductor Coefficients

There are commercial issues related to conductor coefficients. Engineering due diligence includes knowledge of the provenance on any data used for overhead line design. Southwire Certified Data is provide only after a rigorous process. There are no disclaimer statements in data labeled as Southwire certified. Southwire's lawyers have determined that not only is this acceptable, it is desirable. These are typical sources of data for conductor models:

Aluminum Association Consensus: In 1961, the Aluminum Association published "stress-strain-creep curves for Aluminum Overhead Electrical Conductors". The most recent affirmation is dated 1996. Data was sourced from several manufacturers. While the data is of excellent quality, most dates from before 1970, and does not reflect changes in manufacturing since that time. The Aluminum Association data does not include any ACSS or other HTLS conductors.

Alcoa Legacy: Alcoa SAG10 software included a conductor library based on their judgement of the best available conductor data. Alcoa used both in-house and 3rd party data. Alcoa Legacy data is limited to conventional conductors, and most of the data dates from tests run before 1970. The same data appears in a public-domain on-line site, and is called "Generic Non-Linear". Southwire SAG10 software lists "Legacy" as an option for most conductors. Legacy data should be used for historical reference on lines designed using this data. Recent testing by Southwire has confirmed the ACSR legacy data is reasonably close to data from recent production. However, new line designs should use manufacturer-verified data to ensure the most accurate sag and tension predictions.

Reynolds Legacy: Reynolds Aluminum developed ACSS conductor in the early 1970s. Reynolds ran tests and published stress-strain data for use in designing overhead lines using ACSS conductors. Alcoa included the Reynolds data in SAG10. Reynolds legacy data is listed on the PLS-CADD web site in the Southwire folder. Reynolds did not include creep data. Their engineering opinion was that, for ACSS, load events always govern the final sag. This created a problem when the 2016 NESC added a requirement to consider only creep for the conductor tension limits. It has therefore become necessary to run creep tests and add creep data for ACSS conductors. Independent testing by Southwire has confirmed the Reynolds information is valid for all bobbin-annealed (Reynolds-process) ACSS conductors. As discussed in this report, Reynolds legacy data is not suitable for Southwire ACSS manufactured after 1994, when Southwire developed the batch annealing process.

Manufacturer Verified: Southwire will accept manufacturer-verified data for SAG10 software provided the provenance is known. Southwire disclaims responsibility for data from other manufacturers, but has no reason to believe there are problems. Southwire, in some cases, will classify its own data as Manufacturer Verified if the certification process is incomplete, but we have no reason to believe there are problems with the data, and there would be only minor if any change before it was certified. To date, only 3M and Fushi Copperweld have provided data for SAG10 software.

Southwire Certified: Southwire recognized that reliability and safe ground clearance called for a higher standard for conductor data. Accordingly, a documented process was developed with a goal of certifying data as being vetted to the highest available standard. The analysis includes testing at an ISO 17025 accredited (QA for safety-related data) laboratory. The data is independently error-checked, and cross-checking using data from multiple Southwire manufacturing lines. The new data is cross-checked against legacy data to determine if there are major differences. Multiple data sources are then modeled for the best fit matching current Southwire production. The data provenance is preserved in archived test reports, which can be provided upon request. Southwire Certified data is provided with SAG10 software, and is available on request from the Southwire web site. For protection of the IP, Southwire Certified data is not available from uncontrolled sources. For engineering and corporate governance reason, Southwire expressly prohibits use of Southwire Certified data for competitor products.

Vibration Performance

In-service vibration levels depend on the local climate, local terrain, conductor tension, and conductor self-damping. If the vibration level is predicted to be above a safe level, bolt-on Stockbridge dampers from reputable suppliers are effective protection for single conductors. Spacer/dampers from reputable suppliers are effective protection for bundled applications.

Figure 9 shows Southwire data comparing the self-damping of ACSS and ACSR conductors. These results are typical: at final sag, Southwire ACSS has ~10X more damping than ACSR in the low frequency range, and ~100X more damping than ACSR in the upper frequency range. It is generally accepted in the industry that ACSS conductors are self-damping at final sag.

