

[54] **STEEL SUPPORTED ALUMINUM
OVERHEAD CONDUCTORS**

[75] Inventor: **Harold W. Adams**, Richmond, Va.

[73] Assignee: **Reynolds Metals Company**,
Richmond, Va.

[22] Filed: **Nov. 16, 1972**

[21] Appl. No.: **307,076**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 206,269, Dec. 9, 1971, abandoned, which is a continuation-in-part of Ser. No. 51,128, June 30, 1970, abandoned.

[52] U.S. Cl. **174/130, 174/42, 174/128**

[51] Int. Cl. **H01b 5/10**

[58] Field of Search **174/128, 129 R, 126 CP, 174/130, 131 A, 131 R, 42, 40 R, 126 R**

[56] **References Cited**

UNITED STATES PATENTS

3,240,570 3/1966 Grimes, Jr. et al. 174/128 UX

3,264,404 8/1966 Trebby et al. 174/129 R X
3,647,939 3/1972 Schoerner 174/130 X

FOREIGN PATENTS OR APPLICATIONS

1,194,321 6/1970 Great Britain 174/130

Primary Examiner—A. T. Grimley

Attorney, Agent, or Firm—Glenn, Palmer, Lyne & Gibbs

[57]

ABSTRACT

The disclosed composite conductors have a steel component for supporting the weight of the composite conductor, and an annealed aluminum component for purposes of electrical conductivity. Annealing the aluminum component gives it relatively low yield strength and relatively high elongation characteristics, and thereby improves service performance of the conductor.

23 Claims, 7 Drawing Figures

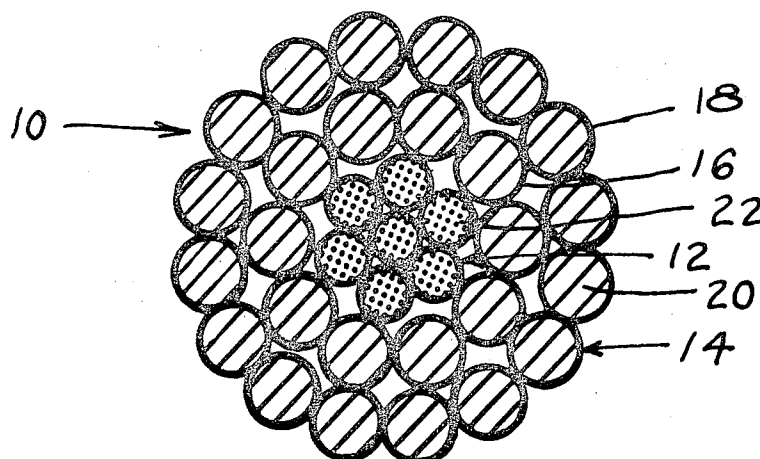


Fig. 1

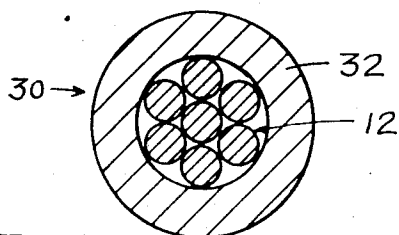
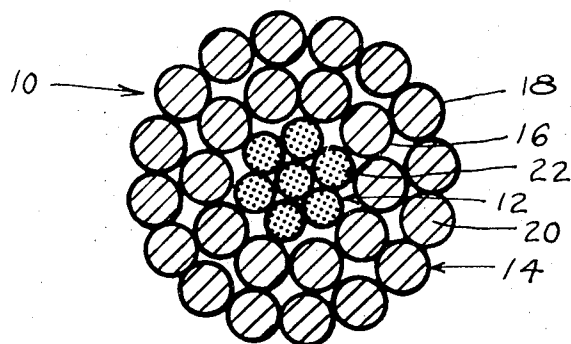


