The Limitations of Compression Connectors on HTLS Applications — and the ClampStar Solution

A Research-Based Assessment for HTLS Overhead Transmission Lines

Prepared June 2026 · Based on peer-reviewed research, industry technical brochures, and certified laboratory test data

Technical Author: Carl Tamm, President, Classic Connectors USA — Former Chair, ANSI C119.7 Committee | Voting Member, CIGRE US National Committee & IEEE-PES TP&C and ANSI C119 Committees

Technical Author: Trisha Crawford, Design Engineer, Classic Connectors USA — Bachelor of Science in Mechanical Engineering, University of Alabama at Birmingham | Mechanical Design Specialist

Contributing Author: Chris Costanzo, Director of Market Development, Classic Connectors USA — Founding Member, 40-Year Electric Utility Industry Professional

Authors' Note: This paper synthesizes peer-reviewed ORNL/EPRI research, independent engineering analysis, and certified third-party laboratory test data to examine the limitations of compression connectors and composite core conductors in HTLS applications and presents the ClampStar solution that addresses these limitations. Carl Tamm's role as former Chair of the ANSI C119.7 Committee directly informed the framing of the standards gap discussion in Section 3.6.3. All source documents are listed in Appendix A and cited throughout.

Executive Summary

The North American transmission grid is undergoing a fundamental transformation. Driven by growing power demand and the practical impossibility of obtaining new right-of-way, utilities are reconductoring existing lines with High Temperature, Low Sag (HTLS) conductors capable of carrying significantly more current at significantly higher temperatures than the ACSR conductors they replace.

ACSS (Aluminum Conductor, Steel Supported), the original HTLS conductor, rated for continuous operation at 250°C, has proven through independent engineering analysis to be not merely adequate but in most cases superior to composite core alternatives, achieving up to 99% greater ampacity than Drake ACSR at a continuous temperature rating 70°C higher than competing composite core conductors. Advanced ACSS variants with ultra-high-strength and giga-strength steel cores, combined with high-temperature corrosion-resistant coatings, have eliminated the historical concerns about steel core performance and extended expected service life by decades.

Yet ACSS and all HTLS conductors share a fundamental weak point: their compression connectors, used for splicing and termination. Twenty years of analytical work at Oak Ridge National Laboratory (ORNL), corroborated by neutron diffraction measurements and physical pull-out tests, demonstrates that the compressive residual hoop-stress generated during crimping, the only gripping mechanism a compression connector possesses, sheds up to 95% of its peak value the moment the die is removed, a consequence of elastic spring-back. Thermal cycling at temperatures as modest as 125°C then strips away a further 92–95%. For ACSS conductors running continuously at 250°C, these two effects combine to render grip essentially nonexistent.

The soft, fully annealed aluminum stranding of ACSS further compromises the electrical interface from the moment of installation, producing fewer microscopic contact points and higher baseline resistance than an equivalent ACSR connector.

This failure mechanism is not unique to ACSS. Any HTLS conductor is subject to the same compression-connector hoop-stress degradation; both the rate and severity increase with operating temperature. Section 2 examines this in the context of a comparative performance assessment of available HTLS conductor types.

The Classic Connectors Thermo-Speed-Lock (TSL) connector family, validated by Kinectrics Inc. through 500 current cycles at 335°C, followed by an additional 500 cycles at 390°C under 35% RBS tension, resolves this problem at its root. By replacing the residual hoop-stress grip mechanism with a mechanically maintained keeper assembly secured by torque-limiting fasteners, the TSL connector eliminates thermal degradation of grip, installation error vulnerability, and the inspectability gap that makes compression connector quality impossible to verify after installation. Where compression connectors are already in service, the ClampStar engineered shunt provides a proven retrofit solution that restores electrical integrity without requiring a line outage.

> **Key Finding**
>
> Compression connector technology, unchanged in its fundamental operating principle for over 100 years, is physically unsuitable for HTLS service. The failure is not a matter of installation quality, connector size, or manufacturer selection. It is thermodynamic in nature, and no incremental improvement to the compression paradigm can overcome it. The TSL connector's departure from that paradigm is not an improvement; it is a necessary replacement.

1. Background: The ACSR-to-ACSS Transition

1.1 Why HTLS Conductors Are Being Deployed

The majority of overhead transmission lines currently in service were built using ACSR (Aluminum Conductor, Steel Reinforced), a conductor type designed for continuous operation at approximately 75°C and rated for short-term emergency operation up to 100°C. These temperature limits constrain the ampacity of a typical 230 kV line to approximately 400 MVA.

Growing power demand, combined with the inability of electric utilities to obtain new right-of-way for additional circuits, has compelled utilities to increase the ampacity of existing infrastructure. The two primary means of doing so are increasing line voltage, which requires taller towers and wider corridors, or increasing the current carried by existing conductors. The latter approach requires High-Temperature, Low Sag (HTLS) conductors that can operate at temperatures beyond the thermal limits of ACSR while maintaining acceptable sag characteristics.