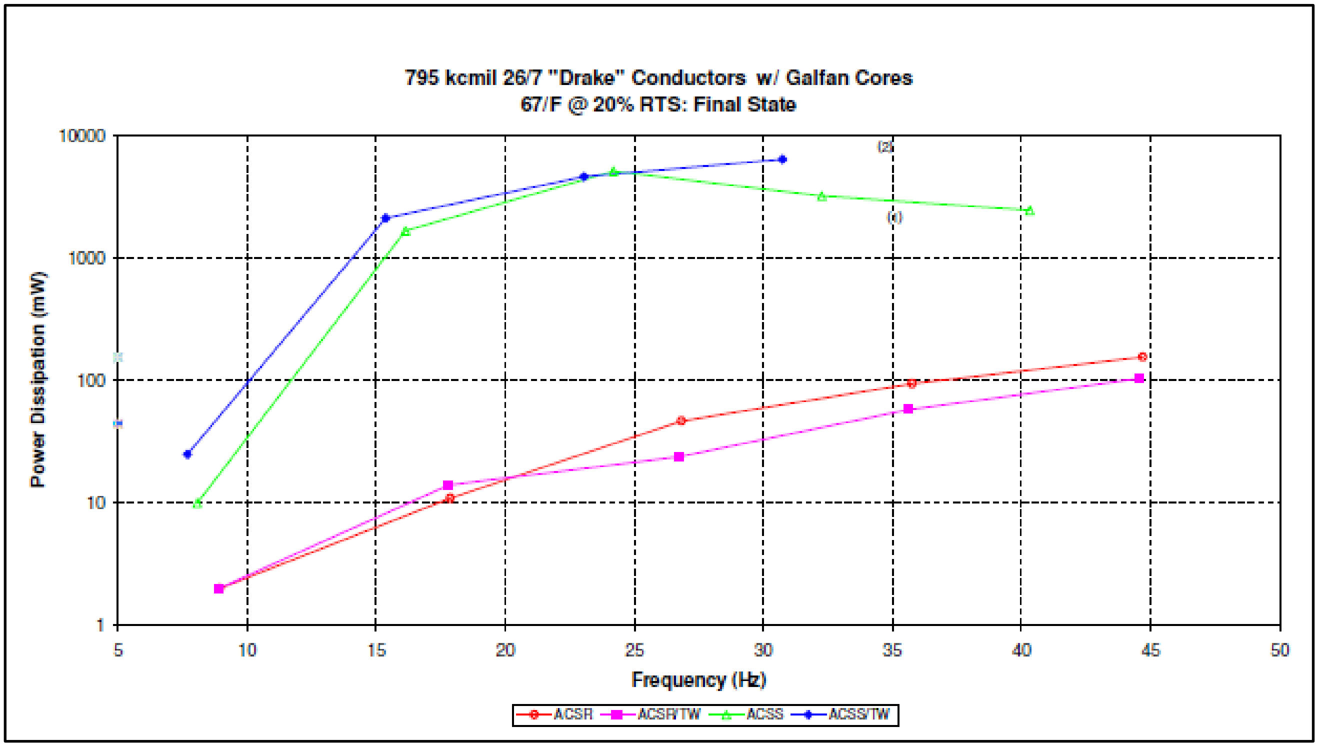

Figure 9: Self-damping data for ACSR and ACSS conductors

A concern for ACSS is vibration damage occurring before the aluminum strands relax and provide enhanced self-damping. Accordingly, it is a common engineering practice to specify dampers to guard against conductor fatigue during the time the conductor is at initial condition. Southwire's stress-strain data shows the batch-annealing process allows the aluminum strands to creep far more rapidly than the partially strain-hardened aluminum strands from the Reynolds bobbin-annealing process. A close examination of Figure 2 shows the batch-annealed aluminum does not exhibit an initial linear-elastic region, and that the yield stress is about 20% lower.

Research is underway to examine the early-life ACSS self-damping to determine if Southwire ACSS can be considered a self-damping conductor. Testing is still underway. Preliminary results suggest Southwire-process ACSS is self-damping within a day of installation.