Fig. 2

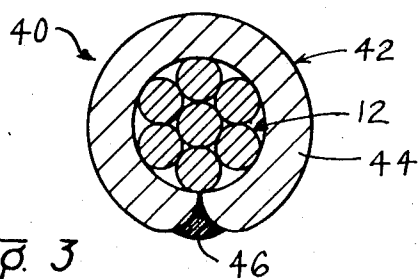


Fig. 3

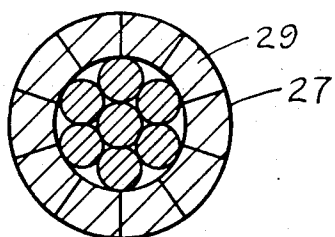


Fig. 4

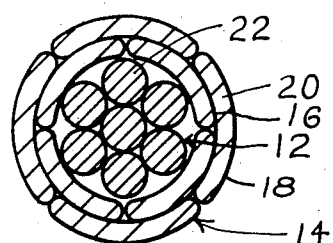
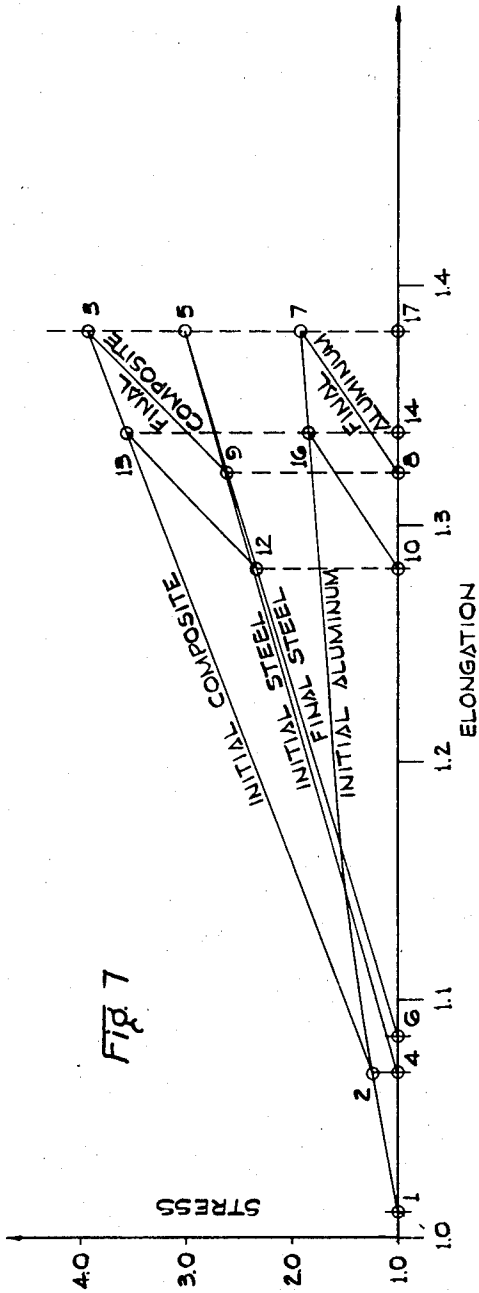
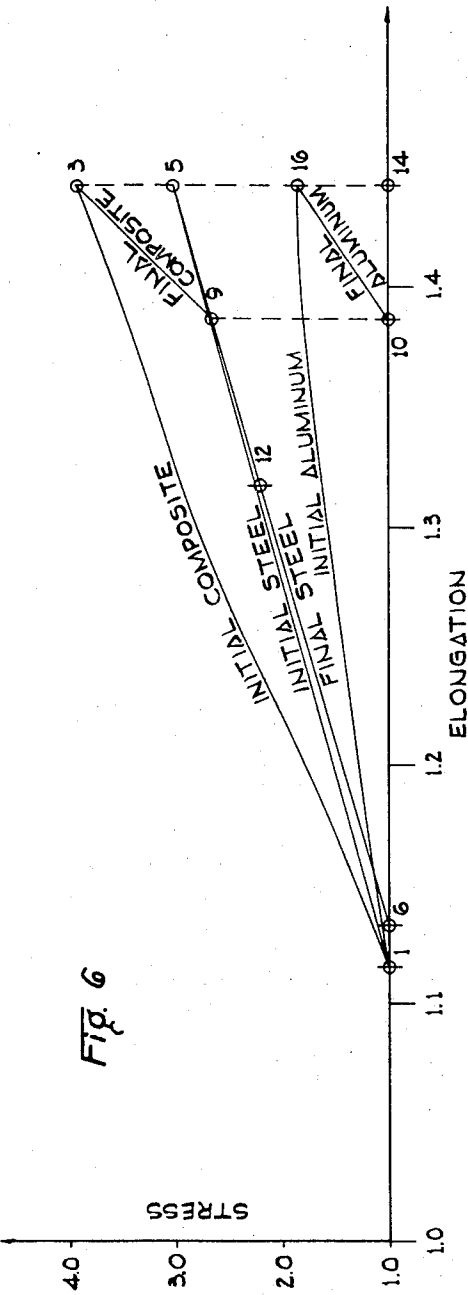


Fig. 5



NOTE: Units of axes not to scale

STEEL SUPPORTED ALUMINUM OVERHEAD CONDUCTORS

This application is a Continuation-in-Part of applicant's prior application, Ser. No. 206,269, now abandoned filed Dec. 9, 1971, which in turn is a Continuation-in-Part of applicant's prior application Ser. No. 51,128, now abandoned filed June 30, 1970.

