

[54] **REINFORCED COMPOSITE
ALUMINUM ALLOY CONDUCTOR
CABLE**

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[*] Notice: The portion of the term of this patent subsequent to May 19, 1987, has been disclaimed.

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 814,198, Apr. 7, 1969, Pat. No. 3,513,251, which is a continuation-in-part of Ser. No. 779,376, Nov. 27, 1968, abandoned, which is a continuation-in-part of Ser. No. 730,933, May 21, 1968, abandoned.

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

[51] **Int. Cl.**.....H01b 5/08

[58] **Field of Search**174/126, 128, 130, 110;
29/193

[56] **References Cited**

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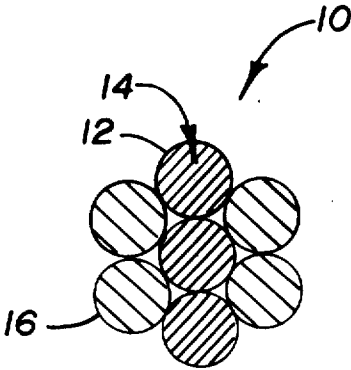
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[57] **ABSTRACT**

A multistrand cable for transmission of electrical power including aluminum alloy strands having a minimum electrical conductivity of 61 percent IACS and at least one strand of high-strength material with a maximum conductivity of less than 61 percent IACS.

18 Claims, 6 Drawing Figures



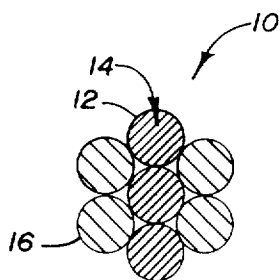


FIG-1

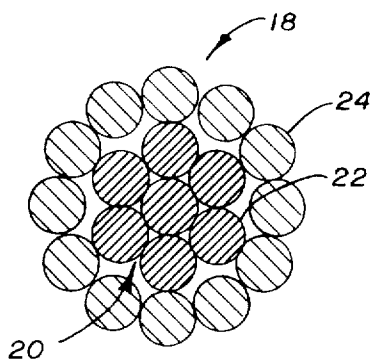


FIG-2

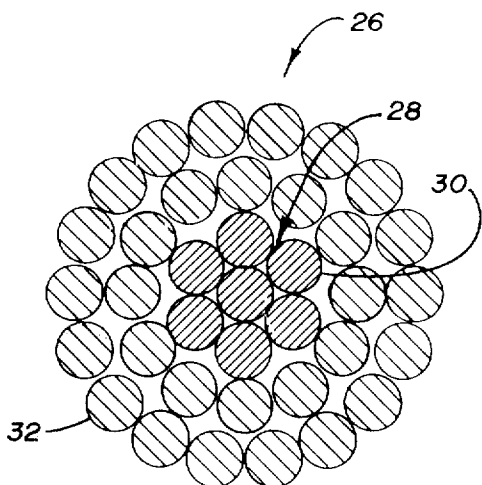


FIG-3

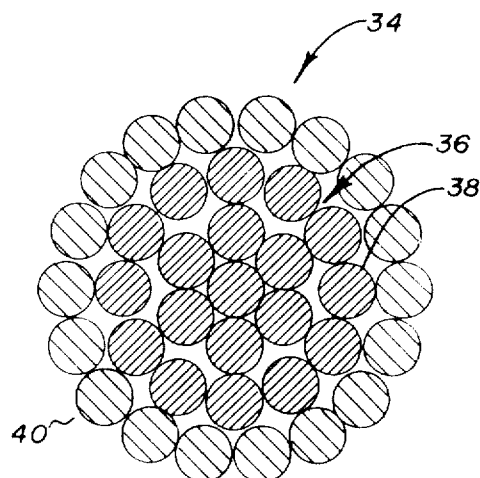


FIG-4

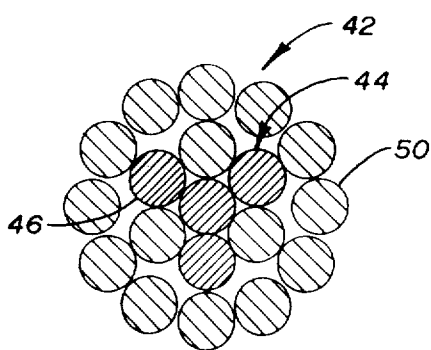


FIG-5

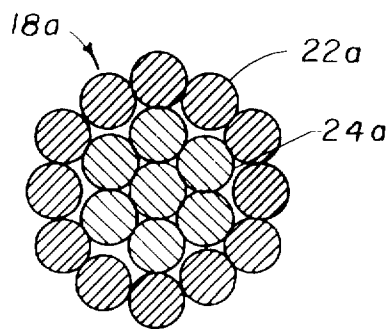


FIG-6

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REINFORCED COMPOSITE ALUMINUM ALLOY CONDUCTOR CABLE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of my copending application Ser. No. 814,198, filed Apr. 7, 1969, now Pat. No. 3,513,251, issued May 19, 1970, which is a continuation-in-part of application Ser. No. 779,376, filed Nov. 27, 1968 (and now abandoned), which is in turn a continuation-in-part of application Ser. No. 730,933, filed May 21, 1968 (and now abandoned).

The present invention concerns a composite electrical conductor and more particularly relates to a multistrand aluminum alloy electrical conductor including at least one reinforcing strand of high-strength material. The cable of the present invention is especially adaptable and useful for power frequency transmission of electrical energy where great strength for the conductor is required.

It is an object of this invention therefore, to provide an improved relatively lightweight multistrand conductor of composite construction wherein certain strands of the conductor have a relatively higher electrical conductivity but less strength than the remaining strands making up the conductor. The multistrand electrical conductor of this invention is particularly adaptable and useful in those environments where a conductor of composite construction not only must have the overall characteristic of relatively high electrical conductivity but at the same time a relatively high strength-to-weight ratio.