Fatigue Endurance

Most metals exhibit an endurance limit, which is the vibration level where fatigue damage becomes a concern. Fatigue endurance of the HS285 steel was evaluated by the Georgia Tech Research Institute (GTRI) using a torsional fatigue test on single strands. HS285 core demonstrated higher fatigue endurance than standard steel core. Fatigue tests were also run on completed conductor comparing ACSR, ACSS, and TW versions. In all cases, the fatigue breaks are in the aluminum strands with no recorded breaks of a steel core strand. Test reports are available.

Corrosion Life

Mischmetal coatings for steel were introduced in 1981 by a European consortium, the International Lead Zinc Research Organization (ILZRO). The original brand name was Galfan®, which is a French contraction for GALvanized FANtastic. Bezinal® is another brand name for mischmetal coating. Mischmetal coated steel has earned a formidable reputation for long-life in outdoor applications including highway guardrails exposed to road salt.

The technology was developed for conductor core in a joint development between Southwire and our core steel alliance partner. Industry corrosion testing shows that a Class A (standard thickness) mischmetal coating exceeds the corrosion protection of a Class C (thickest) hot dip coating. Mischmetal coatings rival Alumoweld® in general corrosion, and far exceed Alumoweld for damage tolerance. All zinc coatings are to some degree self-healing as the zinc surrounding a scratch provides galvanic protection for the damaged area. A breach of an Alumoweld coating is catastrophic as the aluminum is not chemically active and does not provide galvanic protection to steel. Figure 10 shows industry data on the relative corrosion protection of steel coatings.

Figure 10: Industry data showing relative corrosion performance of Galfan (misch metal) and other coatings

Compare Galfan to other coatings

5 = Best 1 = Worst

	Galfan	Hot-Dipped Galvanized	Electro-galvanized	Galvanneal	Galvalume	Aluminized
Formability	5	3	5	3	3	2
Corrosion Resistance (bare)	4	3	3	2	5	5
Sacrificial Protection	5	5	5	5	3	1
Corrosion Resistance (formed)	5	3	3	3	3	2
Paint Adhesion	5	4	5	5	4	2
Corrosion Resistance (painted)	5	4	4	5	3	3
Weldability	4	4	5	5	2	1
Heat Resistance/Reflectivity	3	3	3	2	4	5

Heat Tolerance

High-temperature operation of all-aluminum and ACSR conductors is limited by concerns over annealing (softening) and loss-of-strength of the aluminum strands. Fully-annealed aluminum used for ACSS eliminates any concerns over further annealing. 1350 O-temper aluminum is not further degraded by exposure near its melting point of approximately 630 °C.

Hot-dip zinc coatings used for standard steel core are subject to increased corrosion due to exposure of approximately 150 °C. . Hot-dip zinc coatings flake off after brief exposure at 325 °C as shown in Figure 11.

The steel core tolerates extreme temperatures with only modest loss-of-strength due to minor stress-relief of cold work from steel wire drawing.