BACKGROUND OF THE INVENTION

Conventional aluminum conductors employed in the construction of overhead lines are exposed in service to hazards which may cause different kinds of damage, the degrees of which are extremely difficult to predict. Among these hazards and the types of damage are:

1. Aeolian vibration which can result in fatigue breakage of aluminum wires and damage to fixtures attached to the conductor. Tension limitations based upon aeolian vibration considerations are principal parameters in overhead line design. (Aeolian vibration is a relatively high frequency, low amplitude resonant oscillation that is normally caused by winds from about 3 to 15 miles per hour. Amplitudes of aeolian vibration are less than the conductor diameter.)
2. Galloping conductors which can result in in-span flash-overs and damage to support hardware, conductor fixtures, insulators and structures. (Galloping is a low frequency, large amplitude resonant phenomenon. Most usually it occurs when an ice formation on the conductor causes the overall cross-section to assume the shape of an air foil, so there is an actual lift of the conductor by the wind. Amplitudes of galloping can be several feet.)
3. Subspan oscillation which can result in the clashing of subspan members and in severe wear of conductors at points where devices such as subspan spacers and suspension clamps are attached, and damage to conductor hardware fixtures. (Subspan oscillation is a low frequency, moderate amplitude resonant phenomenon. It is caused by forces associated with turbulence in the wake of an up-wind member of a multiconductor bundle.)
4. High operating temperatures resulting from heavy electrical loads which can result in the partial annealing and acceleration of creep of aluminum wires. High operating temperatures, especially during emergencies, become an increasingly important factor as power system capacities are progressively enlarged.
5. Creep, or inelastic elongation, of aluminum wires that takes place over a relatively long period of time which can result in an increase in conductor sag and problems with electrical clearances. The rate of creep is a function of elapsed time, temperature, stress, and of the amount of prior creep at any given point in time.

The principle of providing aluminum upon steel as an overhead conductor has been widely used in recognition of the high conductivity of the former and the high strength of the latter. The designation by which this kind of conductor is usually known in technical and trade literature is "ACSR" for Aluminum Conductor, Steel Reinforced. The industry-recognized manufacturing specification for conventional ACSR is ASTM Specification B 232 entitled "Standard Specification for Aluminum Conductors, Concentric-Lay-Stranded

Steel Reinforced, (ACSR)" (referring herein more particularly to ASTM specification B-232-71a dated July 10, 1971). The principle is also employed, however, with the type of conductor described by Edwards (U.S. Pat. No. 3,378,631).

Basic to the sag and tension performance of any overhead conductors, are their stress-strain characteristics. These characteristics are established by tensile tests on completely fabricated conductors and by separate tensile tests on any central portion that may be made of material different from that used for overlying portions. In these tests the elongation of the test specimen is measured concurrently with the tensile load, and the data can be graphically plotted to define the stress-strain characteristic of the test specimen. When data from tests on a composite aluminum-steel conductor, and on its steel component are superimposed on the same graph, analysis of the stress-strain behavior of the composite conductor and of its aluminum and steel components is possible. Thus, the proportion of tension borne by aluminum and steel components at any level of tension or of strain of the composite conductor and at any operating temperature can be determined. Also the effect of any non-elastic elongation of any component that may occur as a result of stress imposed during installation or during service may be investigated.

A major objective in the design and manufacture of conductors heretofore employed for overhead lines has been that the tensile strengths of component metals be as high as practical so as to produce the highest practical tensile strength in the conductor. Thus, for example, ASTM Specification B 232 referred to previously requires that the aluminum wires be in the hard drawn temper (H 19). This is the temper in which the maximum strength of EC grade aluminum wires is attained. A property of hard drawn EC wires prescribed by ASTM Specification B 232 that relates to this invention is a relatively low elongation of from 1.2 to 2.2 percent. This elongation is less than the 3.0 to 4.5 percent elongation provided by the conventional zinc-coated steel core wire that ASTM B 232 calls for as core wire (by cross-reference to ASTM B 498), and prevents the practical utilization of the strength of the steel beyond its strength at one percent extension which is approximately only 85 to 90 percent of its ultimate strength.

Conventional accessories such as dead ends, jumper terminals, splice connectors, armor rods, jumper filler rods, come-alongs, socks, grading rings, suspension clamps, stringing sheaves and the like used in the stringing, cutting, sagging, terminating and splicing of ACSR conductors do not disturb the relative positions of the aluminum and steel strands of the conductors and so do not significantly affect the division of tension between the aluminum and steel portions of the conductors. When tension is applied to a long length of conventional steel reinforced aluminum conductor having such fittings on each end, both the aluminum and steel components are stretched equally and substantial stresses develop in both the aluminum and steel components.

SUMMARY OF THE INVENTION

The conductors disclosed herein each comprise an electrically conductive aluminum component supported on a steel component. The aluminum component is of an alloy and temper that provides high electrical conductivity preferably not lower than 61 per-

cent IACA (International Annealed Copper Standard determined by International Electrotechnical Commission); low yield strength, below about 8500 psi for 0.2 percent permanent elongation; and high ductility with elongation not less than five percent in ten inches. The stress-strain characteristics of aluminum-steel conductors in which the aluminum component has a low yield strength described above are quite different from the stress-strain characteristics of conventional aluminum-steel conductors which are identical except for using a high yield strength aluminum component. Accordingly, the sag and tension performances and the division of total tensions between aluminum and steel components are quite different when low yield strength aluminum is used instead of high yield strength aluminum in steel reinforced overhead power lines.