ACSS (Aluminum Conductor, Steel Supported) is the original HTLS conductor, developed by Reynolds Aluminum in the 1970s. It is rated for continuous operation at 250°C. Unlike more recently developed HTLS conductors using carbon fiber or metal matrix composite cores, ACSS uses a conventional steel core, however the core of Advanced ACSS conductors utilizes higher-strength steel, commonly MA5 (Ultra High Strength, 285 ksi) and MA8, referred to as Giga Strength (310 ksi), allowing for higher ground clearance. An additional advancement is the use of improved corrosion-resistant coatings on the core wire, which have eliminated corrosion concerns at high temperature (250°C), extending service life by decades. The hard-drawn 1350-H19 aluminum stranding of ACSR is replaced on ACSS with fully annealed 1350-O (zero-temper) aluminum. This distinction is the source of every significant difference in how ACSS connectors must be designed and qualified.

1.2 Why ACSR Anneals and ACSS Does Not

The hard-drawn aluminum stranding of ACSR (1350-H19) derives approximately 70% of its tensile strength from the cold-working process used in its manufacture. When this material is heated above approximately 93°C for sustained periods, the crystalline structure begins to recrystallize, a process known as annealing, and the work-hardened strength is progressively lost. CIGRE Technical Brochure 905 ("Sustainability of Overhead Line

Conductors and Fittings," CIGRE Working Group B2.68, July 2023) provides quantitative annealing models (Morgan, CIGRE, and Goh equations) confirming that tensile strength reduction becomes significant above 95°C and accelerates rapidly at higher temperatures. This is the primary reason ACSR has a continuous temperature rating of 75°C with an emergency rating maximum of 125°C.

ACSS begins its service life with fully annealed aluminum stranding. Its tensile strength as a conductor is already at the post-anneal floor — nominally 8,500 psi tensile strength, compared to 23,500 psi for 1350-H19. Because it cannot anneal further, it is thermally stable at elevated temperatures. The steel core, which is unaffected by annealing at these temperature ranges, carries a majority of the conductor's mechanical tension above the knee point (knee point for ACSR is typically 70° to 90°C. ACSS is "steel-supported" because the knee point temperature is typically below 40°C.), allowing continuous operation at 250°C without sag penalty or mechanical degradation.

The consequence of this material difference for connectors is fundamental and is the central theme of this entire body of research.

2. ACSS as a Superior HTLS Conductor

2.1 Independent Engineering Assessment

Before examining the connector problem in detail, it is important to establish why that problem matters at the scale it does. An independent white paper by Paul Springer of Springer Power Consulting LLC, written for regulators, commission staff, utility planners, and design engineers, provides a rigorous engineering basis for understanding where ACSS fits in the HTLS landscape.

Applying transparent IEEE 738 thermal rating calculations, non-linear sag modeling, and like-for-like diameter comparisons, Springer's analysis establishes that ACSS/TW with high-strength steel core is not a legacy technology being displaced by newer alternatives, but rather a genuinely advanced conductor that in most cases equals or outperforms composite core conductors on capacity, structural resilience, and total owning cost. On a corrected, equal-diameter basis, ACSS/TW/MA5 achieves a 99% capacity increase over Drake ACSR, compared to a 69.5% increase for the leading composite core option, and it does so at a continuous operating temperature rating of 250°C, 70°C higher than the 180°C ceiling of composite core conductors.

That 70°C temperature differential is directly consequential to the connector integrity problem that is the primary subject of this report. Compression connector hoop-stress degradation affects both conductor types, but is considerably more severe at the higher operating temperatures that only ACSS can sustain. The full white paper is recommended reading for anyone involved in HTLS conductor selection and is available at: https://www.springerpowerconsulting.com/_files/ugd/8472d0_a58062a55e8b422b96bac4ea59990fec.pdf

It is worth noting that Springer has also observed that HTLS conductors are rarely operated at their rated maximum temperatures in practice, particularly on long-haul merchant transmission lines where energy losses at high current levels are economically prohibitive. On a 300 km, 230 kV line using 1033.5 kcmil ACSS/TW/MA5 conductor, delivery efficiency drops from approximately 92% at 1,000 A (64.9°C) to approximately 70% at 2,500 A (250°C), meaning that at rated temperature, roughly 30% of supplied energy is lost as heat. This is one reason all twelve current renewables mega-projects use conventional ACSR rather than HTLS conductors. However, this observation does not diminish the connector integrity concern that is the central subject of this report. The compression connector degradation documented by the ORNL research is cumulative and expressed in thermal cycles rather than hours at temperature. A line that reaches 200°C during fifty peak demand events per year, never sustaining that temperature continuously, will still exhaust its connector's compressive grip within a few years of service. For the significant number of HTLS reconductoring projects driven by right-of-way constraints rather than merchant revenue optimization, the thermal cycling argument remains fully applicable, and the connector problem remains unsolved until the compression paradigm is replaced.

2.2 The Connector Implication for All HTLS Conductors

While Springer's paper focuses on conductor selection, its findings establish a critically important point when read alongside the connector research reviewed in subsequent sections: the compression connector hoop-stress problem is not unique to ACSS. It affects all HTLS conductors, including those with composite cores rated at 180°C.

The physics of compressive residual stress relaxation under thermal cycling applies to any conductor operating at elevated temperatures. In all cases, the connector's grip is a thermally degrading residual stress artifact created during a one-time crimping event. In all cases, the connector tube alloy loses strength as operating temperature rises, thermal expansion reduces the contact force at the conductor-sleeve interface, and the compressive residual stress that provides the only available grip degrades toward zero. The ORNL data show that significant degradation is already occurring at 125°C to 150°C, well within the continuous operating range of composite core conductors. Section 5 documents empirical confirmation of this failure mode under rigorous third-party test conditions.