These and other objects, features, and advantages of the instant invention will become apparent from a review of the following specification when taken in conjunction with the accompanying figures of the drawing, wherein:

FIG. 1 illustrates a typical cross-sectional view of one form of a multistrand conductor embodying the present invention;

FIGS. 2-6 inclusive illustrate similar cross-sectional views of further multistrand conductors embodying the present invention.

With further reference to the drawings, and particularly FIG. 1, a multistrand conductor 10 is illustrated wherein a plurality of strands, such as the three strands 12 make up the high-strength portion 14 of the conductor and a plurality of strands, such as the four outer strands 16, make up the high-conductivity portion thereof. This particular cross-sectional pattern illustrates an innermost core of relatively high-strength strands 12 surrounded by an outer concentric layer including two diametrically opposed high-strength strands 12 positioned between circumferentially opposed pairs of the outer relatively high conductive strands 16. It is to be understood, of course, that the outer strand layer made up of strands 12 and 16 is tightly wound in a suitable helical fashion in either direction about the innermost core strand 12. The outer strands 16 are made from material that has a relatively higher electrical conductivity than that of strands 12. The strands 12, on the other hand, are made from a material of relatively greater strength but lower electrical conductivity properties when compared to strands 16. Since strands 16 advantageously have high electrical conductivity and desirably have relatively light weight, a material such as an aluminum alloy is preferred for the construction thereof. In addition, it is quite preferred that the aluminum alloy of strands 16 have the highest tensile strength available together with acceptable electrical conductivity and percent elongation. On the other hand strands 12 should be constructed from a material which will supply initially great strength and secondarily other available characteristics. If high overall conductivity is desired for the composite cable a heat-treatable alloy such as alloy No. 6201-T81 (Aluminum Association designation) is preferred for strands 12. If lower overall conductivity is acceptable for the composite cable but greater overall strength is desired, a material such as steel is preferred for strands 12.

Referring to FIG. 2 a multistrand conductor 18 is shown comprising a core 20 made up of seven high-strength alloy strands 22 of which six are helically and tightly wound about a

central strand. The core is surrounded by 12 helically and tightly wound outer strands 24 of electrically conductive aluminum alloy. The cross-sectional pattern of the conductor 18 in FIG. 2 preferably has one core strand 22 completely surrounded by a concentric layer of the remaining six core strands 22, all generally disposed in nesting contact with each other. The relatively high-conductivity strands 24 making up the outer layer of the conductor 18 may or may not be in abutting contact with the associated core strands 22 of the concentric core layer depending upon how the outer strands are spirally wrapped about the core during manufacture. As compared with the multistrand conductor 10 of FIG. 1 it is obvious that both the number of the strands 22 of the core 20 and the number of the outer strands 24 have been increased to thereby provide not only for increased electrical conductance but to provide for an increase in strength of the cable or conductor.

The multistrand conductor 26 of FIG. 3 has a core 28, the core strands 30 of which may be the same number as that of the core 20 in FIG. 2 and the core has the same general cross-sectional pattern. An additional layer of strands, however, have been added to increase substantially in number the high-conductivity strands so that there are now 30 of these strands 32. The core of the multistrand conductor of FIG. 3 also has for all practical purposes the same strength properties as the core of FIG. 2. The electrical conductance of the cable, however, has been greatly increased in view of the greater number of high-conductivity strands present.

In FIG. 4 a multistrand conductor 34 is shown which has a core 36 in which the number of preferably helically wound core or high-strength strands 38 and central strand exceed the number of helically wound outer high-conductive strands 40 which surround core 36. The particular cross-sectional arrangement of the core strands 38 in FIG. 4 differentiates from the similar pattern shown in FIGS. 2-3 in that an additional concentric layer of core strands 38 is employed. In this embodiment certain of the strands making up the outermost concentric core layer are advantageously in nesting engagement with various strands of the outer conductor layer, as well as with various strands making up the remainder of the core. Although the conductor of FIG. 4 may be of the same overall size as that of FIG. 3 it has a greater strength since it employs a larger number of high-strength alloy strands.

In FIG. 5 a multistrand conductor 42 is disclosed wherein the three high-strength strands 46 of the six-strand layer 44 are preferably interdigitated in a symmetrical fashion with the three high-conductivity strands 50 in that layer. As compared to the conductor 18 in FIG. 2, the conductor 42 is of decreased strength but of greater electrical conductance by virtue of the fact that three high-conductivity strands are used to replace three high-strength alloy strands. This, together with the comparison of conductors 26 of FIG. 3 and 34 of FIG. 4 cited above demonstrates the flexibility made possible by the instant invention to meet conductor strength and conductance requirements at optimum economy without resorting to different strand diameters.

The above-described patterns for the multistrand conductors 10, 18, 26, 34 and 42 are to be considered as preferred embodiments of the invention and other cross-sectional patterns for a multistrand conductor are contemplated by the instant invention. Furthermore, although the strands in the aforescribed FIGS. 1-5 have substantially the same diameter, the multistrand conductor of the instant invention can be comprised of strands of different diameters, i.e., for different strand layers.

In the embodiments illustrated in the above FIGS. 1-5, the preferred materials for the core strands and the outer conductor strands are respectively a high-strength metallic material in combination with a particular electrically conductive grade of aluminum. The multistrand conductor in one application of the aforescribed embodiments utilizes outer relatively high-conductive strands of aluminum alloy which have an electrical conductivity of at least 61 percent while the high-strength

alloy strands are made from a heat-treated aluminum alloy commercially identified as 6201-T81 wire, which has an electrical conductivity of at least 52½ percent. These conductivity percentages were established according to the American Society for Testing Materials.