Because the elongation of the aluminum alloy is greater than that of the steel wire or cable, the normal restriction for limiting the use of the strength of the steel to that at one percent extension does not apply, and the full ultimate strength of the steel can be utilized. It is possible in some cases to design a cable for an overhead power line in accordance with the present invention, using lower yield strength aluminum than in a corresponding conventional cable, but requiring no greater size or strength of the steel component than is used in the conventional cable.

The aluminum component is preferably formed conventionally before being stranded on to the steel support. In the case of conventional composite stranded cable, for example, the aluminum component is first drawn to wire of a hard temper, and then the hard wires are pulled through the stranding equipment which forms the composite cable. The hard temperature of the aluminum wires helps to resist tension and rubbing as they are pulled through the stranding equipment. After the cable has been stranded and reeled, the size of the reel and the presence of conventional paper cushioning material would interfere with any subsequent heat treating step. The steel core may be coated or otherwise sheathed in aluminum, but if it is galvanized, as it often is, the presence of low melting zinc is a further deterrent to raising the completed conductor to aluminum annealing temperature.

The present invention, however, contemplates annealing the aluminum component before the conductor is finally mounted overhead. While this might be done by electric resistance heating, for example, even at as late a stage as when the cable is being mounted, it is ordinarily preferable to impart all of the desired characteristics to the cable before it leaves the factory. A continuous anneal might be used after the cable has been stranded but before it is reeled, or a coil of the cable might be heated to annealing temperature in an oven. However, such practices would require special equipment and possibly preclude use of a galvanized steel core, and the present preferred manufacturing process is to anneal the aluminum component after it has been drawn down but before it is stranded. A full anneal of the aluminum component is preferred for this purpose. The resultant annealed aluminum component is then passed through the stranding machine, with suitable precautions to protect the softened aluminum. These precautions will depend on the particular equipment, but in general consist of applying lubricant to the surface of the annealed aluminum wires and one or more of the steps of easing the back tension on the aluminum

wires in the strander, reducing the speed of the strander, modifying the wire guides to reduce scuffing, enlarging the closure dies which press the stranded aluminum wires against the steel core, and reducing the pressure of the closure dies. A special advantage of this procedure is that the stranding operation imparts a small amount of cold work and consequent hardness to the aluminum wires, while still keeping them within the requirements of an upper limit of about 8500 psi yield strength and ductile elongation capability of at least about 5 percent in ten inches, which is greater than the elastic elongation capability of the steel component conventionally used in accordance with ASTM specifications. This limited increase in hardness above complete annealing temper is considered useful in withstanding subsequent operations of taking the cable into the field and stringing it in place on its overhead supports.

The composite cable of the present invention may be installed using either of the following conventional techniques:

a. The cable is strung between overhead supports and initial forces in excess of normal load are applied, either by mechanically bending or stretching, or both. The initial forces impose sufficient tensile stress on the aluminum component to cause it to stretch inelastically while the excess load is applied. When the excess forces are partially relieved, and the cable is left to hang from its supports under normal load conditions, the aluminum component is preferably free of stress, since it has been pre-stretched to its length under normal load, and the whole normal load is then carried by the steel component. The steel component thus determines the amount of normal sag, to a predetermined limit. Subsequent increased forces caused by wind or ice may cause the steel to stretch elastically, but it will return the cable to substantially its original position whenever there is no excess load. Electrical overloads will have little or no effect, because the resultant temperature increase would not be high enough to weaken the steel, and could not significantly weaken the already annealed and unstressed aluminum component.

b. The cable is strung between overhead supports and left under normal load conditions, without application of any excess force before or during mounting. This leaves the cable with an initial lesser sag than the predetermined final normal sag. When increased forces of wind or ice act on the cable, the steel component stretches elastically and the aluminum component stretches principally inelastically. Consequently, when these increased forces are removed and normal load conditions return, the cable will tend to return to the amount of sag which it is designed to have when the steel component is supporting the whole load and the aluminum component is unstressed. Thereafter, the cable can resist mechanical and electrical overloads in the same manner as the cable described in paragraph (a) above.

The substantially unstressed condition of the aluminum component reduces hazards of aeolian vibration and loss of strength as a result of high operating temperatures. It is believed that it is also less susceptible to the hazards of subspan oscillation and galloping.

There are several reasons why this is so. First, there is little or no consequential radial force in the aluminum wires under those operating conditions that are most conducive to the aeolian vibration, galloping and subspan oscillation phenomena, so there is a substantial degree of conductor self-damping by interstrand and/or interlayer friction, or by impact interference. Second, even should some degree of vibration or oscillation occur, fatigue failure of aluminum wires is avoided by avoiding consequential stresses in them. Third, relative to aluminum wires, steel wires under tension are much more resistant to vibration damage; they are not adversely affected by operating temperatures that cause annealing of aluminum wires; and they have a very low creep rate throughout the operating temperature and stress spectrum. Fourth, since there is no reliance on the strength of aluminum under operating conditions conducive to long-time creep, the creep of aluminum is not a factor. Fifth, because the yield strength of the aluminum is very low, the tensile strength will also be so low that there can be no significant loss of strength of the aluminum by possible annealing at high operating temperatures.