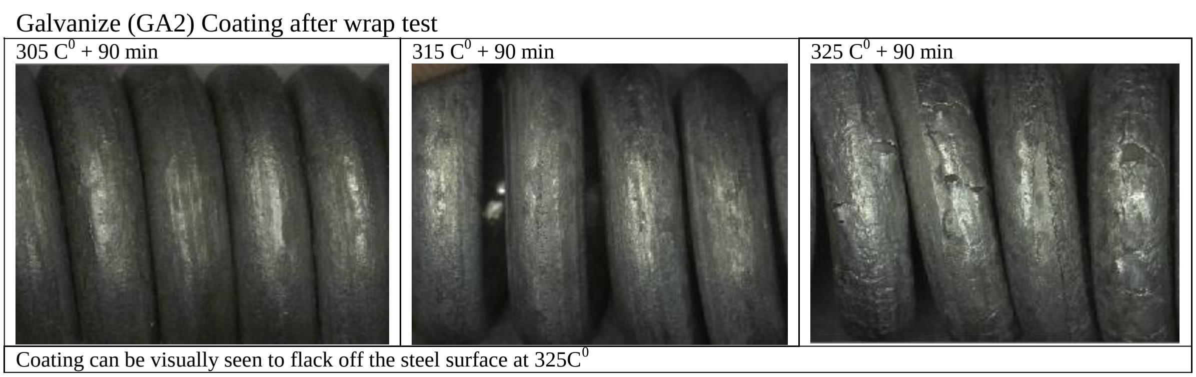

Figure 11: Adhesion test following high-temperature exposure of hot-dip zinc coating

Mischmetal coatings are chemically stable during and after long-term exposure to 330 °C, and tolerate exposure up to 380 °C. The thermal limit is the melting point of the alloy at 390 °C. See Figure 12 for adhesion test on mischmetal coated steel core strand.

Galfan Coating after wrap test

305 C^0 + 90 min

325 C^0 + 90 min

370 C^0 + 90 min

380 C^0 + 90 min

390 C^0 + 90 min

No coating flack off after the wrap test even at the coating melt point. However, coating does start to melt at 390C^0

Figure 12: Adhesion test following high-temperature exposure of misch metal coating

Testing

The table below summarizes the design tests, type tests, and production tests performed on ACSS/HS285 conductors. The true test is in the real-world, where ACSS/HS285 has been in service since 2005. To date, there are no conductor failures, and no evidence of corrosion despite installation in industrial zones along the seacoast.

Test	Applicable Standard	Summary of Test Procedure	Summary of Result
Routine production tests	ASTM B958 plus Southwire's strength margin to compensate for steel annealing due to high-temperature exposure.	Dimensions Coating weight Coating adhesion Tensile/elongation after-annealing) Mandrel wrap (after annealing)	Routine/production tests are performed by the steel supplier. Southwire tests the steel core after the conductor annealing process to ensure the heat exposure does not degrade the properties below MA5 requirements.
High-temperature aging test for core strands	Southwire internal requirement	Tensile test and coating adhesion test are performed after heat aging	Lot is rejected if coating degrades or HS285 tensile strength is not demonstrated after heat aging

Chemical exposure test	Industry literature	Standard chemical resistance is published by Galfan	Expect 2X to 3X longer corrosion life than hot-dip class A coated core.
Tensile tests – single core strands	ASTM A370	Standard axial tensile pull	Pass
Tensile tests – complete 7-strand or 19-strand core	Southwire	Apply cast-resin lab terminations. Tensile is typically run at the end of the stress-strain test	Pass
Tensile tests – full conductor	Cofer Center internal procedure	Apply cast-resin lab terminations. Tensile is typically run at the end of the stress-strain test	RBS or greater
Stress-corrosion cracking test	GTRI test to evaluate notch-sensitivity of HS285 strand compared to a GA2 steel strand	Wires were bent into a 4-inch diameter U-bend, and a notch was filed at the peak of the bend. The notch is monitored for cracking in a corrosive environment.	Resistance to stress-corrosion cracking is equal to excellent performance of GA2 steel core.
Charpy impact test	Per Charpy, a notched sample is fractured over a range of temperatures at high strain rate	GTRI modified the standard Charpy sample to permit testing of a single core strand.	HS285 is consistently tougher than GA2 core, with no distinct nil-ductility transition temperature.
Stress-Strain Test	ASTM draft standard based on Aluminum Association guide	Conductor & core put through load sequence. Data used to predict sags & tensions across full range of expected operating temps and ice/wind loads.	SAG10 data
AEP Sequential Mechanical Test (torture test)	Per AEP's published test description.	Sheave test (30 passes) Galloping test (100,000 cycles, high amplitude) Aeolian vibration test (100,000,000 cycles) Cyclic loading test (11 cycles with hold periods)) Residual strength test (pull to break)	PLP fittings system: Pass – exceeded RBS
Fatigue test – individual strand	MTS Servo 20K torsional fatigue machine	±35° twist over a 4 inch length of single-strand. Standard GA2 strand also run for comparison	HS285 strand demonstrates superior fatigue endurance

Fatigue test – overall conductor	IEEE 1138	100,000,000 vibration cycles with the conductor held in commercial hardware	In all cases, the aluminum outer strands fatigue before any damage to the steel core
Self-damping	IEEE 573	Self-damping is compared to comparable ACSR conductors	Southwire ACSS process demonstrates 10X greater self-damping at low frequency, and 100X greater damping in the upper frequency range.

