White Paper

SOLO HD® Single-Die High-Temperature Compression System

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ABSTRACT

New developments in transmission compression technology are limited due to the success and reliability of the standard two-die compression systems available. Most full-tension compression accessories suitable for elevated conductor temperatures require two sizes of dies for installation, as well as field-injection of filler compound. A compression system that involves only a single die set without requiring filler compound would simplify power transmission line construction.

With a continual need for new construction and replacement of existing aerial conductors, in conjunction with a new generation of linemen, efficiency is critical for installation – including speed, consistency and reliability. The new ANSI-qualified AFL SOLO HD compression system utilizes a specialized core grip to eliminate speculation from the compression process, removing obstacles and providing a consistent and quality installation.

1. INTRODUCTION

AFL's Accessories division has been designing and manufacturing compression accessories for over 80 years.[1] New technology in the compression line of products for electric power transmission lines is not introduced often, relative to this timeframe. Alcoa Conductor Accessories, prior to becoming AFL, developed standard two-stage full-tension compression accessories in the 1920s, which use a two-die system to install the compression accessory onto a steel core type stranded aluminum conductor, such as ACSR (Aluminum Conductor, Steel Reinforced). The single-stage system for standard operating temperature ACSR conductor was later developed and released by Alcoa in the mid-1970s, requiring a single die set for full-tension compression accessory installation. The single-stage and standard two-stage full-tension compression accessories achieve the mechanical and electrical performance requirements for ACSR applications as governed by ANSI (American National Standards Institute). ACSS (Aluminum Conductor, Steel Supported) was later developed in the 1970s, allowing transmission line operation at temperatures up to 250°C.[2] Full-tension compression accessories for ACSR and ACSS conductors must hold at least 95% of the conductor's RBS (rated breaking strength) in an ultimate load tensile program, while also achieving required temperature and resistance stability requirements through a CCT (current-cycling test) program.[4]

2. COMPRESSION INSTALLATION TECHNIQUES

For steel core type stranded aluminum conductors including ACSR and ACSS, the stranded steel core provides most of the conductor's mechanical strength during operation. When full-tension compression accessories, dead end terminations or mid-span splices, are applied in installation of ACSR or ACSS, the stranded steel core of the conductor must be anchored by a core-gripping system within the compression assembly. A two-stage full-tension compression fitting uses a first hex die set, designated SH (steel hex) as shown in ***Figure 1***, to compress a steel barrel onto the exposed core to hold the conductor's stranded steel core under tension. Each sequence of die closure overlaps the previous, compressing into the span direction.

This compression of a galvanized steel barrel onto the conductor's steel core is considered the first stage of the two-stage full-tension compression process.

Figure 1 – Steel eye barrel compression for a two-stage fitting

The second stage of installation involves sliding the aluminum body portion of the two-stage compression fitting over the previously-compressed steel component, filling the aluminum body with filler compound, and using a second hex die set designated AH (aluminum hex) to compress the aluminum body onto the complete conductor, displayed in ***Figure 2***.

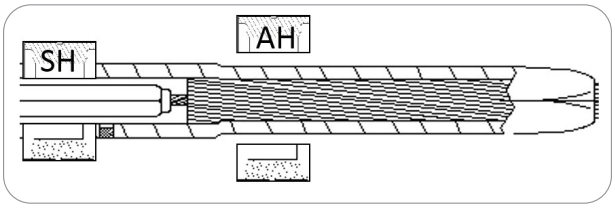

Figure 2 – Die sets and process used in two-stage compression

A single-stage full-tension compression fitting uses a single die set, designated CD (circular dies), to compress an outer aluminum body onto a specialized core grip which then compresses onto and grips an ACSR conductor's exposed steel core. The lobed core grip is made of aluminum so the outer aluminum body is able to compress and form the core grip onto the conductor's stranded steel core. The single stage of installation involves inserting the conductor's exposed steel core into the lobed core grip, then inserting the conductor, core and core grip into the outer aluminum body of the dead end or splice assembly. The outer aluminum body has been prefilled with filler compound and is compressed using the single set of CD dies.