To reduce any possibility of corrosion, the entire conductor may be impregnated with a suitable grease to preclude the entry of moisture. The grease may be employed simply as a coating of individual wires or as a means to fill up the voids in the interstices and thus to preclude the entry of moisture. However, it is not necessary or possible to keep all of the internal voids filled with grease.

The invention is further hereinafter discussed with reference to the drawings, wherein present preferred embodiments are shown for purposes of illustration only

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a transverse cross-sectional view of a steel supported aluminum overhead conductor comprising a sheath of aluminum wires helically stranded over a core of stranded steel alloy wires;

FIG. 2 is a transverse cross-sectional view of a steel supported aluminum overhead conductor comprising a seamless tube of aluminum provided about a core of stranded steel alloy wires;

FIG. 3 is a transverse cross-sectional view of a steel supported aluminum overhead conductor comprising a welded seam tube of aluminum provided about a core of stranded steel alloy wires;

FIG. 4 is a transverse cross-sectional view of a steel supported aluminum overhead conductor comprising a sheath of keystone-sectioned aluminum wires about a core of stranded steel alloy wires;

FIG. 5 is a transverse cross-sectional view of a steel supported aluminum overhead conductor comprising a sheath of flat, round-edged aluminum strips helically stranded about a core of stranded steel alloy wires;

FIG. 6 is a stress strain analysis of one typical conductor of the invention at 70° F; and

FIG. 7 is a stress strain analysis of that typical conductor of the invention at 0° F.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Following a practice which is common in the industry, the entire article of the invention is referred to herein as a "conductor" even though the aluminum

portion thereof would in a strictly technical sense be more accurately designated the conductor. It is believed that this practice will cause no problem for those skilled in the art and familiar with its practices and vocabulary.

Unless otherwise indicated or obvious from the context, absolute values of dimensions given herein are for illustrative purposes only, to enable a more concise discussion of the preferred embodiments.

With reference to FIG. 1, there is depicted a steel supported aluminum overhead conductor 10 comprising a steel core 12 and an electrically conductive tubular aluminum component 14 received over the core 12. In the instance depicted, the aluminum component is in the form of two superimposed layers 16, 18 of helically wound layers of aluminum wires 20.

The steel core 12 may be of any desired kind but is preferably made of stranded steel wires. They may, for example, be identical in composition and fabrication to the cores used in standard ACSR conductors; see the following ASTM specification as in effect on June 30, 1970: B 232 "Aluminum Conductors, Steel Reinforced, Concentric-Lay Stranded (ACSR)", B 341 "Aluminum-Coated (Aluminized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR)", B 502 "Aluminum-Clad Steel Core Wire for Aluminum Conductors, Aluminum-Clad Steel Reinforced (ACSR-AW)", and B 498 "Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR)".

As illustrated, the steel core 12 consists of seven 0.1360 diameter steel strands 22 helically stranded to produce a core having an O.D. of 0.4080 inch. (This is the same core of galvanized steel strands as is found in 795 MCM 26/7 ACSR "Drake" conductor manufactured by Reynolds Metals Company of Richmond, Virginia.)

Aluminum wires 20 are fully annealed and then stranded directed directly upon the core 12.

Exemplary characteristics of a steel supported aluminum overhead conductor constructed in accordance with the embodiment of FIG. 1 are presented in Table I.

TABLE I

1. Size: 636,000 Circular Mils
2. Stranding:
 - a. Core: 7 × 0.1085 Steel
 - b. Aluminum: 24 × 0.1628 EC Aluminum
3. Cross Section:
 - a. Steel: 0.0648 Sq. In.
 - b. Aluminum: 0.4995 Sq. In.
 - c. Total: 0.5643 Sq. In.
4. Rated Strength (with 250,000 psi steel wire): 23,449 lbs.

"Rated Strength" of a steel supported aluminum overhead conductor is calculated as follows for purposes of the present invention:

- a. The strength contribution of the aluminum is calculated by multiplying the total area of the aluminum wires by the minimum average strength of the aluminum wires and the product of this by the appropriate rating factor from table 4 of ASTM B 232.
- b. The strength contribution of the steel is calculated by multiplying the total area of the steel wires by the ultimate tensile strength of the steel wires and

by the appropriate rating factor from table 4 of ASTM B 232.

c. The total rated strength of the cable is determined by adding (a) and (b).

Sample Calculation:

636 MCM 24/7 steel supported aluminum conductor

area of aluminum = 0.4992

area of steel = 0.0648

diameter aluminum wires = 0.1628

diameter steel wires = 0.1085

minimum average strength of aluminum = 11,500 psi

ultimate strength of steel = 205,000 psi

rating factor — aluminum = 0.93

rating factor — steel = 0.96

Rated Strength

aluminum = $(0.4992)(11,800)(0.93) = 5,470$ lbs.

steel = $(0.0648)(205,000)(0.96) = 12,730$ lbs.

total = 18,200 lbs.