Performance Map for ACSS/HS285 and Alternatives

Every transmission line design is customized for the line route, power delivery needs, and numerous other engineering and non-engineering constraints. A performance map is provided to show the relative position of ACSS/HS285 in the HTLS conductor market. The following admittedly hand-picked ground rules were applied to this evaluation. Other constraints can favor other conductors, but this example is considered representative:

- A 795.0 kcmil ACSR "Drake" circuit needs to be up-rated to 1700 amp continuous, with no increase in structure loading. "Nip and tucks" are available at modest cost to allow an additional two feet of sag compared to the maximum ACSR sag at 100 °C.
- Round-wire conductors only - no TW conductors considered
- Ruling span is 800 feet, in NESC "Medium"

Constraints based on ACSR "Drake":

1. Maximum conductor tension: 10,876 lb (initial loaded tension for ACSR "Drake")
2. Maximum sag is: 22.29 ft ("Drake" sag at 100 C is 20.29 ft)

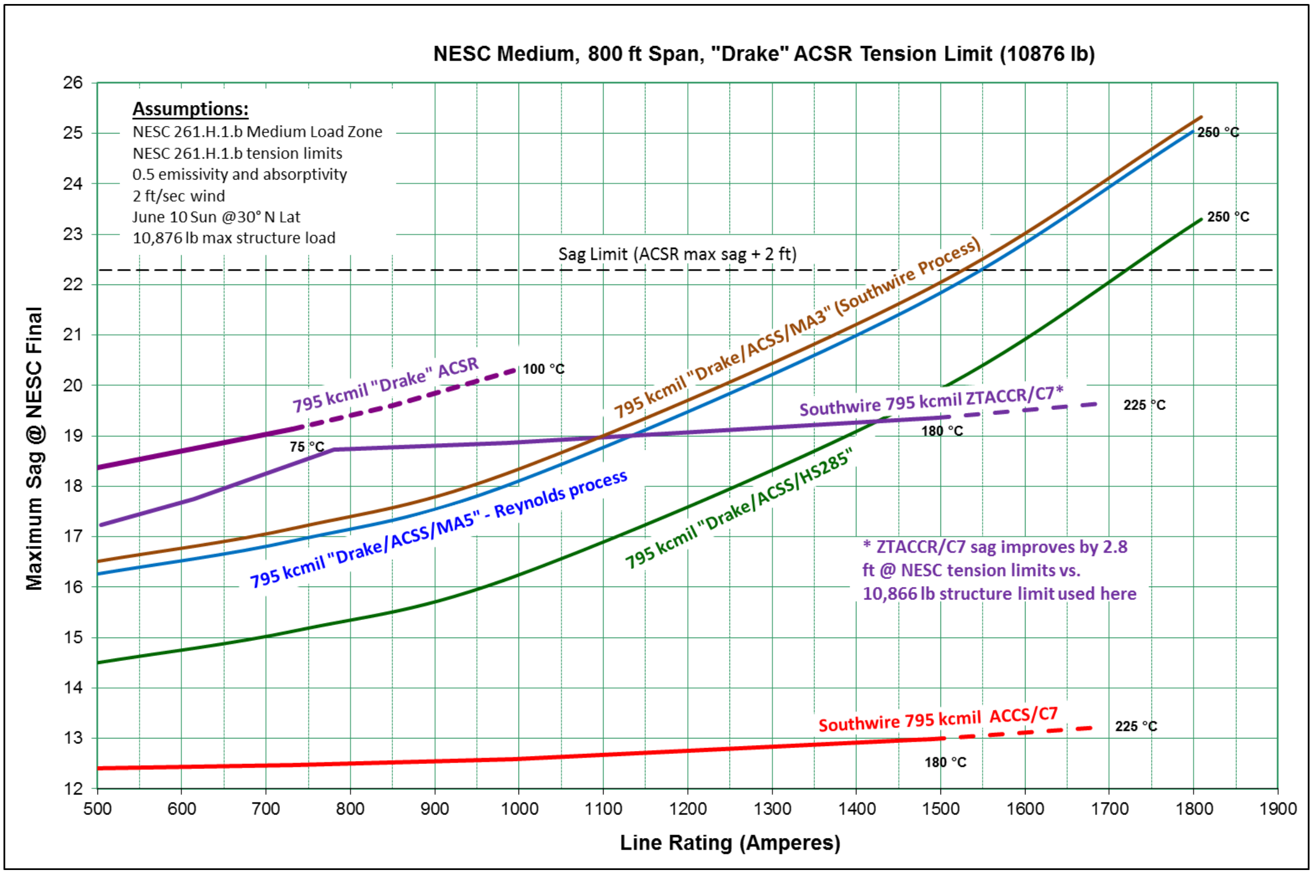

Figure 13: performance map for same-size as ACSR “Drake”, reconductor options

In this conductor selection example, Southwire ACSS/HS285 (green line) meets the 1700 amp target with ground clearance to spare. Reynolds-process ACSS/MA5 (blue line) requires an additional two feet of sag mitigation. Southwire ACSS/MA3 (brown line) performance is comparable to Reynolds-process ACSS/MA5. The two conductors with carbon fiber composite core (Southwire ZTACCR/C7 and Southwire ACCS/C7) excel at high-temperature sag, but do not meet the ampacity requirement due to lower thermal limits than ACSS.

Southwire ACSS/HS285 vs. Conventional ACSS/MA5

- Objective test data (see Figure 13) positions ACSS/HS285 in a class by itself, between the ultra-low-sag composite core conductors and the conventional ACSS/MA5 conductor. For additional reference, Southwire ACSS/MA3 has comparable high-temperature sag to the conventional Reynolds-process ACSS/MA5, despite 16% lower stringing tension for ACSS/MA3 (brown curve in Figure 13).