Figure 3 – Single-stage dead end compression accessory

The established full-tension compression technologies, both two-stage and single-stage, require cleaning of the conductor's aluminum stranding and use of filler compound prior to compression. A hydraulic pump and press head are used to close the die sets onto the compression accessory components and full die closure is required for proper installation. Various sizes of pump and press are used in the compression process depending upon the conductor and compression accessory size, with 60-ton and 100-ton tooling and dies being the most common for power transmission lines.

3. EXISTING TECHNOLOGY FOR ELEVATED TEMPERATURES

ACSS conductors are designed for operation up to 250°C. At these elevated temperatures above which ACSR can effectively operate, compression accessory designs above the performance capabilities provided by the standard two-stage and single-stage full-tension compression accessories are needed. The standard two-stage compression accessories are designed for continuous conductor operating temperatures up to 100°C and will also perform during emergency loading up to 120°C.[3] With the existing single-stage compression accessories for ACSR, that utilize the lobed aluminum core grip, the limitation is 100°C conductor operating temperature. This single-stage full-tension compression system however cannot be used for emergency conductor loads above 100°C as in application of standard two-stage fittings for ACSR. At conductor temperatures up to 120°C the two-stage full-tension fittings are able to mechanically hold the steel core sufficiently as the stranded steel core is retained within the compressed steel barrel. The single-stage full-tension fittings utilize the lobed aluminum core grip to hold an ACSR conductor's stranded steel core – at temperatures above 100°C the aluminum core grip separates from the steel core as the conductor temperature elevates.[5] The separation of the aluminum core grip from the steel core at elevated temperatures increases the possibility of electrical and mechanical failure in the single-stage compression fitting. Although this single-stage series of compression accessories simplifies installation by requiring only one die size for full-tension applications, it cannot be utilized to install ACSS.

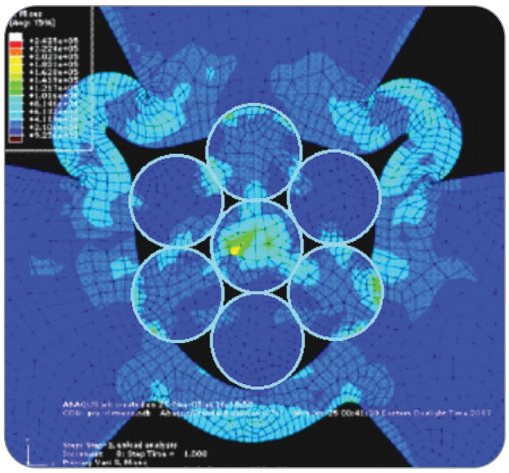

Figure 4 – Steel core in a single-stage core grip[5]

When ACSS was introduced to the energy market as an elevated temperature conductor offering, the demand emerged for full-tension compression fittings suitable for operation up to 250°C. A series of two-stage full-tension compression accessories was then developed to meet the temperature requirements of ACSS. The two-stage compression fittings for elevated temperature applications are similar in design to the standard two-stage accessories, yet include additional aluminum body compression length as the aluminum body is treated to match the properties of ACSS aluminum stranding. In a fully-annealed condition the outer aluminum body is at the same temper of the ACSS stranding and will not change properties at temperatures above 120°C.

The two-stage full-tension compression accessories for ACSS applications utilize the same dies and tooling for installation as used to install two-stage accessories used with ACSR. For example, if a two-stage fitting for 795M Drake 26/7 ACSR requires 30AH and 14SH die sets for installation, those same die sets are used to install two-stage fittings for ACSS. Compression accessories designed for ACSS can be used on the ACSR code name and stranding equivalent, however the standard two-stage fittings cannot be installed and put into service with ACSS. All two-stage compression fitting installations, including those using compression accessories designed for ACSS, involve cleaning of the conductor's aluminum stranding and use of filler compound prior to compression. The conductor stranding is cleaned to remove existing oxidation, by use of a wire brush hand-cleaning method or the portable ConductaClean® unit.