> **A Universal HTLS Problem**
>
> Any transmission line operating above the thermal ceiling of legacy ACSR, whether reconductored with ACSS, ACSS/TW, ACCC, or another HTLS conductor type, is subject to the same fundamental compression connector hoop-stress degradation mechanism, differing only in severity and rate as a function of operating temperature. At 180°C, compressive residual stress in a connector is already severely reduced. At 250°C, it is effectively zero.

3. Compression Connector Limitations

3.1 The Electrical Interface: How It Is Created and Why It Matters

When a compression connector is crimped onto a conductor, the clamping force applied by the hydraulic die set creates the electrical interface between the connector sleeve and the aluminum stranding. The quality of this interface, measured by its resistance, determines both the immediate electrical performance and the long-term thermal stability of the connection.

For ACSR conductors, the hardened 1350-H19 stranding (crush resistance: 23,500 psi) resists the inward displacement of the connector bore. This resistance forces the connector material to deform around the stranding, fracturing the aluminum oxide layer on both surfaces. The resulting high compressive forces generate numerous microscopic contact points known as asperities, where bare metal-to-metal contact exists. These are the low-resistance pathways through which electrical current crosses the connector-to-conductor interface.

For ACSS conductors, the fully annealed 1350-O stranding (crush resistance: 4,000 psi) cannot resist the advancing connector bore. Instead of creating the mechanical interaction that generates asperities, the strands simply extrude out from beneath the compression zone. The result is significantly fewer asperities, a substantially higher interface resistance, and a connection that is electrically compromised from the moment it is installed. This behavior also produces the bird-caging commonly observed at ACSS compression connectors, as the extruding strands protrude radially beyond the normal conductor cross-section.

3.2 The Hoop-Stress Problem

The Wang et al. FEM (Finite Element Model) work, which required 27 hours on one of the world's fastest supercomputers at the time to solve, provides precise quantification of what compressive residual stress actually remains in a connector after the die set is removed. The results are striking: upon die closure, the compressive stress at the conductor section interface ranges from approximately 33,100 to 37,100 psi. After die removal, when the hoop-stress relaxes elastically, the remaining residual stress falls to between 1,700 and 6,700 psi. This represents a retention of only 5.13% to 18.05% of the peak crimping stress.

This is the grip available at ambient temperature, before any thermal cycling has occurred. Every subsequent thermal cycle further reduces this already marginal compressive residual stress field. The connector begins its service life with less than one-fifth of the stress it experienced during crimping, and this fraction continues to decline throughout its operational life.

3.3 Thermal Cycling Degradation: The ORNL Findings on ACSR

Parameter	Value / Finding
Peak stress at die closure (conductor section)	33,100 – 37,100 psi
Residual stress after die removal	1,700 – 6,700 psi
Residual stress retention	5.13% – 18.05% of peak
TSC conductor section: force loss at 200°C heat-up cycle	92% (heat-up), 94% (cool-down)
SSC conductor section: compressive force at 150°C (full tension)	Near zero
SSC core-grip: complete force loss	At approximately 300°C, heat-up cycle
TSC core-grip: retains significant compressive force	Up to 450°C

The Wang et al. research series, conducted at ORNL (Oak Ridge National Laboratory) with support from EPRI (Electric Power Research Institute) and DOE (U.S. Department of Energy), developed a comprehensive analytical and experimental protocol for evaluating the lifetime of ACSR splice connectors under thermal cycling. The key findings, applicable to both SSC (Single Stage Connector) and TSC (Two Stage Connector) types, are as follows.

3.3.1 The Conductor Section Fails First

FEM thermal cycling simulations consistently show that the conductor section of a splice connector loses its compressive clamping force far more rapidly than the core-grip section. Under full-tension loading, the conductor section of both SSC and TSC systems begins to show significant compressive stress reduction when thermal cycling temperatures reach 125°C to 150°C. By 200°C, the TSC conductor section has lost 92–94% of its initial compressive force. The conductor section acts as the temperature driver; its rapid degradation causes the connector surface temperature to rise, while the core-grip section is the primary structural anchor that retains the conductor cable at higher temperatures.

3.3.2 The Critical Role of Tensile Loading

A critical finding of the ORNL research is that thermal cycling without tensile loading shows substantially less degradation than the same thermal cycling with tensile loading applied. Simulations without tension show no significant compressive strength reduction until 250°C, while simulations with tension (25% RBS) show 92–95% reduction at 100–125°C. This means that laboratory testing without representative conductor tension dramatically underestimates in-service degradation, a finding with direct implications for standards development, as existing ANSI C119.4 testing does not require representative tensile loading.

3.3.3 The TSC Significantly Outperforms the SSC

The direct SSC vs. TSC comparison reveals a critical structural advantage of the two-stage design for ACSR applications. The principal reason is the material used for the core-grip section: the SSC uses an aluminum core-grip to clamp the steel core, creating a thermally mismatched interface, while the TSC uses a steel fitting sleeve to connect the steel cores, a far more thermally stable arrangement. The SSC core-grip section loses its compressive force completely at the 300°C heat-up cycle, while the TSC core-grip section retains significant compressive stress up to 450°C. Pull-out testing of TSC systems consistently resulted in failure of the conductor wire rather than the connector, confirming the connector's structural superiority on ACSR conductor. It is important to note that while the TSC significantly outperforms the SSC for ACSR applications, neither compression connector type, SSC or TSC, provides adequate performance for ACSS conductors operating at their rated temperature of 250°C, where the thermal degradation mechanism documented in this section reduces compressive grip to effectively zero regardless of connector design.