Referring now to FIG. 2, there is shown a steel supported aluminum overhead conductor 30 which includes a steel core 12 as described above in relation to FIGS. 1 and 2, and a tubular aluminum component 32 extruded in an integral condition over the core. The extrusion operation is performed at temperatures which leave the aluminum component in annealed condition having the properties required for purposes of the invention. Exemplary values for the conductor 30 are provided in Table II.

TABLE II

	As Fabricated
Core outside diameter	.450 inch
Tube thickness	.1053 inch
Tube inside diameter	.450 inch
Tube outside diameter	.6606 inch

Referring now to FIG. 3, there is shown an alternative to the construction depicted in FIG. 2 in that a steel supported aluminum overhead conductor 42 is provided with a tubular aluminum component 40 by wrapping a single broad strip 44 of electrically conductive annealed aluminum about the core 12 and welding its formerly laterally opposite edges to one another at 46 utilizing conventional welding equipment and techniques. Exemplary values for the conductor 40 are the same as in Table II.

Aluminum strands of other-than-circular cross-sectional shape may be employed. By way of illustration (FIG. 4), there may be used, upon a 7×0.1489 inch helically stranded steel core 12 having an outer diameter of 0.4467 inch, a tube of electrically conductive annealed aluminum 27 having an inside diameter at the time of fabrication of 0.4467 inch and consisting of 10 trapezoidally shaped wires 29 having a thickness of 0.20 inch.

In the example of FIG. 5, the first, inner layer of the tubular aluminum conductor is provided by three helically stranded, round-edge aluminum strips each 0.1 inch thick and approximately 0.4 inch wide, this layer having an internal diameter of 0.399 inch at the time of fabrication, and an external diameter of 0.599 inch. The second, outer layer of the tubular aluminum conductor is helically stranded immediately upon the first, in an opposite helical sense, and consists of four, round-edged aluminum strips each 0.1 inch thick and approximately 0.4 inch wide, this layer having an inter-

nal diameter of 0.599 inch at the time of manufacture, and an external diameter of 0.799 inch. In each instance, the strips of aluminum are curved about the longitudinal axis of the tubular aluminum conductor so that each is arcuate as seen in transverse cross-section.

The strips 20 are of electrically conductive aluminum and fully annealed before stranding.

The layer 16 could be formed from a greater or a lesser number of strips 20. To illustrate an alternative, the following table relates to a layer 16 consisting of two helically intertwined round edge strips of aluminum.

TABLE III

	As Fabricated
Thickness of each strip	.070 inch
Inside diameter	.399 inch
Outside diameter	.539 inch
Nominal strip width, approx.	.600 inch

The layer 16 of Table III may be stranded over the same 0.399 inch O.D. steel core as described above and an outer aluminum layer 18 of opposite helical sense may be laid directly on the layer 16 of this alternative example.

As should be apparent, integral or welded tubes, wire and strip may all alternatively be used in the fabrication of conductor in accordance with the invention disclosed in this document. The particular mode which would be preferable at any given point in time would be the one that could most economically be produced at that time or meet other considerations of design prejudice.

FURTHER DISCUSSION OF STEEL SUPPORTED ALUMINUM OVERHEAD CONDUCTORS PERTINENT TO ALL DISCLOSED EMBODIMENTS

1. The sag performance of the conductor is not affected by the possible changes in strength of creep characteristics of the aluminum wires that might be caused by elevated temperature operation. Because of properties of the steel wires commonly used in the construction of conventional ASCR are not affected by temperatures that cause annealing of aluminum wires, the ultimate solution can be achieved by designs that rely for mechanical strength entirely upon the steel core under all expected operating conditions.
2. The mechanical strength of conventional ACSR conductors is provided by the combined strength of both the hard drawn aluminum and the steel wires. The distribution of load between the aluminum and steel wires depends upon the proportionate area of each in the particular design, the operating temperature, and the amount of creep that may be imparted to the aluminum wire over a period of time. For all normally expected operating conditions, tensions could be caused to be borne almost entirely by the steel wires if the hard drawn aluminum wires were replaced by completely annealed aluminum wires. This is because the yield strength of annealed aluminum wires is very low and they tend to stretch, or creep, rapidly when put under any consequential stress.
3. When annealed aluminum wires are used, the rated strength of ACSR conductors is calculated differently than if hard drawn wires are used. This

is because of the fact that the elongation of hard drawn aluminum wires (in the order of 2 percent) is substantially less than that of steel wires (in the order of 5 percent), whereas the elongation of annealed wires is substantially more (in the order of 20 percent). With hard drawn aluminum wires having low elongation, the rated strength of a conductor is calculated on the basis of the full strength of the aluminum wires plus the strength of the steel at only 1 percent elongation. With annealed aluminum wires having greater elongation, however, the full strength of the steel wires can be used for calculating the rated strength.