4. SOLO HD PERFORMANCE REQUIREMENTS

Two-stage compression accessories for ACSS and ACSR require two sizes of dies for installation. This constraint complicates the installation procedure with the need for additional tooling and handling. An accessory that requires only one size of dies while being capable of operation at 250°C simplifies installation. In development of the new SOLO HD (one hex die) single-stage high-temperature compression system, AFL specified performance criteria intended to maximize the benefits of using this system in power transmission line installations. The SOLO HD compression series adheres to the same ANSI performance guidelines as the existing two-stage full-tension compression fittings for ACSS and ACSR.

A. Mechanical Requirements

- The SOLO HD full-tension fittings must exhibit strength equivalence to two-stage compression accessories for ACSS and ACSR.

B. Electrical Requirements

- The SOLO HD full-tension fittings must exhibit electrical ampacity and resistivity equivalence to two-stage accessories for ACSS and ACSR.

C. Installation Requirements

- The SOLO HD full-tension fittings must be a single-stage (one die set) system capable of quick installation and elevated temperature operation up to 250°C.
- Dead ends and mid-span splices must be suitable for ACSS and ACSR conductor applications
- Mid-span splices must be capable of traveling over sheave wheels without affecting performance.

5. SOLO HD DESIGN THEORY

The lobed core grip used in the legacy single-stage compression dead end and splice (***Figures 3 and 4***) mechanically grips the core during conductor standard operating temperatures at or below 100°C – however it begins to lose grip of the steel core at temperatures above this value.[5] This existing core grip is made of aluminum in order to form around and grasp the core during compression as the outer aluminum body is compressed. Due to the thermal expansion rates between aluminum and steel, the lobed core grip does not hold the steel core at elevated temperatures. In evaluating this disadvantage, a newly-developed single-stage full-tension compression fitting with the ability to perform at elevated temperatures must utilize a core grip design that is not solely constructed of aluminum.

Initial design concepts of the SOLO HD single-die high-temperature compression system began by examining the means to anchor the conductor's stranded steel core. The new core-gripping system must form over the core by a single die set compressing the outer aluminum body, emit heat away from the steel core at elevated operating temperatures, while also maintaining a sufficient mechanical grip on the core. The patented[6,7] SOLO HD core grip assembly design is able to mechanically hold a conductor's stranded steel core at temperatures up to 250°C, by implementing a stainless steel

barrel for mechanical strength and trapezoidal aluminum lobes to emit heat away from the core as illustrated in ***Figure 5***. The stainless steel barrel does not lose mechanical hold of the stranded steel core at elevated temperatures, while an aluminum filler sleeve and the trapezoidal lobes encompass and anchor the core while emitting heat away from the center of the system, detailed in ***Figure 6***. By compressing the outer aluminum body with the AH die set, the reduction in area of the aluminum body collapses the lobes and insert onto the core, providing the means of gripping the core in union with the stainless steel barrel's material strength.

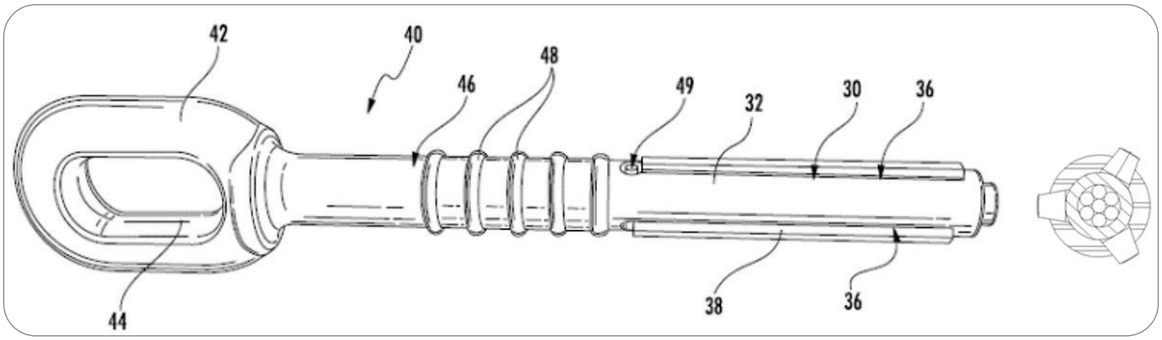

Figure 5 – SOLO HD steel eye core assembly with stainless barrel [6,7]