3.3.4 Lifetime Predictions for ACSR

Combining the FEM thermal cycling simulation results with a governing equation for the frequency-dependent splice surface temperature, the ORNL team derived the following effective lifetime predictions for a standard 600-ft span ACSR Drake conductor system:

Parameter	Value / Finding
100°C conductor operating temperature (SSC)	~27,850 thermal cycles (~38 years)
125°C conductor operating temperature (SSC)	~3,100 thermal cycles (~4.2 years at 2 cycles/day)
150°C conductor operating temperature (SSC)	~550 thermal cycles (~9 months at 2 cycles/day)
Any temperature up to 300°C (TSC)	Shear resistance remains well above service tension through 5,000 cycles

These findings confirm that even for ACSR, where the initial electrical interface quality is far superior to ACSS, the SSC design is unsuitable for sustained operation above 100°C. The implications for ACSS, which is rated for continuous operation at 250°C, are severe.

3.4 Current Localization: An Additional Failure Mechanism

The Classic Connectors analysis introduces an important failure mechanism not addressed in the ORNL analytical papers: the localization of electrical current transfer within a compression connector. This phenomenon operates regardless of whether the connector is installed on ACSR or ACSS.

Because the connector tube presents lower electrical resistance than the conductor itself, current transfers from the outer strand layer to the tube at two discrete zones: the mouth of the connector (where approximately 70–80% of the current transfers) and deep within the connector at the terminus of the conductor strands (where the remainder transfers). Between these two zones, there is essentially no current transfer, because there is no voltage differential across the strand-to-tube interface in the middle section of the connector.

The thermal energy generated at these current transfer zones, particularly at the high-current mouth zone, is calculated to reach 300°C to 400°C at the microscopic asperities, far exceeding the nominal conductor operating temperature. This localized overheating accelerates the degradation of the interface and the relaxation of residual compressive stress at precisely the locations where that stress is most critical. It also explains why making longer connectors for ACSS provides no inherent electrical benefit: the middle section of the connector carries no current, so additional length only delays the same ultimate failure.

3.5 Material Strength Loss at Elevated Temperature

Independent of connector-specific mechanisms, the aluminum alloys used in connector construction lose significant strength at elevated operating temperatures. Data for the 3003-H14 alloy (used by both major ACSS connector manufacturers under slightly different temper designations) shows ultimate tensile strength reductions from 21,800 psi at 25°C to 13,900 psi at 200°C (63.7% of baseline) and to only 4,210 psi at 300°C (19.3% of baseline). Yield strength at 300°C falls to just 11.7% of its ambient value.

For ACSR connector materials at 260°C, the ORNL thermomechanical testing measured strength reductions of: 1350-H19 conductor: 77%; 3003-H183 sleeve: 67%; 6061-T6 core-grip: 45% (60% with 10-hour thermal hold). These strength losses compound the loss of compressive residual stress, as the connector material becomes increasingly unable to maintain the clamping force that was induced during crimping.

3.6 ACSS-Specific Connector Challenges

3.6.1 The Electrical Interface Deficiency

As established in Section 3.1, the compression of an ACSS connector produces fundamentally fewer asperities than the compression of an ACSR connector, because the fully annealed 1350-O stranding flows plastically out of the compression zone rather than resisting the connector bore. This electrical interface deficiency exists from the moment of installation; it is not a consequence of thermal aging. ACSS compression connectors, therefore, begin their service life with a higher baseline electrical resistance and fewer, lower-quality contact points than equivalent ACSR connectors, leaving a critically reduced margin before thermal runaway occurs. Empirical confirmation of this failure mode is provided in Section 5.

3.6.2 Bird-Caging

Bird-caging, the protrusion of outer-layer strands beyond the normal conductor cross-section, is a direct consequence of the plastic flow of ACSS aluminum stranding during compression. When the strands cannot resist the advancing connector bore, they extrude axially out of the connector and upon clearing the connector bore they expand radially outward, forming the characteristic basket or bird-cage shape at the connector mouth. This is both a visual indicator of inadequate electrical interface formation and a practical problem in its own right. CIGRE Technical Brochure 905 documents bird-caging as a recognized degradation mechanism for both in-span and dead-end compression connectors, noting that it captures water, accelerates corrosion, and is regularly observed in Transmission System Operator questionnaire responses. The technical brochure recommends removal and re-splicing of any bird-caged conductor section.

3.6.3 The Standards Gap

The existing ANSI C119.4 standard, the primary qualification standard for overhead line connectors, was developed in 1962 for ACSR conductors with a maximum continuous operating temperature of 75°C. Its test methodology applies a 50°C thermal uplift to establish a test temperature of 125°C. Applying the same absolute temperature multiplier (398.15K / 348.15K = 1.1436) to ACSS's 250°C operating temperature yields an equivalent test temperature of approximately 325°C. The draft ANSI C119.7 standard, specifically intended to address connectors for aluminum-to-aluminum conductors designed for operation between 93°C and 250°C, is still in development. ACSS connectors have accordingly gone unqualified for nearly the entirety of the technology's service life, and today remain governed by a standard written for a fundamentally different conductor type operating at a 160 °C lower temperature.