- Southwire ACSS, including ACSS/HS285 has better self-damping than Reynolds-process ACSS, due to more complete annealing of the aluminum strands.

- Southwire ACSS, including ACSS/HS285 has tighter stranding, because ACSR strander settings are used. Stranding soft aluminum requires lower strand tensions, and results in looser stranding. Loose stranding leads to bird cages and increased likelihood of installation issues.

- Properties for Southwire ACSS are measured *after* manufacturing, and strength ratings are met *after* heat exposure. Production tests on Reynolds-process ACSS are *before* stranding and *before* in-service heat exposure. Ratings for Reynolds-process ACSS do not account for loss-of-strength due to in-service heat exposure.

- Full-range "Southwire Certified" stress-strain data is provided for Southwire ACSS including ACSS/HS285. Others use Reynolds-legacy test data from the 1970s. The Reynolds data does not cover the full ACSS/MA5 tension range. "Extrapolated data", a temporary patch in SAG10 Software, is needed to design lines using publically-available MA5 conductor coefficients.

- Southwire has a comprehensive library of test reports documenting the development of ACSS/HS285 as an engineered system. MA5 is a mash-up of available ASTM materials with no comparable history of development and testing.

Economic Implications of the Southwire ACSS Sag Advantage

Price premiums charged for HTLS conductors are justified by cost savings in structures and right-of-way. In our example, 795.0 kcmil ACSS/HS285 in an 800-foot span has two (2) feet less sag than Reynolds-process ACSS/MA5. With structure optimization and/or optimized structure spacing, the sag advantage translates into structures that are, on average, two feet shorter or optimally-placed in such a way that similar cost benefit is achieved through fewer structures. Tower height is added or removed from the base and possibly from the foundation. A conservative estimate of the incremental structure cost in the typical size range is $1000 per foot. By simple logic, the 2 feet sag difference is worth $2000 per span.