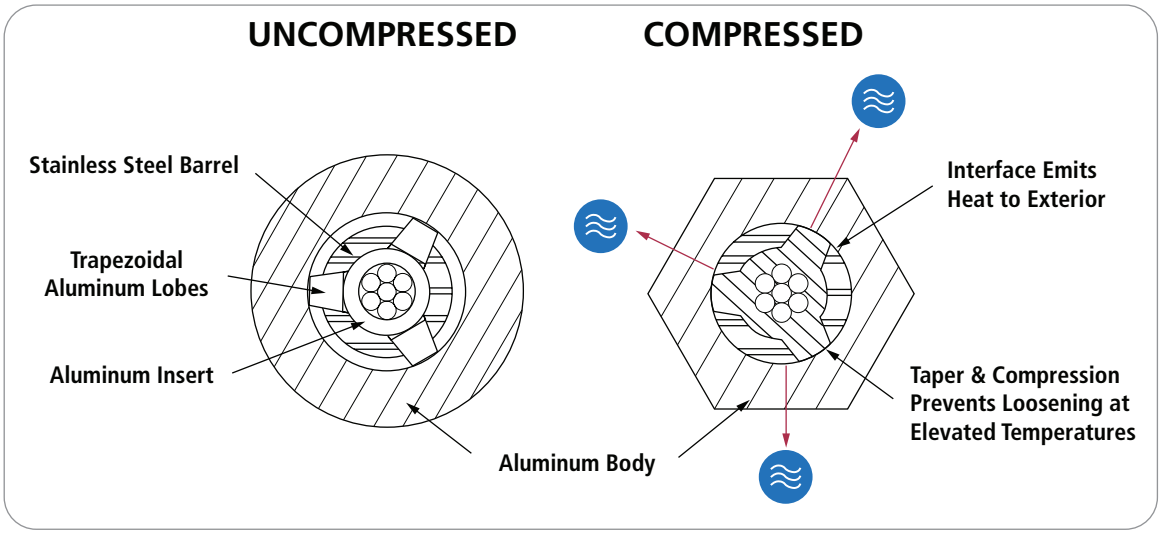

Figure 6 – Uncompressed and compressed sections over a steel core

The existing two-stage full-tension compression accessories for standard and elevated operating temperatures must have filler compound applied as the steel compression barrel requires a galvanized coating. Once the galvanized steel is compressed with the first (SH) hex die set the exterior galvanization is removed during this process, causing raw steel to be exposed. Filler compound is consequently required within the two-stage fitting as the dead end and splice contain raw steel after compression, leading to corrosion if not encompassed fully by the filler compound as shown in ***Figure 7***.

Figure 7 – Two-stage steel barrel, corroded due to insufficient compound

The stainless steel barrel used in the SOLO HD will not corrode as opposed to the compressed galvanized steel in two-stage compression accessories, eliminating the requirement for filler compound within the SOLO HD dead end and splice assemblies. SOLO HD full-tension accessories are also compressed the length of the aluminum body using AH dies, displayed in ***Figures 8 and 9***.