In one embodiment it is preferred to use a suitable heat-treated aluminum alloy for the aforescribed high-strength alloy strands of the multistrand conductor. The chemical composition limits of such an aluminum alloy as listed with the Aluminum Association is as follows:

Elements:	6201 Aluminum Alloy
1. Copper	0.10%
2. Iron	0.50%
3. Silicon	0.50%-0.90%
4. Manganese	0.03%
5. Magnesium	0.60%-0.90%
6. Zinc	0.10%
7. Chromium	0.03%
8. Boron	0.06%
9. Other elements, each	0.03%
10. Other elements, total	0.10%
11. Aluminum	Remainder

It is to be understood that in the above composition the percentages are maximum figures unless shown as a range.

In another embodiment of this invention it is preferred to use steel for the high-strength strands. Those steels customarily used in power transmission lines are suitable for use in this embodiment of the present invention.

The chemical composition of the high-conductivity strands is one of the most critical features of the present invention. It has been found that when the alloying elements are carefully controlled within certain prescribed ranges and the high-conductivity strands are prepared from the aluminum alloy composition in a particular fashion, a strand is obtained with improved tensile strength, percent elongation and bendability. It should be understood that while the alloy of the high-conductivity strands is essentially all aluminum, the amount devoted to alloying elements is extremely significant even though quite small in total quantity. The aluminum content of the present alloy comprises from about 98.95 to less than about 99.45 weight percent. Particularly superior results are achieved when from about 99.15 to about 99.40 weight percent aluminum is employed. The iron content of the present alloy for the high-conductivity strand is of extreme importance and should be from about 0.45 to about 0.95 weight percent. Superior results are achieved when from about 0.55 weight percent to about 0.80 weight iron is employed.

The silicon content of the high-conductivity strands is also of significant importance and should be from about 0.01 to about 0.15 weight percent. Superior results are achieved when the silicon content is from 0.01 to about 0.07 weight percent. The ratio between the percentage iron and percentage silicon is another important consideration in this alloy. That ratio should be 1.99:1 or greater with a preferable ratio between percentage iron and percentage silicon being 8:1 or greater. Thus, if the present aluminum alloy contains an amount of iron within the low area of the present range for iron content, the percentage of aluminum must be increased rather than increasing the percentage of silicon outside the ratio limitation previously specified. It has been found that properly processed wire having aluminum alloy constituents which fall within the above-specified ranges possesses acceptable electrical conductivity and improved tensile strength and ultimate elongation and in addition has a novel unexpected property of surprisingly increased bendability and fatigue resistance.

The high-conductivity aluminum alloy is prepared by initially melting and alloying aluminum with the necessary amounts of iron or other constituents to provide the requisite alloy for processing. Normally, the content of silicon is main-

tained as low as possible without adding additional amounts to the melt. Typical impurities or trace elements are also present within the melt and it is important to closely control these elements within a range of from about 0.0001 to about 0.05 weight percent for each element. The total content of trace elements should be from about 0.004 to about 0.15 weight percent. Of course, when adjusting the amounts of trace elements due consideration must be given to the conductivity of the final alloy since some trace elements affect conductivity more severely than others. The typical trace elements include vanadium, copper, manganese, magnesium, zinc, boron and titanium. If the content of titanium is relatively high (but still quite low compared to the aluminum, iron and silicon content), small amounts of boron may be added to tie up the excess titanium and keep it from reducing the conductivity of the wire.

Iron is the major constituent added to the melt to produce the alloy of the present invention. Normally, about 0.50 weight percent is added to the typical aluminum component used to prepare the present alloy. Of course, the scope of the present invention includes the addition of more or less iron together with the adjustment of the content of all alloying constituents.

Strands of high-conductivity aluminum alloy are prepared by initially continuously casting the melted alloy into a continuous bar. The bar is then hot-worked in substantially that condition in which it is received from the casting machine. A typical hot-working operation comprises rolling the bar in a rolling mill substantially immediately after being cast into a bar.

One example of a continuous casting and rolling operation capable of producing continuous rod as specified in this application is as follows:

A continuous casting machine serves as a means for solidifying the molten aluminum alloy metal to provide a cast bar that is conveyed in substantially the condition in which it solidified from the continuous casting machine to the rolling mill, which serves as a means for hot forming the cast bar into rod or another hot formed product in a manner which imparts substantial movement to the cast bar along a plurality of angularly disposed axes.

The continuous casting machine is of conventional casting wheel type having a casting wheel with a casting groove partially closed by an endless belt supported by the casting wheel and an idler pulley. The casting wheel and the endless belt cooperate to provide a mold into one end of which molten metal is poured to solidify and from the other end of which the cast bar is emitted in substantially that condition in which it solidified.

The rolling mill is of conventional type having a plurality of roll stands arranged to hot form the cast bar by a series of deformations. The continuous casting machine and the rolling mill are positioned relative to each other so that the cast bar enters the rolling mill substantially immediately after solidification and in substantially that condition in which it solidified. In this condition, the cast bar is at a hot-forming temperature within the range of temperatures for hot-forming the cast bar at the initiation of hot-forming without heating between the casting machine and the rolling mill. In the event that it is desired to closely control the hot-forming temperature of the cast bar within the conventional range of hot-forming temperatures, means for adjusting the temperature of the cast bar may be placed between the continuous casting machine and the rolling mill.

The roll stands each include a plurality of rolls which engage the cast bar. The rolls of each roll stand may be two or more in number and arranged diametrically opposite from one another or arranged at equally spaced positions about the axis of movement of the cast bar through the rolling mill. The rolls of each roll stand of the rolling mill are rotated at a predetermined speed by a power means such as one or more electric motors and the casting wheel is rotated at a speed generally determined by its operating characteristics. The rolling mill

serves to hot-form the cast bar into a rod of a cross-sectional area substantially less than that of the cast bar as it enters the rolling mill.