4. The utility of the principles of the invention, in practice, is believed to be even more substantial for conductors having an over-all diameter greater than one inch.

5. Although conductor grade "pure" aluminum, designated "EC" aluminum is the preferred composition of the conductor sheath, other soft-when-annealed aluminum alloys can be utilized provided they meet the other criteria set forth herein, for instance, aluminum alloys in the 5000 series under the Aluminum Association's designation system that contain magnesium as the principal alloying constituent. More specifically, an aluminum alloy containing 0.2 magnesium may be used which has, in the annealed temper, the following typical characteristics:

Conductivity — 62.4 percent
Yield Strength — 7000 psi
Elongation in 10 inches — 19 percent
Tensile Strength — 14,000 psi

DISCUSSION OF FIGS. 6 AND 7

There is provided in FIGS. 6 and 7 a stress-strain analysis of steel supported aluminum overhead conductors constructed in accordance with the principles of the invention. From them, in connection with this specification, including the respective keys provided below, it is believed that the teaching of the present invention will become readily apparent.

FIG. 6:70°F.

Feature	Significance of Feature
Line 1-3	Initial composite stress-strain characteristic at 70°F
Line 1-5	Initial steel stress-strain characteristic at 70°F
Line 5-6	Final steel stress-strain characteristic at 70°F
Line 1-16	Initial aluminum stress-strain characteristic at 70°F
Line 16-10	Final aluminum stress-strain characteristic at 70°F
Line 3-9-6	Final composite stress-strain characteristic at 70°F
Line 1-10	Inelastic stretch of aluminum necessary to cause all stress at 70°F without ice and wind to be borne of steel (same as 1-10 on 0°F chart)
Line 1-14	Total stretch of aluminum necessary to impart inelastic stretch in aluminum of the amount between 1-10 (same as 1-14 on 0°F chart)
Line 14-3	Total pre-stretch stress at 70°F necessary to impart inelastic stretch in aluminum of the amount between 1-10
Point 12	Point of operation at 70°F without ice and wind load after excursion to Point 3
Point 3	Point on initial composite stress-strain curve at pre-stretch tension

FIG. 7—0°F.

Feature	Significance of Feature
Line 1-2-3	Initial composite stress-strain characteristics of 0°F
Line 4-5	Initial steel stress-strain characteristic at 0°F
Line 6-5	Final steel stress-strain characteristic at 0°F
Line 1-7	Initial aluminum stress-strain characteristic at 0°F
Line 7-8	Final aluminum stress-strain characteristic at 0°F
Point 3	Point of operation 0°F with ice and wind load
Line 3-9-6	Final composite stress-strain characteristic at 0°F after excursion to Point 3
Line 1-10	Inelastic stretch of aluminum necessary to cause all stress at 0°F without ice and wind load to be borne by steel
Line 6-12-13-3	Initial composite stress-strain characteristic at 0°F as modified by pre-stretching to impart inelastic stretch in aluminum of the amount between Points 1 and 10
Line 1-14	Total stretch of aluminum necessary to impart inelastic stretch in aluminum of the amount between Points 1 and 10
Line 1-17	Total stretch of composite conductor and of aluminum at 0°F with ice and wind loads
Line 4-17	Total stretch of steel at 0°F with ice and wind loads
Line 17-3	Total stress in composite at 0°F with ice and wind loads
Line 17-5	Proportion of total stress borne by steel at 0°F with ice and wind loads
Line 17-7	Proportion of total stress borne by aluminum at 0°F with ice and wind loads
Point 12	Point of operation at 0°F without ice and wind load
Line 10-12	Total operating stress with no ice or wind after excursion to Point 3, or stringing stress after pre-stretching to impart inelastic stretch of an amount between Points 1 and 10. All tension is on the steel.

Upon occasion it will be found to be preferable not to prestretch the conductor to such an extent that substantially all mechanical tension is borne by the steel under the assumed ice and wind loading conditions (see above of the the application). Rather, a value of prestretching tension can be determined that will inelastically elongate the aluminum sufficiently so that when tension is relaxed to the sagging-in value, all but a very small amount of tension in the aluminum, at the temperature of prestretching and sagging-in, is relieved. This technique provides for a small amount of tension to be borne by the aluminum throughout the pulling-in and sagging-in operations and thus eliminates any possibility of the "basketing" of stranded aluminum filaments during these operations. When this technique is employed, there will be some small amount of stress in the aluminum at temperatures lower than the sagging-in temperature, and there will be fairly substantial stress in the aluminum under assumed ice and wind loading conditions. These stresses are not sufficient to reduce the advantages claimed for the invention, however.

References herein to aluminum components include components of suitable aluminum alloys. The aluminum component is not intended to include minor amounts of aluminum present for the primary purpose

of protecting the steel core, as in the case of an aluminumized steel core, for example.

While present preferred embodiments of the invention have been illustrated and described, it will be understood that the invention is not limited thereto but may be otherwise embodied and practiced within the scope of the following claims.