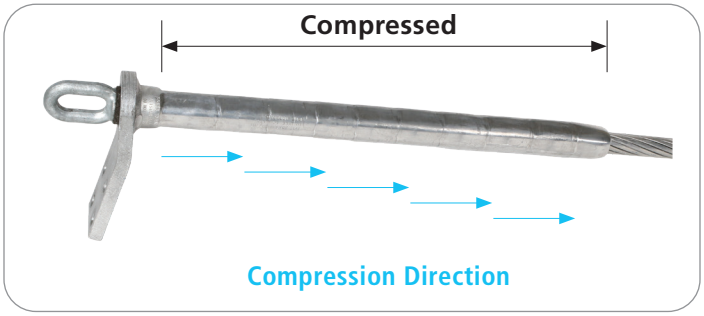

Figure 8 – Fully compressed SOLO HD dead end assembly

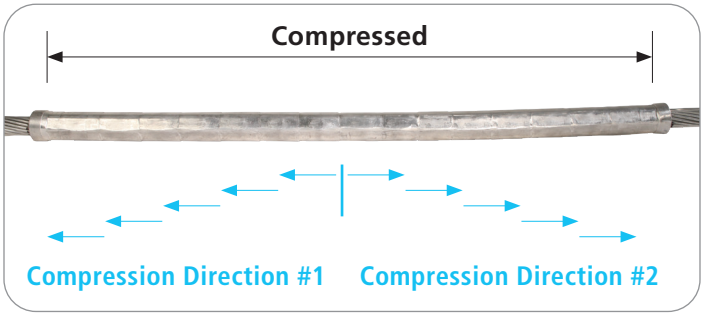

Figure 9 – Fully compressed SOLO HD mid-span splice

The SOLO HD full-tension dead ends and mid-span splices utilize a series of aluminum alloy that has a greater strength value through the barrel cross-section than that of the two-stage aluminum barrel. As the aluminum body material is stronger, the SOLO HD dead end and splice aluminum bodies are 20% shorter in compression length than the two-stage accessories designed for operation up to 250°C. Although the SOLO HD aluminum bodies are made of a stronger series of aluminum, the body outside diameter and cross-sectional remains the same as that of the two-stage. This allows for the same hydraulic press and AH die set, 60-ton or 100-ton, to be utilized in installation of each conductor size. Using code name Drake conductor again as an example, the SOLO HD dead end and splice will use the same AH die set as required for Drake two-stage fitting installation. With the increase in strength of the aluminum body material and no uncompressed portion of aluminum body in the center of the splice as shown in ***Figure 9***, the splices move freely through sheave wheels without damaging the splice or conductor stranding. This is advantageous through installation terrain where a reduction in conductor reel setup locations is desired.

6. SOLO HD TESTING AND RESULTS

SOLO HD has passed all testing requirements as specified by ANSI C119.4 for compression accessories. Test programs completed per ANSI protocol include ultimate tensile load at ambient, sequential sustained load at 250°C then ambient, 500 current cycles at 250°C and the mid-span splice sheave wheel test. The sustained load at elevated temperature testing procedure is detailed in drafts of ANSI C119.7, which is yet to be finalized and officially released. For a new series of compression accessories, ANSI requires no less than three conductor sizes – small, medium and large, are qualified in each testing program. The conductors used in qualifying the SOLO HD compression system included 636M Grosbeak 26/7 ACSS (small), 768.2M Maumee Type 13 ACSS/TW (small), 795M Drake 26/7 ACSS (medium) and 1590M Falcon 54/19 ACSS (large). The requirement for quantity of compression fittings tested in each program is described on the following pages, with passing results of each test detailed.

A. Ultimate Mechanical Load at Ambient Temperature

- Three dead ends and three splices for each conductor size are required to pass for qualification.
- Each conductor size is tensile tested in span, with a dead end on both ends and a splice in the middle.
- Results are shown in Table 1, typical failure is conductor break in span.