The peripheral surfaces of the rolls of adjacent roll stands in the rolling mill change in configuration; that is, the cast bar is engaged by the rolls of successive roll stands with surfaces of varying configuration, and from different directions. This varying surface engagement of the cast bar in the roll stands functions to knead or shape the metal in the cast bar in such a manner that it is worked at each roll stand and also to simultaneously reduce and change the cross-sectional area of the cast bar into that of the rod.

As each roll stand engages the cast bar, it is desirable that the cast bar be received with sufficient volume per unit of time at the roll stand for the cast bar to generally fill the space defined by the rolls of the roll stand so that the rolls will be effective to work the metal in the cast bar. However, it is also desirable that the space defined by the rolls of each roll stand not be overfilled so that the cast bar will not be forced into the gaps between the rolls. Thus, it is desirable that the rod be fed toward each roll stand at a volume per unit of time which is sufficient to fill, but not overfill, the space defined by the rolls of the roll stand.

As the cast bar is received from the continuous casting machine, it usually has one large flat surface corresponding to the surface of the endless band and inwardly tapered side surfaces corresponding to the shape of the groove in the casting wheel. As the cast bar is compressed by the rolls of the roll stands, the cast bar is deformed so that it generally takes the cross-sectional shape defined by the adjacent peripheries of the rolls of each roll stand.

Thus, it will be understood that with this apparatus, cast aluminum alloy rod of an infinite number of different lengths is prepared by simultaneous casting of the molten aluminum alloy and hot-forming or rolling the cast aluminum bar.

The continuous rod produced by the casting and rolling operation is then processed in a reduction operation designed to produce continuous high-conductivity strands of various gauges. The unannealed rod (i.e., as rolled to *f* temper) is cold drawn through a series of progressively constricted dies, without intermediate anneals, to form a continuous strand of desired diameter. At the conclusion of this drawing operation, the alloy strand will have an excessively high tensile strength and an unacceptably low ultimate elongation, plus a conductivity below that which is industry accepted as the minimum for an electrical conductor, i.e., 61 percent IACS. The strand is then annealed or partially annealed to obtain a desired tensile strength and cooled. At the conclusion of the annealing operation, it is found that the annealed alloy strand has the properties of acceptable conductivity and improved tensile strength together with unexpectedly improved percent ultimate elongation and surprisingly increased bendability and fatigue resistance as specified previously in this application. The annealing operation may be continuous as in resistance annealing, induction annealing, convection annealing by continuous furnaces or radiation annealing by continuous furnaces, or, preferably, may be batch annealed in a batch furnace. When continuously annealing, temperatures of about 450° to about 1200° F. may be employed with annealing times of about 5 minutes to about 1/10,000 of a minute. Generally, however, continuous annealing temperatures and times may be adjusted to meet the requirements of the particular overall processing operation so long as the desired tensile strength is achieved. In a batch annealing operation, a temperature of approximately 400° to about 750° F. is employed with residence times of about thirty (30) minutes to about twenty-four (24) hours. As mentioned with respect to continuous annealing, in batch annealing the times and temperatures may be varied to suit the overall process so long as the desired tensile strength is obtained. Simply by way of example, it has been found that the following tensile strengths in the present aluminum strand are achieved with the listed batch annealing temperatures and times.

TABLE I

Tensile Strength	Temperature	Time
12,000 to 14,000	650° F.	3 hours
14,000 to 15,000	550° F.	3 hours
15,000 to 17,000	520° F.	3 hours
17,000 to 22,000	480° F.	3 hours

During the continuous casting of this alloy, a substantial portion of the iron present in the alloy precipitates out of solution as iron aluminate intermetallic compound (FeAl_2). Thus, after casting, the bar contains a dispersion of FeAl_2 in a supersaturated solid solution matrix. The supersaturated matrix may contain as much as 0.17 weight percent iron. As the bar is rolled in a hot-working operation immediately after casting, the FeAl_2 particles are broken up and dispersed throughout the matrix inhibiting large cell formation. When the rod is then drawn to its final gauge size without intermediate anneals and then aged in a final annealing operation, the tensile strength, elongation and bendability are increased due to the small cell size and the additional pinning of dislocations by preferential precipitation of FeAl_2 on the dislocation sites. Therefore, new dislocation sources must be activated under the applied stress of the drawing operation and this causes both the strength and the elongation to be further improved.

The properties of the present aluminum alloy strand are significantly affected by the size of the FeAl_2 particles in the matrix. Coarse precipitates reduce the percent elongation and bendability of the wire by enhancing nucleation and thus, formation of large cells which, in turn, lowers the recrystallization temperature of the strand. Fine precipitates improve the percent elongation and bendability by reducing nucleation and increasing the recrystallization temperature. Grossly coarse precipitates of FeAl_2 cause the strand to become brittle and generally unusable. Coarse precipitates have a particle size of above 2,000 angstrom units and fine precipitates have a particle size of below 2,000 angstrom units.

A typical alloy No. 12 AWG wire strand of the present invention has physical properties of 15,000 p.s.i. tensile strength, ultimate elongation of 20 percent, conductivity of 61 percent IACS, and bendability of 20 bends to break. Ranges of physical properties generally provided by No. 12 AWG wire strand prepared from the present alloy include tensile strengths of about 12,000 to about 22,000 p.s.i., ultimate elongations of about 40 percent to about 5 percent, conductivities of about 61 percent to about 63 percent and number of bends to break of about 45 to 10.

A more complete understanding of the nature of the high conductivity strands will be obtained from the following examples.