If a Reynolds-process ACSS/MA5 meets the line design requirements, a Southwire-process ACSS/MA3 provides equal performance. Purchasing conductor on first cost with no consideration of non-conductor cost impacts is ill-advised.

Safety and Installation

See Southwire's ACSS Installation Guide for specific instructions. ACSS/HS285 does not introduce any new safety risks into overhead line construction, maintenance, or operation.

Environmental

Southwire is committed to environmental stewardship. All Southwire manufacturing sites have achieved zero landfill status or are on a near-term schedule to reach zero landfill status. ACSS/HS285 production has the same environmental footprint as ACSS. The difference relative to ACSR is the natural gas consumed during the annealing process.

Energy consumed by conductor manufacturing is a negligible component of the carbon footprint of an overhead conductor. By far the greatest energy consumption by a transmission conductor is the line loss during 50 or more years of operation. Southwire's ACSS conductors exceed the industry standard for conductivity, which means that for equal conductor size, Southwire ACSS conductors exhibit lower line losses. Choosing a conductor with the greatest aluminum area is another effective strategy for reducing line loss. HS285 steel core can be smaller for the same strength rating, and thereby allow for reduced line loss from a correspondingly greater aluminum area.

For environment-friendly packaging, Southwire offers several options, including new and innovative packaging directed at reducing landfill waste and improving recycle options for packaging materials. Steel reels are re-used, and the steel is recycled when the reels are worn out or damaged. For protective wrapping, Southwire has introduced a polymer wrap that is 100% recyclable. To avoid the use of razor knives to remove the wrapping, a fabric rip cord connected to an easy-to-find "Rip Chip" plastic pulling disc is incorporated in the wrap to allow for no-tools, easy removal of the protective wrapping.

Lubricants used for wire drawing are recycled. When lubrication is needed during stranding operations, Southwire uses a "disappearing oil" designed for minimal environmental impact.

Additional details on the Southwire environmental, sustainability and other corporate governance programs can be found on the Southwire website at www.southwire.com

Quality

Southwire is, deservedly, world-renown as the quality and technology leader in overhead conductors. All Southwire manufacturing locations, the Corporate Offices, labs, and R&D center are accredited to ISO 9001. Corporate R&D, including the overhead conductor laboratory, are accredited to the stringent ISO 17025 Standard.

Operational Perfection at Southwire (OPS) is our long-standing program that drives all manufacturing operations to minimize waste, improve quality, and improve working conditions for all employees. A copy of the Corporate QA Manual is available upon request.

Successful quality management starts at the top of any organization, and carries through to all parts of the organization. Under the OPS program, equipment operators are relieved of all duties and are assigned to multi-week process-improvement initiatives. For example, operators have studied tedious and labor-intensive machine changeovers with assistance from manufacturing experts and engineers. A focus area is the development of ergonomic equipment changeovers that eliminate the need for tools. When tools are required, they are maintained within easy reach of the workspace to minimize lost time seeking tools or the hazards and quality impact from use of improvised tools.

Southwire sources its HS285 core from stable alliance partners. Quality and continuity of supply are paramount in alliance relationships. Stable supply relationships also lower costs due to improved business forecasts and assured supply. Steel supplier quality programs are accredited and audited by Southwire. A Certified Test Report (CTR) documenting the QC measurements, the acceptance criteria, and pass/fail status accompanies each reel of core strand. The steel core is traceable through the Southwire manufacturing process.

Similarly, Southwire provides a Certified Test Report (CTR) for each reel of conductor. All manufacturing-related requirements from the applicable ASTM Standards are documented by actual measurement. The CTR also lists the acceptance criterion, and pass/fail status.

The ACSS/HS285 design was qualified by exhaustive testing starting in 2002 and continuing to the present. A particular accomplishment is passing the AEP Sequential Mechanical Test. Test reports are available upon request.

A copy of Southwire's ISO 9001 Accreditation Certificate along with more details on our OPS approach to quality can be found on the Southwire website at www.southwire.com.

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