What is claimed is:

1. An electrical conductor for an overhead power line, comprising a steel core and an aluminum component having an electrical conductivity of at least 61 percent IACS around the core, said aluminum component being in at least partially annealed condition and having a yield strength below 8500 psi for 0.2 percent permanent elongation down to the yield strength of the aluminum component when in fully annealed condition whereby the consequential stresses at stringing the conductor overhead between space supports can permanently elongate the aluminum component enough to transfer substantially all the tensile load to the steel core at the time of installation, thus achieving improved qualities of fatigue resistance and self damping of the aluminum component, and of resistance of the conductor to increase of sag after installation.

2. The electrical conductor of claim 1, in which the steel core is galvanized.

3. The electrical conductor of claim 1, in which the steel core is aluminumized.

4. The electrical conductor of claim 1, in which the aluminum component has a capability of ductile inelastic elongation of at least about 5 percent in ten inches.

5. The electrical conductor of claim 4, in which the aluminum component is fabricated of EC aluminum.

6. The electrical conductor of claim 1, in which the aluminum component has received a small amount of work hardening after substantially complete annealing.

7. The electrical conductor of claim 1, in coiled form but mountable between widely spaced overhead supports with the steel component carrying substantially the whole tensile load and the aluminum component substantially unstressed, whereby subsequent sag of the cable below its initial position is minimized.

8. A steel supported aluminum overhead conductor comprising:

a steel core;

a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the tubular aluminum conductor having an electrical conductivity no lower than 61 percent IACS.

9. The steel supported aluminum overhead conductor of claim 8 wherein the tubular aluminum conductor is fabricated of EC aluminum.

10. The steel supported aluminum overhead conductor of claim 9 wherein the tubular aluminum conduc-

tor, at conductor operating temperature, is in a fully annealed condition of temper.

11. The steel supported aluminum overhead conductor of claim 8 wherein the tubular aluminum conductor is fabricated of aluminum having an elongation in 10 inches of not less than 5 percent.

12. The steel supported aluminum overhead conductor of claim 11 wherein the aluminum has an elongation in ten inches of about 19 percent.

13. A steel supported aluminum overhead conductor comprising:

a steel core;

a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the steel core being fabricated of zinc-coated steel wire in accordance with ASTM B 232 and having an elongation in ten inches of no greater than 4.5 percent and the tubular aluminum conductor being fabricated of aluminum having an elongation in 10 inches of not less than 5 percent.

14. The steel supported aluminum conductor of claim 13 wherein the tubular aluminum conductor is fabricated of EC aluminum, having, in use at operating temperature, a fully annealed condition of temper.

15. The steel supported aluminum conductor of claim 13 wherein the tubular aluminum conductor is fabricated of an aluminum alloy having about 0.2 percent magnesium as the principal alloying constituent, and having, in use at operating temperature, a fully annealed condition of temper, plug greater strength and lesser creep than EC aluminum in the same condition of temper.

16. A steel supported aluminum overhead conductor comprising:

a steel core;

a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the steel core being helically stranded steel wires.

17. The steel supported aluminum overhead conductor of claim 16 wherein the steel core has at least the capability for bearing tensile stress as is prescribed by ASTM B 232 for cores of conventional ACSR.

18. A steel supported aluminum overhead conductor comprising:

a steel core;

a tubular aluminum conductor received upon said core and being of such composition and soft tem-

13

per that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the tubular aluminum conductor comprising at least one layer of helically stranded aluminum wires.

19. A steel supported aluminum overhead conductor comprising:

- a steel core;
- a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the tubular aluminum conductor comprises at least one integral tube of aluminum encompassing the steel core.

20. The steel supported aluminum overhead conductor of claim 9 wherein the integral tube of aluminum exists as a strip of aluminum folded until opposite edges thereof lie adjacent one another and a weldment or mechanical joining proceeding along the strip edges integrally connecting the strip edges to create the integral tube of aluminum.

21. A steel supported aluminum overhead conductor comprising:

- a steel core;
- a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension result-

14

ing from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the tubular aluminum conductor comprising at least one layer of helically stranded aluminum wires of keystone cross-sectional shape.

22. A steel supported aluminum overhead conductor comprising:

- a steel core;
- a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the tubular aluminum conductor comprising at least one layer of helically stranded aluminum strips.

23. A steel supported aluminum overhead conductor comprising:

- a steel core;
- a tubular aluminum conductor received upon said core and being of such composition and soft temper that for all conductor operating temperatures, when the ambient temperature is above that at which ice and snow would accumulate on said conductor, substantially all mechanical tension resulting from the strung-overhead disposition of the conductor is borne by the steel core, and the tubular aluminum conductor, if called upon to bear any consequential stress would, instead, elongate inelastically leaving such stress to be borne by the steel core; the outer diameter of the steel core being substantially equal to the inside diameter of the tubular aluminum conductor at the time of fabrication.

* * * * *

50

55

60

65