EXAMPLE NO. 1

A comparison between prior EC aluminum alloy strands and the present aluminum alloy strands is provided by preparing a prior EC alloy with aluminum content of 99.73 weight percent, iron content of 0.18 weight percent, silicon content of 0.059 weight percent, and trace amounts of typical impurities. The present alloy is prepared with aluminum content of 99.45 weight percent, iron content of 0.45 weight percent, silicon content of 0.056 weight percent, and trace amounts of typical impurities. Both alloys are continuously cast into continuous bars and hot-rolled into continuous rod in similar fashion. The alloys are then cold-drawn through successively constricted dies to yield a No. 12 AWG continuous strand. Sections of the strand are collected on separate bobbins and batch furnace-annealed at various temperatures and for various lengths of time to yield sections of the prior EC alloy and the present alloy of varying tensile strengths. Several samples of each section are tested in a device designed to measure the number of bends required to break each sample at a particular flexure point. Through uniform force and tension, the device

fatigues each sample through an arc of approximately 135°. The wire is bent across a pair of spaced opposed mandrels having a diameter equal to that of the strand. The mandrels are spaced apart a distance of about 1½ times the diameter of the strand. One bend is recorded after the strand is deflected from a vertical disposition to one extreme of the arc, returned back to vertical, deflected to the opposite extreme of the arc, and returned back to the original vertical disposition. The speed of deflection, force and tension are substantially equal for all tested samples. The results are as follows:

TABLE IIA

EC Alloy Strand		Present Alloy Strand	
Tensile Strength	No. of Bends to Break	Tensile Strength	Average No. of Bends to Break
10,083	43-½	13,500	44
12,788	24	14,300	43
13,480	21-½	15,100	36
14,168	14	16,025	29-½
15,200	13-¾	17,050	23
16,100		17,134	18
17,125	9-¾	18,253	14
18,186	8-¾	19,571	13
23,069	5-½	25,286	4-¾
29,309	4	35,986	3-¾

As shown in Table IIA, the present alloy has a surprisingly improved property of bendability over conventional EC alloy.

Several samples of the present alloy No. 12 AWG strand and EC alloy No. 12 AWG strand, processed as previously specified, are then tested for percent ultimate elongation by standard testing procedures. At the instant of breakage, the increase in length of the strand is measured. The percent ultimate elongation is then figured by dividing the initial length of the strand sample into the increase in length of the strand sample. The tensile strength of the strand sample is recorded as the pounds per square inch of cross-sectional diameter required to break the strand during the percent ultimate elongation test. The results are as follows:

TABLE IIB

EC Alloy Strands		Present Alloy Strands	
Tensile Strength	Percent Ultimate Elongation	Tensile Strength	Percent Ultimate Elongation
		13,500	30.8%
10,000	30.5%	14,300	30%
12,700	21%	15,525	24%
13,500	14%	16,150	19%
14,200	11.5%	16,550	16%
15,000	8%	17,200	13.2%
16,500	3.5%	18,270	8.6%
18,300	2%	19,000	6.7%

As shown in Table IIB, the present alloy has a surprisingly improved property of percent ultimate elongation over conventional EC alloy

EXAMPLES 2 THROUGH 7

Six aluminum alloys are prepared with varying amounts of major constituents. Those alloys are reported in the following table:

TABLE III

Example No.	% Al	% Fe	% Si
2	99.73	0.180	0.059
3	99.52	0.385	0.063
4	99.46	0.450	0.056
5	99.36	0.540	0.064

6	99.275	0.680	0.015
7	99.20	0.750	0.030

The six alloys are then cast into six continuous bars and hot-rolled into six continuous rods. The rods are cold-drawn through successively constricted dies to yield No. 12 gauge strands. The strands produced from the alloys of examples No. 2 and 4 are resistance annealed and the remainder of the examples are batch furnace annealed to yield the tensile strengths reported in Table IV. After annealing, each of the strands is tested for percent conductivity, tensile strength, percent ultimate elongation and average number of bends to break by standard testing procedures for each, except that the procedure specified in Example No. 1 is used for determining average number of bends to break. These results are reported in the following table.

TABLE IV

Example No.	Conductivity in % IACS	Tensile Strength	Ultimate Elongation	Average No. of Bends to Break
2	62.8	15,150	8.1	15½
3	61.3	15,153	28.0	27½
4	61.5	15,152	37.5	28
5	61.5	15,152	35.0	28½
6	61.25	14,300	28.0	32
7	61.2	15,800	25	28

From a review of these results, it may be seen that Example No. 2 falls outside the scope of the present invention in percentage of components. In addition it will be noted for Example No. 2 that the percentage of ultimate elongation is somewhat lower than desirable and the average number of bends to break the sample is lower than the remaining examples.

A characteristic of high-conductivity aluminum alloy strands which is not indicated by the historical tests for tensile strength, percent elongation and electrical conductivity is the possible change in properties as a result of increases, decreases or fluctuations of the temperature of the strands. It is apparent that the maximum operating temperature of a strand or series of strands will be affected by this temperature characteristic. The characteristic is also quite significant from a manufacturing viewpoint since many insulation processes require high-temperature thermal cures.

It has been found that the aluminum alloy strands for use in the high-conductivity portion of the present cable have a characteristic of thermal stability which exceeds conventional EC grade aluminum alloy strands. In order to demonstrate this feature a group of three-eighths inch continuously cast and rolled aluminum alloy rods is selected. All samples of the present high-conductivity strands are fabricated from these quantities of rod. Three commercially pure alloy rods, with compositions and properties normally associated with electrical conductor (EC) alloy, are also chosen in order to broaden the base for comparison. The chemical composition of the alloy rod samples is listed in Table V.