3.6.4 Installation Errors

Industry consensus attributes 80% of premature compression connector failures (defined as failure within 30 years of installation) to installation errors. The most common are:

- Failure to properly brush the conductor surface before insertion is the principal cause of many failures, as brushing creates surface roughness that increases asperity formation.
- Failure to fully insert the conductor into the connector sleeve before crimping reduces the mating surface area and the depth of core engagement.
- Failure to adequately fill two-die connectors with corrosion inhibitor compound before compression.
- Use of an improper inhibitor compound, particularly critical for ACSS, as standard inhibitors break down at 250°C operating temperatures.
- Inadequate lubrication of dies and presses, resulting in bowed connectors or uneven compression.

Because compression connectors are fully encapsulated after installation, there is no practical means of inspecting installation quality after the fact without X-ray photography, infrared survey, or resistance measurement, all of which are expensive, time-consuming, and can only detect problems after they have already developed.

3.7 Industry Context: CIGRE Technical Brochure 905

CIGRE Technical Brochure 905, "Sustainability of Overhead Line Conductors and Fittings – Conductor Condition Assessment and Life Extension, Volume 1: State of the Art," published in July 2023 by CIGRE Working Group B2.68, provides the global industry-wide context for the connector issues documented in the ORNL research. Drawing on questionnaire responses from 29 Transmission System Operators worldwide, TB 905 establishes that compression fittings have a recognized minimum service life of approximately 20 years and a maximum documented life of up to 95 years in mild environments. The most common replacement criterion is an increasing or unacceptably high rate of failures, a reactive criterion confirming that utilities frequently lack predictive tools to identify failing connectors before they reach a critical state. The document also provides quantitative annealing models (Morgan, CIGRE, and Goh equations) confirming that 1350-H19 tensile strength is reduced by 10% after only 250 hours at 125°C, and establishes a four-tier condition rating system for joint resistance measurement. Critically, TB 905 explicitly limits its scope to conductors operating below 95°C and excludes all HTLS conductors, including ACSS, meaning the most at-risk connector applications are not addressed by the current state-of-the-art sustainability guidance.

4. The ClampStar Solution

4.1 Design Philosophy of the Thermo-Speed-Lock Connector

The Classic Connectors Thermo-Speed-Lock (TSL) product family, comprising dead-end (TSLD), splice (TSLS), and jumper terminal (JTE) connectors, is designed specifically for ACSS conductor. Its fundamental departure from compression technology is the abandonment of compressive residual hoop-stress as the grip mechanism.

Rather than relying on a residual stress state created by a one-time crimping event and thermally degraded thereafter, the TSL connector uses a precision gripping unit tightened by torque-limiting fasteners to apply and maintain a controlled, verifiable clamping force. The torque-limiting fasteners shear at a prescribed torque value, ensuring consistent and repeatable clamping independent of operator judgment or equipment condition. An internal tube captures and retains the exposed steel core of the conductor independently of the aluminum stranding grip.

4.2 How the TSL Addresses Each Known Failure Mode

4.2.1 Electrical Interface Quality

The TSL connector does not rely on plastic interaction between a connector bore and soft aluminum stranding to create the electrical interface. The keeper assembly provides direct, controlled contact between machined surfaces and the conductor strands. Pre-installation surface preparation, specifically, light brushing of the contact surfaces, is specified and results in the creation of asperities through deliberate mechanical action rather than as an incidental byproduct of a crimping process.

4.2.2 Thermal Degradation of Grip

Because the TSL connector’s clamping mechanism is mechanically maintained rather than being a residual stress artifact, the progressive loss of compressive force with temperature documented extensively in the ORNL research does not apply in the same manner. The inherent recovery by elastic effect of the bolt and clamp ensures that the gripping unit maintains mechanical engagement with the conductor throughout the thermal cycling range.

4.2.3 Installation Errors

The TSL design systematically eliminates the most consequential installation error categories: no hydraulic press or die set is required; a visible inspection window confirms full conductor insertion before assembly is completed; the correct inhibitor compound is factory-installed; and the torque-limiting fasteners provide verifiable, consistent clamping force. The installation requires approximately three minutes and standard hand tools rather than a hydraulic pump and specialized die set.

4.2.4 Inspectability

Because the TSL connector’s clamping elements are visible after installation, sheared fastener heads confirm proper torque application, and the inspection window confirms full conductor insertion, installation quality can be visually confirmed without X-ray. This addresses a fundamental limitation of compression technology, where the quality of the internal interface is permanently concealed after crimping.

4.3 The ClampStar Shunt: Remediation of Existing Connectors

The ClampStar shunt (CSR, CSS, and CS2 series) is an engineered electrical/mechanical bypass device designed to be installed over an existing compression connector that has degraded or failed in service. It functions as a permanent bypass electrical connection while the failed connector continues to carry mechanical tension. This allows restoration of electrical integrity without requiring de-energization, re-tensioning, or replacement of the failed connector.

The ClampStar shunt directly addresses the practical reality confirmed by CIGRE TB 905, that utilities often lack predictive tools to identify failing connectors before they reach a critical state, and that replacement of compression connectors on energized lines is logistically complex. By providing a retrofit solution, the shunt enables utilities to respond to identified connector degradation without waiting for a planned outage. Both the Thermo-Speed-Lock connector and the ClampStar shunt were subjected to rigorous third-party validation under conditions exceeding those required by the applicable draft standard, as documented in Section 5.