Table 1 – Tensile Test Results

CONDUCTOR	TENSILE LOAD ACHIEVED (lbs)	% RBS	RESULT
Grosbeak ACSS RBS: 20,700 lbs.	24,517	118%	Passed
	24,638	119%	Passed
	24,555	118%	Passed
Drake ACSS RBS: 25,900 lbs.	30,858	119%	Passed
	30,983	119%	Passed
	31,119	120%	Passed
Falcon ACSS RBS: 42,600 lbs.	51,006	120%	Passed
	51,054	120%	Passed
	51,589	121%	Passed

B. Sustained Load at 250°C then Ambient

- Four dead ends and one splice for each conductor size are tested for qualification.
- Each conductor size is tensioned in span to 25% RBS at an operating temperature of 250°C, with a dead end on both ends and a splice in the middle. The span is held in tension, at temperature, for 168 hours. The conductor and compression accessories are monitored for slip and damage.
- After the 168-hour hold the tension is removed and each span decreases to ambient temperature.
- Each conductor size is then tensioned in span to 77% RBS. The span is held in tension, at ambient, for 168 hours.
- After the second 168-hour hold each span is tensile tested to failure. Results are shown in Table 2, typical failure is conductor break in span.

Table 2 – Post-Sustained Load Tensile Test Results

CONDUCTOR	TENSILE LOAD ACHIEVED (lbs)	% RBS	RESULT
Maumee ACSS/TW RBS: 23,000 lbs.	23,397	102%	Passed
	22,998	100%	Passed
Drake ACSS RBS: 25,900 lbs.	27,300	105%	Passed
	27,607	107%	Passed
Falcon ACSS RBS: 42,600 lbs.	43,538	102%	Passed
	43,123	101%	Passed

C. Current Cycling at 250°C

- Four dead ends for each conductor size are tested for qualification.
- Each conductor size is installed in a loop configuration with the compression accessories and a length of control conductor included. The control conductor operates at a temperature of 250°C for 500 current cycles. The compression accessories are monitored for temperature and resistance stability.
- Results are shown in Table 3, all compression accessories operate at a temperature below that of the conductor.

Table 3 – Current Cycling Test Results

CONDUCTOR	MAX. TEMPERATURE STABILITY (acceptance ±10)	MAX. RESISTANCE STABILITY (acceptance ±10)	RESULT
Grosbeak ACSS RBS: 20,700 lbs.	7.5	1.8%	Passed
Drake ACSS RBS: 25,900 lbs.	8.6	0.9%	Passed
Falcon ACSS RBS: 42,600 lbs.	7.2	4.6%	Passed

D. Sheave Wheel Mechanical Cycling at Ambient

- One splice for each conductor size is tested for qualification.
- Each conductor size is tensioned in an angled span to 15% RBS, with a dead end on both ends and a splice in the middle. The sheave wheel is fixed mid-span above the dead ends, with a total span deflection angle of 30 degrees (15 degrees per side).
- The splice is pulled 15 cycles (30 passes) over the sheave. The span is then removed and tensile tested to failure. The results are shown in Table 4, all splices deflect (bend) no more than 14 mm.

Table 4 – Post-Sheave Test Results

CONDUCTOR	TENSILE LOAD ACHIEVED (lbs)	% RBS	RESULT
Maumee ACSS/TW RBS: 23,000 lbs.	23,762	103%	Passed
Drake ACSS RBS: 25,900 lbs.	33,764	107%	Passed
Falcon ACSS RBS: 42,600 lbs.	49,152	115%	Passed

7. SUMMARY

The SOLO HD compression system provides a quicker full-tension compression accessory installation, particularly for applications requiring elevated conductor temperatures. Filler compound is not required due to the use of stainless steel in the patented core assembly design and the solid mass created when the dead end and splice assemblies are fully compressed. With filler compound eliminated and only one AH die size required for applications up to 250°C – the resulting decrease in compression installation errors adds certainty to project installation and longevity of the power transmission line system.

SOLO HD advantages:

- Qualified for conductor operation up to 250°C.
- One product can be used on ACSR and ACSS.
- Two-piece design: steel core assembly and outer aluminum body.
- No filler compound required.
- Single die set (AH) installation.
- Faster installation.
- No additional training to use new equipment.
- Splices can be pulled through stringing blocks.

8. ACKNOWLEDGEMENT

The author acknowledges product release contributions of Dan Baggett, Eric Borowicz, Rodolfo Elizondo, Mike Gravelle, Steven Kranz, Ray McCoy, Jon Potter, Wayne Quesnel and Kelvin Turner.

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