TABLE V

Chemical Composition, Weight Percent

(Rod Designation)	Fe	Si	Mg	Mn	Cu	B	Ti, V, Ni, Cr Less than each
70 EC Al-No. 1	.09	.054	.002	.001	.003	.006	
EC Al-No. 2	.10	.052	.002	.001	.003	.006	.001%
EC Al-No. 3	.14	.053	.002	.001	.002	.011	
75 Present Alloy	.60	.050	.002	.002	.004	.006	

Processing methods such as the sequences and amounts of each drawing operation and associated anneals have an effect on the properties of finished strands. The manufacturing processes used were limited to five (5) common methods to produce commercially pure aluminum strands with fairly wide ranges of properties or tempers. The processing of the present alloy was limited to three tempers, each of which are annealed after all drawing operations. Table VI lists the values for ultimate tensile strength ultimate elongation as measured in 10 inches, and electrical conductivity of 14 AWG solid strands obtained by the various methods of manufacture.

TABLE VI

	Temper	H-18	H-26	H-24	H-12	"O"
EC-No. 1	Tensile	26.2	18.0	15.3	14.3	9.2
	Elongation	1.5	1.2	8.3	2.0	28.0
	Conductivity	62.7	63.6	63.5	63.7	63.8
EC-No. 2	Tensile	29.7	17.7	15.1	15.0	10.2
	Elongation	1.4	1.3	7.2	2.1	26.8
	Conductivity	62.4	63.3	63.4	63.6	63.9
EC-No. 3	Tensile	23.0	17.8	14.9	14.6	9.2
	Elongation	1.6	1.1	4.3	2.5	29.3
	Conductivity	63.4	63.5	63.7	63.6	64.0
Present Alloy	Tensile		18.2	15.5		13.0
	Elongation		10.0	19.0		27.9
	Conductivity		62.1	62.6		62.9

Tensile—KSI

Elongation—%

Conductivity—%IACS

H—18 — drawn from $\frac{3}{8}$ -in. Rod to 0.064 Dia.H—26 — drawn from $\frac{3}{8}$ -in. Rod to 0.064 Dia. — partially annealed to 18 KSIH—24 — drawn from $\frac{3}{8}$ -in. Rod to 0.064 Dia. — partially annealed to 15 KSIH—12 — drawn from $\frac{3}{8}$ -in. Rod to 0.081 Dia. — fully annealed — Drawn to 0.064 Dia."O" — drawn from $\frac{3}{8}$ -in. Rod to 0.064 Dia. — fully annealed

Several significant points stand out in this comparison. The ultimate elongation of the present alloy in the H26 and H24 tempers is significantly greater than any other alloy temper except fully annealed. In the fully annealed condition the present alloy tensile strength is from 27 to 41 percent greater than the EC alloys. The electrical conductivity of all alloy wires is well within the range of present specifications for electrical conductor grade aluminum alloy. The strained hardened H12 temper alloys have considerably less elongation than those of the same tensile strength in the H24 temper.

Two particular thermal tests are performed. A recrystallization hardness test of the alloys in which Rockwell H hardness readings are taken on samples after thermal soaks at various temperatures is run. Specimens used for this test are 0.060 inches thick strips fabricated from the alloy rods by cold rolling. The results of this test are reported in Table VII.

TABLE VII

Rockwell H Hardness

At Varying Temperatures

	100°	150°	200°	250°	300°
EC No. 1	85	80	78	70	19
EC No. 2	83	81	80	71	25
EC No. 3	78	72	68	73	20
Present Alloy	92	92	91	80	49

The second thermal test consists of measuring the ultimate tensile strength of the alloy strands in the H26 temper series after thermal soak periods of 4 hours at 225° C., 250° C., and 275° C. The strand tensile thermal stability test results are reported in Table VIII.

TABLE VIII

THERMAL STABILITY ULTIMATE TENSILE STRENGTH — KSI

Wire Designation	Finished Strand Tensile Strength	After 4 hr. at 225° C.	After 4 hr. at 225° C.	After 4 hr. at 225° C.
EC No. 1—H26	18.0	17.6	15.7	11.8
EC No. 2—H26	17.7	17.7	16.1	12.7
EC No. 3—H26	17.8	10.0	10.0	9.5
Present Alloy—H26	18.2	18.5	18.3	17.1

A significant aspect shown by the results of these tests is the lack of thermal stability obtainable with commercially pure EC aluminum alloys. The test samples fabricated from alloy rod EC No. 3 show a significant decrease in thermal stability in both the recrystallization hardness and the tensile strength tests. In fact, this alloy has almost completely softened after a 4-hour soak period at 225° C. On the other hand, the strands fabricated from the present high-conductivity alloy demonstrate a relatively high degree of thermal stability in both the recrystallization hardness and tensile strength tests.

One of the principal advantages of a multistrand conductor having both high-strength strands and high-conductivity strands of aluminum is that the high-strength strands not only provide the strength needed but even enhance rather than detract from the electrical conductivity of the cable as a whole. When used in combination with the strands of electrically conductive aluminum, fewer high-conductivity strands are needed to meet a given conductance requirement. Accordingly, the multistrand conductor of relatively small cross section can be readily tailored to meet the particular strength and electrical conductivity requirements for any given application. A unique feature of tailoring the conductor for different applications, assuming all strands are of the same diameter, is that a high-conductivity strand can be selectively exchanged for a high-strength strand to thereby meet the required new properties of strength and electrical conductance. Another unique feature involved in tailoring the conductor by selectively exchanging strands is that the overall weight of the conductor remains substantially the same. An example of such an exchange is the aforescribed FIGS. 3-4 with the same overall number of strands employed, but wherein the number of strands 38 in FIG. 4 have been increased while the number of strands 40 have been proportionately reduced. Similarly, FIGS. 2 and 5 have the same overall total number of strands but the strength strands and conductivity strands have been selectively interchanged. The multistrand conductor is especially adaptable for power transmission lines at extra high voltages often identified by the abbreviation, "EHV," wherein the voltage carried ranges from 345,000 to 1,000,000 volts.