5. Empirical Validation: Kinectrics Test Results

5.1 Test Configuration

The current cycling test was conducted by Kinectrics Inc. at their Louisville, Kentucky laboratory, completed February 12, 2026, under Kinectrics Report K-657046-RP-0001 R00 (issued April 29, 2026). The test conductor was 768.2 kcmil Maumee ACSS/TW-HS285, manufactured by Southwire. The test protocol aligned with draft ANSI C119.7 (Draft 14, January 6, 2025), with the following parameters exceeding the minimum draft requirements:

- Preconditioning: 25 cycles at 250°C ±5°C (absolute)
- First Current cycling test: 500 cycles at 335°C ±5°C (exceeding the derived equivalent test temperature of ~325°C) (absolute)
- Second Current cycling test: 500 cycles at 390°C ±5°C (absolute)
- Sustained mechanical tension: 35% RTS at room temperature (exceeding the draft standard's 25% requirement)
- Soak duration: 2 hours per cycle at temperature

Classic Connectors fittings testing included four dead-end connectors (DE1–DE4), four jumper terminal connectors (JT1–JT4), one splice (SP1), and one third-party compression splice (SP2) used as a direct comparative sample. A ClampStar shunt (CSR-1140L-048) was installed over SP2 at cycle 50 upon its failure.

5.2 Electrical and Thermal Results

Parameter	Value / Finding through 390 °C
CCI dead-ends: resistance variation thru 1000 cycles	Within ±15%of initial measurement*
CCI jumper terminals: resistance variation thru 1000 cycles	Within ±10% of initial measurement*
CCI splice (SP1): resistance variation thru 1000 cycles	Within ±5% of initial measurement*
Delta of average CCI dead-end temperature vs. average control conductor 335°C and 390°C	240°C and 271°C
Delta of average CCI jumper terminals temperature vs. average control conductor 335°C and 390°C	247°C and 281°C
Delta of average CCI splice (SP1) temperature vs. average control conductor 335°C and 390°C	238°C and 267°C
Temperature stability, cycles 250–500 & 750-1000	Within +/-15% of average — Criterion 2 PASSED

Temperature stability, cycles 375–500 & 875-1000	Within +/-7.5% of average — Criterion 3 PASSED
Compression splice (X-A): thermal runaway	Cycle 50 — temperature exceeded control conductor
ClampStar shunt over failed compression splice	Stable resistance and temperature from cycle 50 through cycle 1000

*draft ANSI C119.7 allows ±20%

The contrast between the two splice connectors in the same test loop is unambiguous: the third-party compression splice failed in thermal runaway within 50 cycles, while the Classic Connectors TSL splice maintained resistance stability within nearly half the allowable variation for all 1000 cycles. The ClampStar shunt, installed over the failed compression splice at cycle 50, immediately restored stable electrical and thermal behavior and maintained it for the remaining 1000 cycles of the test.

5.3 Tensile Test Results

A separate tensile test conducted at Classic Connectors' facility in Prescott, Alabama, tested the TSL Dead-end Connector against a conventional two-die compression deadend on the same conductor sample (768.2 kcmil Maumee ACSS-TW-MA5, (UHS), RBS = 26,500 lbf). The TSL Dead-end Connector was tested through multiple load hold points:

- 60% RBS (15,900 lbf): held 15 minutes — no slippage or distress
- 77% RBS (20,405 lbf): held briefly — no slippage or distress
- 90% RBS (23,850 lbf): held 1 minute — no slippage or distress
- 95% RBS (25,175 lbf): held 1 minute — no slippage or distress
- Maximum load achieved: 27,296 lbf — 103% of conductor RBS

Failure occurred as a midspan rupture of the steel core approximately 36 inches from the connector body, confirming that the connector itself was not the structural limiting element. This constitutes a successful ANSI Class 1 tensile test.

5.4 High Voltage Corona Testing

Corona inception and extinction voltage testing was conducted by Mississippi State University's High Voltage Laboratory (Report No. 2025hv291–2299, May 15, 2025). Seven connector samples from different Classic Connectors product families were tested across single-phase and three-phase configurations at voltages up to 522 kV line-to-ground (equivalent to a 904 kV three-phase system voltage). In the highest voltage test, a terminal with pad and corona shields was tested at 522 kV line-to-ground with no corona present, confirming suitability for UHV applications.

6. Conclusion and Path Forward

The evidence reviewed in this report leads to a clear and well-supported conclusion: compression connector technology is physically unsuitable for the high-temperature, high-ampacity applications that HTLS reconductoring demands. The failure is thermodynamic in nature, rooted in the physics of residual stress relaxation, thermal expansion, and material strength loss, and no incremental improvement to the compression paradigm can overcome it.

For utilities deploying ACSS, the most capable and now demonstrably competitive HTLS conductor available, this failure is acute. The soft, fully annealed aluminum stranding that makes ACSS thermally stable also makes it incompatible with compression connectors from the very first installation. A compression connector on ACSS begins its service life with a compromised electrical interface and a grip mechanism that will approach zero as the conductor approaches its rated operating temperature.

For utilities deploying composite core conductors at 180°C, the problem is less severe but no less real. The same hoop-stress degradation mechanism applies; only the rate differs.

The ClampStar Thermo-Speed-Lock connector resolves this at its root by abandoning the residual hoop-stress paradigm entirely. A mechanically maintained gripping unit, torque-limited fasteners, factory-installed inhibitor, a visual inspection window, and no hydraulic press required, together these eliminate every documented failure mode of compression technology. The Kinectrics test demonstrates that this is not a theoretical improvement: TSL fittings completed 500 cycles at 390°C under 35% RBS tension with resistance stability within half the allowable variation, while a conventional compression splice in the same test loop failed before one-tenth of the required cycles were complete.

For the significant installed base of compression connectors already in service on HTLS lines, the ClampStar shunt provides a proven retrofit path, restoring electrical integrity without a line outage, as demonstrated in Section 5.

The grid is being asked to carry more power at higher temperatures than any of its components were originally designed to handle. ACSS conductor is ready for that challenge. The Thermo-Speed-Lock connector and ClampStar shunt ensure that the weakest link in the system no longer has to be its connectors.

> **Forward-Looking Recommendation**
>
> Any utility planning an HTLS reconductoring project, whether using ACSS or composite core conductor, should evaluate connector qualification testing under representative HTLS conditions per draft ANSI C119.7 rather than the legacy ANSI C119.4 standard. Connector testing conducted without representative tensile loading and at temperatures appropriate only for ACSR does not qualify a connector for HTLS service. The Kinectrics test results presented in Section 5 represent the most rigorous available demonstration of connector performance under realistic ACSS service conditions.

Appendix A: Source Documents Reviewed

The following eight documents form the evidentiary basis for this report. All findings are traceable to these sources.

Wang et al. (PVP2008) [1]	ASME Conference Paper	Foundational FEM and experimental methodology for SSC lifetime prediction on ACSR. Establishes compressive residual stress as the primary lifetime indicator.
Wang et al. (ICREPQ'12) [2]	Conference Paper	Extends methodology to SSC and TSC for ACSR. First direct SSC vs. TSC performance comparison. Introduces TSC lifetime governing equations.
Wang et al. (ORNL/TM-2008/156) [3]	ORNL Technical Report	Full primary report from which the IEEE journal paper was derived. Complete thermomechanical test data, FEM simulation, neutron diffraction validation, and SSC lifetime prediction methodology. Jointly sponsored by DOE and EPRI.
Jiang, Wang et al. (ASME IMECE 2012) [4]	Conference Paper	First comparative study of ACSR and ACSS two-stage splice connectors at high temperature. Introduces ACSS-specific lifetime trend curves.
CIGRE TB 905 (2023) [5]	Industry Technical Brochure	State-of-the-art review of OHL conductor and fitting sustainability. Covers annealing models, bird-caging, joint resistance measurement, and asset management practices globally.
Springer (Springer Power Consulting) [6]	Independent White Paper	Objective engineering assessment of HTLS conductor technologies for regulators and planners. Establishes ACSS/TW as the highest-capacity HTLS option and provides the regulatory and economic framework for conductor and connector investment decisions.
Tamm, C.R. — Classic Connectors Draft [7]	Manufacturer White Paper (Draft)	Synthesizes ORNL research to argue compression technology is unsuitable for ACSS service. Introduces current path localization analysis and the ClampStar/TSL connector as a solution.

Kinectrics Test Package (2025–2026) [8]	Certified Laboratory Test Reports	Current cycling (Kinectrics K-657046-RP-0001 R00, 500 cycles at 335°C); tensile test (103% RBS); and corona testing (522 kV L/G) of Classic Connectors TSL fittings on 768.2 kcmil ACSS/TW-HS285 Maumee conductor.

Appendix B: References

For complete traceability, the following references correspond to the source documents reviewed. PDFs of each document are accessible by clicking each hyperlink where shown.

[1] Wang, J.J., Lara-Curzio, E., King, T., An, K., Hubbard, C. “Effective Lifetime Estimate of Crimped Powerline Splice Connector Operated at High Temperature.” Proceedings of ASME PVP2008, Chicago, IL, July 27–31, 2008. Paper PVP2008-61630.

[2] Wang, J.J., Jiang, H., Ren, F. “The Reliability Investigation on ACSR Splice Connector Systems Used in Overhead Power Transmission Lines.” International Conference on Renewable Energies and Power Quality (ICREPQ’12), Santiago de Compostela, Spain, March 28–30, 2012.

[3] Wang, J.J., Lara-Curzio, E., King, T.J. “The Integrity of ACSR Full Tension Single-Stage Splice Connector at Higher Operation Temperature.” Oak Ridge National Laboratory Technical Report ORNL/TM-2008/156. Prepared for U.S. Department of Energy Office of Electricity Delivery and Energy Reliability and EPRI. Oak Ridge, TN: UT-Battelle, LLC, September 2008. Available: https://info.ornl.gov/sites/publications/files/Pub12595.pdf

[4] Jiang, H., Wang, J.J., Ren, F., Lee, D., Chan, J., Sibilant, G. “Integrity Study of ACSR and ACSS Two Stage Splice Connectors at High Operation Temperatures.” Proceedings of ASME IMECE 2012, Houston, TX, November 9–15, 2012. DOI: 10.1115/IMECE2012-86358.