Another notable property of the all aluminum multistrand conductor is that the aluminum making up each set of strands is relatively corrosion resistant. Further the solution potential of each set of strands is approximately the same and therefore the cable assembly is not subject to galvanic action that normally occurs in cable structures of dissimilar and exposed materials. Thus, the strength of the alloy strands cannot be seriously affected by corrosion during use.

The unique structure and advantage of the conductor of the instant invention will be further apparent from a comparison of this conductor with a multi-strand conductor of the prior art, such as an "ACSR," i.e., Aluminum Conductor Steel Reinforced, having EC aluminum alloy strands and steel

strands. A listing of the properties of the two conductors is as follows:

TABLE IX

Construction	Conductors of Application		ASCR
	4/3*	3/4*	
Diameter of Strands	0.1878	0.1878	0.1878
Actual Area (Circular Mills):			
Conductivity strand	141,076	105,807	211,614
6201	105,807	141,076	
Steel			35,269
Total Area	246,883	246,883	246,883
Percentage of Area:			
Conductivity strand	57.15%	42.85%	85.7%
6201	42.85%	57.15%	
Steel			14.3%
Total	100.00	100.00	100.00
Equivalent Conductivity (IACS)	57.9%	56.6%	53.1%
(Based on International Annealed Copper Standards)			
Weight, lb. per 1,000 ft. cable length:			
Conductivity strand	132.5	99.3	197.7
6201	99.3	132.5	
Steel			93.4
Total	231.8	231.8	291.1
Rated Strength	6,330	6,890	8,420
Strength/Weight ratio	27,310	29,720	28,920

* The 4/3 construction is shown in FIG. 1 while the 3/4 construction is shown in FIG. 5 with the outer strand layer removed. The 6/1 ASCR conductor is the same cross-sectional pattern of FIG. 1 wherein the core strand is steel and the outer strand layer is six strands of E.C. grade aluminum.

It can be obviously concluded from the above figures, that the conductor of the instant invention not only provides greater equivalent electrical conductivity than the prior art ASCR conductor but also provides less weight per unit length and a more controllable strength to weight ratio, to meet given requirements.

In a further advantageous embodiment of this invention and as indicated for example in FIG. 6, an outer layer of high-strength alloy strands 22a is located on the outside of the cable while the relatively higher conductivity strands 24a are disposed toward the inside of the cable structure. This structure retains all of the advantages of the conductor assembly of the instant invention.

One advantage of such an interchange of strands is that the outermost layer of alloy strands presents a relatively harder surface. This harder surface remains substantially smooth and unbroken during handling and installation of the conductor or engagement of the conductor by the customary suspension elements or other accessories to thereby minimize the phenomena of corona effect and consequent current loss, thereby as well as to minimize interference to radio and T.V. reception in proximity of the transmission lines.

As used in this application the word "strand" means a product that is long in relation to its cross section. In cross section, the strand is square or rectangular with sharp or rounded corners or edges, or is round, elliptical, hexagonal or octagonal. The diameter or greatest perpendicular distance between parallel faces is between 3 and 0.0031 inches. In addition it should be understood that the word "strand" may also mean a synthetic material such as a fiber or a thread or yarn prepared from fibers of such material as graphite, a polyamide such as nylon, polyethylene, polypropylene, copolymers of polyethylene and polypropylene and/or other polymers, and polyesters such as polyethylene terephthalate.

Furthermore, as used in this application, the expression "high strength" when used together with the words "strand" or "material" means a strength in excess of 40,000 p.s.i. tensile strength.

While this invention has been described in detail with particular reference to preferred embodiments thereof, it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described hereinbefore and as defined in the appended claims.

I claim:

1. A multistrand cable for transmission of electrical power having at least two strands, one strand consisting essentially of a high strength material with a conductivity of less than 61 percent IACS, the second strand having a minimum conductivity of 61 percent IACS and a diameter or greatest perpendicular distance between parallel faces of between 0.460 and 0.0031 inch and consisting essentially of from about 0.55 to about 0.95 weight percent iron; 0.01 to about 0.15 weight percent silicon; 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium, and from about 98.95 to less than 99.45 weight percent aluminum with from 0.004 to 0.15 weight percent trace elements and an iron to silicon ratio of 8:1 or greater.

2. Multistrand cable of claim 1 wherein the second strand consists essentially of from about 0.80 to about 0.95 weight percent iron; from about 0.07 to about 0.15 weight percent silicon; and from about 98.95 to about 99.13 weight percent aluminum.

3. Multistrand cable of claim 1 wherein the second strand consists essentially of from about 0.55 to about 0.80 weight percent iron; from about 0.01 to about 0.07 weight percent silicon; and from about 99.15 to about 99.40 weight percent aluminum.

4. Multistrand cable of claim 1 wherein the second strand consists essentially of from about 0.55 to less than 0.60 weight percent iron; and from about 0.01 to about 0.15 weight percent silicon; and from about 99.10 to about 99.44 weight percent aluminum.

5. Multistrand cable of claim 1 wherein in the second strand the silicon content is from 0.01 to 0.15 weight percent, the individual trace element content is from 0.0001 to 0.05 weight percent, and the total trace element content is from 0.004 to 0.15 weight percent.

6. Multistrand cable of claim 1 wherein said one strand consisting essentially of high-strength material is selected from the group consisting of strands of steel, aluminum alloy, synthetic fibers and combinations thereof.