[5] CIGRE Working Group B2.68. “Sustainability of Overhead Line Conductors and Fittings – Conductor Condition Assessment and Life Extension, Volume 1: State of the Art.” CIGRE Technical Brochure 905, July 2023. ISBN: 978-2-85873-610-2.

[6] Springer, P. “An Objective Assessment of Conductor Technologies for Transmission Design and Planning.” Springer Power Consulting LLC, April 2026.

[7] Tamm, C.R. “The Demise of Compression Connectors at High Temperatures.” Classic Connectors USA, LLC, Mansfield, OH.

[8] Curley, A., Miller, E., Gorja, G.; Prinsloo, J.; Wallace, D. Classic Connectors Thermo-Speed-Lock DeadEnd Testing Package: (a) Current Cycling Test of Classic Connectors Joints Installed on 768.2 kcmil ACSS/TW-HS285 Maumee Conductor, Kinectrics Report K-657046-RP-0001 R00, January 7, 2026; (b) Classic Connectors Deadend Tensile Test Report: CC Deadend Connector versus Conventional (2-Die) Compression Deadend, Maumee 768.2 kcmil ACSS-TW (Grade 5) UHS Conductor, Classic Connectors Inc., February 28, 2025; (c) Corona Evaluation of Line Connectors, Mississippi State University High Voltage Laboratory, Report No. 2025hv291(9), May 15, 2025.

Appendix C: Abbreviations and Definitions

Abbreviation	Definition
AAC	All Aluminum Conductor
AAAC	All-Aluminum Alloy Conductor
AACSR	Aluminum Alloy Conductor, Steel Reinforced
AC	Alternating Current

ACSR	Aluminum Conductor, Steel Reinforced
ACSS	Aluminum Conductor, Steel Supported
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
AWM	Aircraft Warning Marker
BFD	Bird Flight Diverter
CCI	Classic Connectors Inc.
CIGRE	Conseil International des Grands Réseaux Électriques (International Council on Large Electric Systems)
CTE	Coefficient of Thermal Expansion
DAQ	Data Acquisition System
DC	Direct Current
DOE	United States Department of Energy
DSO	Distribution System Operator
EEI	Edison Electric Institute
EPRI	Electric Power Research Institute
FEM	Finite Element Model (or Finite Element Method)
FERC	Federal Energy Regulatory Commission
HTLS	High Temperature, Low Sag
IACS	International Annealed Copper Standard (unit of electrical conductivity)
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
kcmil	Thousand Circular Mils (unit of conductor cross-sectional area)
kN	Kilonewton
ksi	Kilopounds per Square Inch
kV	Kilovolt
lbf	Pounds-force
MVA	Megavolt-Ampere
NDE	Non-Destructive Evaluation
NEETRAC	National Electrical Energy Testing, Research and Applications Center
NESC	National Electrical Safety Code
OHGW	Overhead Ground Wire
OHL	Overhead Line
OPGW	Optical Ground Wire
OPPC	Optical Fiber Composite Phase Conductor
ORNL	Oak Ridge National Laboratory
psi	Pounds per Square Inch

QMS	Quality Management System
RBS	Rated Breaking Strength (used interchangeably with RTS across source documents)
RTS	Rated Tensile Strength (used interchangeably with RBS across source documents)
SCC	Single Stage Connector (alternate abbreviation used in some ORNL papers; same as SSC)
SEM	Scanning Electron Microscope
SSC	Single Stage Splice Connector
TC	Thermocouple
TMF	Thermal-Mechanical Fatigue
TSC	Two-Stage Splice Connector (also referred to as Two-Die Connector)
TSL	Thermo-Speed-Lock (Classic Connectors product designation)
TSO	Transmission System Operator
TVA	Tennessee Valley Authority
UHV	Ultra High Voltage
UHS	Ultra High Strength (as in HS285 steel core designation)

Appendix D: About the Authors

Carl Tamm, Technical Author, is President of Classic Connectors USA and a 35-year veteran of the electrical industry. He is a nationally recognized technical authority on power grid hardware and a premier forensic subject matter expert on the root causes of overhead power line connector failures, having conducted forensic analysis of hundreds of failed connectors in the field. Carl serves as a voting member of the CIGRE US National Committee, the IEEE-PES Transmission, Protection & Control Committees, and the ANSI C119 Committees, and is the former Chair of the ANSI C119.7 Committee, the standards body developing the connector qualification standard for high-temperature conductors that is central to this paper's findings.

Trisha Crawford, Technical Author, is a Design Engineer with Classic Connectors USA with a demonstrated history in the mechanical and industrial engineering industry. She holds a Bachelor of Science in Mechanical Engineering from the University of Alabama at Birmingham and brings specialized expertise in CAD-based product development, including proficiency in AutoCAD, SolidWorks, and Autodesk Inventor. Her design engineering background informs the technical precision and product development work underlying the ClampStar and Thermo-Speed-Lock connector families documented in this report.

Chris Costanzo, Contributing Author, is Director of Market Development and a founding member of Classic Connectors USA. With more than 40 years as a sales and marketing professional, including two decades of specialized leadership within the electric utility industry, Chris has been instrumental in the development, commercialization, and strategic market positioning of ClampStar® throughout its 18-year history. His deep understanding of utility constraints, contractor needs, and grid modernization priorities makes him uniquely qualified to communicate the practical significance of the engineering findings presented in this report.

End of Report — Prepared June 2026 — All findings traceable to source documents listed in Appendix B