7. A multistrand cable for transmission of electrical power having at least two sets of strands, the strands in one set of strands consisting essentially of a high-strength material with a conductivity of less than 61 percent IACS, the strands in the second set of strands having a minimum conductivity of 61 percent IACS and a diameter or greatest perpendicular distance between parallel faces of between 0.460 and 0.0031 inch and consisting essentially of from about 0.55 to about 0.95 weight percent iron; 0.01 to about 0.15 weight percent silicon; 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium; and from about 98.95 to less than 99.45 weight percent aluminum with from 0.004 to 0.15 weight percent trace elements and an iron to silicon ratio of 8:1 or greater.

8. A multistrand cable for transmission of electrical power having at least two strands, one strand consisting essentially of a high-strength material with a conductivity of less than 61 percent IACS, the second strand being an aluminum alloy and having a minimum conductivity of 61 percent IACS and a diameter or greatest perpendicular distance between parallel faces of between 0.460 and 0.0031 inch and containing substantially evenly distributed iron aluminate inclusions in a concentration produced by the presence of about 0.45 to about 0.95 weight percent iron in an alloy mass consisting essentially of about 98.95 to less than 99.45 weight percent aluminum, 0.01 to about 0.15 weight percent silicon; and 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium, said iron aluminate inclusions having a particle size of less than 2,000 angstrom units.

9. Multistrand cable of claim 8 wherein in the second strand iron is present in a concentration of about 0.55 to about 0.95 weight percent; silicon is present in a concentration of about 0.01 to about 0.15 weight percent; and aluminum is present in a concentration of about 98.95 to about 99.44 weight percent.

10. Multistrand cable of claim 8 wherein in the second strand iron is present in a concentration of about 0.80 to about 0.95 weight percent; silicon is present in a concentration of about 0.07 to about 0.15 weight percent; and aluminum is present in a concentration of about 98.95 to about 99.13 weight percent.

11. Multistrand cable of claim 8 wherein in the second strand iron is present in a concentration of about 0.50 to about 0.80 weight percent; silicon is present in a concentration of about 0.01 to about 0.07 weight percent; aluminum is present in a concentration of about 99.15 to about 99.40 weight percent.

12. Multistrand cable of claim 8 wherein in the second strand iron is present in a concentration of about 0.45 to less than 0.60 weight percent; silicon is present in a concentration of about 0.01 to about 0.15 weight percent; and aluminum is present in a concentration of about 99.10 to about 99.54 weight percent.

13. Multistrand cable of claim 8 wherein in the second strand iron is present in a concentration of about 0.55 to less than 0.60 weight percent; silicon is present in a concentration of about 0.01 to about 0.15 weight percent; and aluminum is present in a concentration of about 99.10 to about 99.44 weight percent.

14. Multistrand cable of claim 8 wherein in the second strand the silicon content is from 0.01 to 0.15 weight percent, the individual trace element content is from 0.0001 to 0.05 and the total trace element content is from 0.004 to 0.15 weight percent.

15. Multistrand cable of claim 8 wherein said one strand consisting essentially of high-strength material is selected from the group consisting of strands of steel, aluminum alloy, synthetic fibers, and combinations thereof.

16. A multistrand cable for transmission of electrical power having at least two sets of strands, the strands of one set of strands consisting essentially of a high-strength material with a conductivity of less than 61 percent IACS, the strands in the second set of strands being an aluminum alloy and having a minimum conductivity of 61 percent IACS and a diameter or greatest perpendicular distance between parallel faces of between 0.460 and 0.0031 inch and containing substantially evenly distributed iron aluminate inclusions in a concentration produced by the presence of about 0.45 to about 0.95 weight percent iron in an alloy mass consisting essentially of about 98.95 to less than 99.45 weight percent aluminum, 0.01 to

0.15 weight percent silicon; and 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium, said iron aluminate inclusions having a particle size of less than 2,000 angstrom units.

17. A multistrand cable for transmission of electrical power having a plurality of high-strength core strands and a plurality of outer conductor strands, said high-strength core strands consisting essentially of an aluminum alloy having up to 0.10 percent by weight copper, up to 0.50 percent by weight iron, up to 0.03 percent by weight manganese, up to 0.10 percent by weight zinc, up to 0.03 percent by weight chromium, up to 0.06 percent by weight boron, about 0.50 to 0.90 percent by weight silicon, about 0.60 to about 0.90 percent by weight magnesium, and the balance aluminum; said outer conductor strands consisting essentially of an aluminum alloy with a minimum conductivity of 61 percent IACS and containing from about 0.55 to about 0.95 weight percent iron; 0.01 to about 0.15 weight percent silicon; 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium; and from about 98.95 to less than 99.45 weight percent aluminum with from 0.004 to 0.15 weight percent trace elements and an iron to silicon ratio of 8:1 or greater.

18. A multistrand cable for transmission of electrical power having a plurality of high-strength core strands and a plurality of outer conductor strands, said high-strength core strands consisting essentially of an aluminum alloy having up to 0.10 percent by weight copper, up to 0.50 percent by weight iron, up to 0.03 percent by weight manganese, up to 0.10 percent by weight zinc, up to 0.03 percent by weight chromium, up to 0.06 percent by weight boron, about 0.50 to 0.90 percent by weight silicon, about 0.60 to about 0.90 percent by weight magnesium, and the balance aluminum; said outer conductor strands consisting essentially of an aluminum alloy with a minimum conductivity of 61 percent IACS and containing substantially evenly distributed iron aluminate inclusions in a concentration produced by the presence of about 0.45 to about 0.95 weight percent iron in an alloy mass consisting essentially of about 98.95 to less than 99.45 weight percent aluminum, 0.01 to about 0.15 weight percent silicon, and 0.0001 to 0.05 weight percent each of trace elements selected from the group consisting of vanadium, copper, manganese, magnesium, zinc, boron, and titanium, said iron aluminate inclusions having a particle size of less than 2,000 angstrom units.

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