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(54) **Beryllium-Copper conductor**

(57) A process is provided for forming an age hardened wire for use as an electrical conductor, which wire is formed from a copper base alloy consisting of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy, with the nickel and beryllium being present in the copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0. The process comprises the steps of providing a copper base alloy material consisting

of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy, which nickel and beryllium are present in the copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0, cold working the material in a single step; and age hardening the cold worked material in a single step to form a wire in a cold worked and aged hardened condition having an electrical conductivity of at least about 60% IACS.

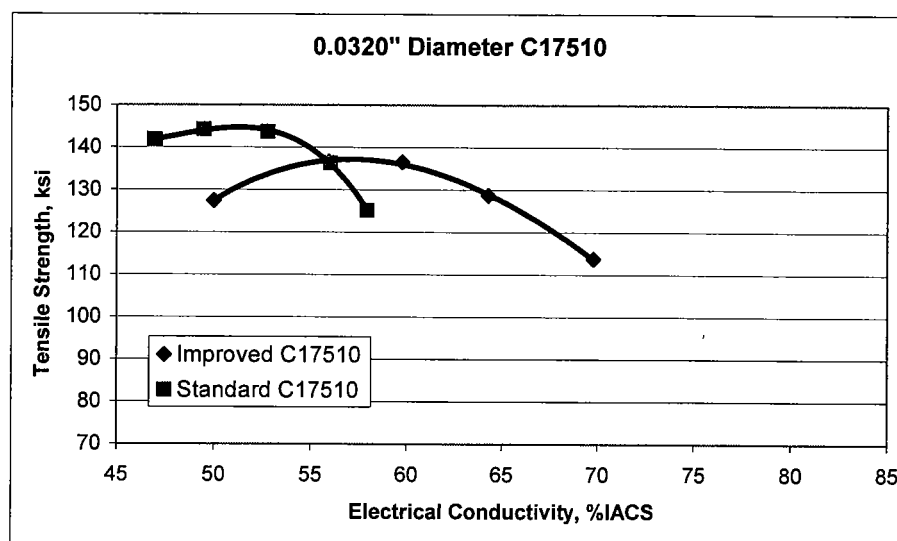


FIG. 1

Description

CROSS REFERENCE TO RELATED APPLICATION(S)

5 [0001] This application claims the priority of U. S. Provisional Patent Application No. 60/903,788, entitled Beryllium-Copper Conductor, filed on February 27, 2007.

BACKGROUND

10 (1) Field of the Invention

[0002] The present invention relates to an electrical conductor formed from a beryllium-copper alloy which can be formed into a single end or stranded wire.

15 (2) Prior Art

[0003] Alloy C17510 is a high conductivity Be-Cu alloy used both as an electronic connector and an electrical conductor. U.S. patent numbers 4,594,116; 4,727,002; and 4,838,959 describe the process and the resultant properties obtained for an electrical conductor using this alloy. The aim is to obtain a product having 95 ksi tensile strength and 60% IACS electrical conductivity. The described process consists of deforming a solution annealed wire greater than 99% cross sectional area followed by over-aging. This process is different than what is normally utilized for this alloy where the material is aged directly after solution treatment (AT or TF00 temper) or after deforming 60% (HT or TH04 temper) to obtain maximum tensile strength. This aging treatment for a conductor is designed to provide a higher electrical conductivity at the cost of tensile strength.

25 [0004] The main attributes of a conductor are its electrical conductivity and tensile strength. These two characteristics are often conflicting. Attempts to increase one result in reduction of the other. It is quite beneficial to conceive of methods to increase conductivity without sacrificing the strength of the conductor.

[0005] Alloy C17510 in conductor applications is typically supplied with silver plating. The higher aging temperature required to age this wire at finish can result in a yellow discoloration. This discoloration is an unacceptable condition which requires great care to prevent and when ensued is cause for rejection of the conductor. It would be quite beneficial to conceive a method to avoid this discoloration.

SUMMARY OF THE INVENTION

35 [0006] The present invention discloses a new alloy composition to improve electrical conductivity of C 17510 and improve surface brightness of the silver plated product following final heat treatment.

[0007] In accordance with the present invention, there is provided an age hardened wire for use as an electrical conductor. The wire is formed from a copper base alloy consisting of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy. The nickel and beryllium are present in the copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0. The wire is in a cold worked and aged hardened condition so as to have an electrical conductivity of at least about 60% IACS.

45 [0008] Further in accordance with the present invention, there is provided a process for forming an age hardened wire for use as an electrical conductor. The process broadly comprises the steps of providing a copper base alloy material consisting of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy, said nickel and beryllium being present in said copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0, cold working said material in a single step; and age hardening said cold worked material in a single step to form a wire in a cold worked and aged hardened condition having an electrical conductivity of at least about 60% IACS.

50 [0009] Other details of the beryllium-copper conductor of the present invention, as well as other objects and advantages attendant thereto, are set forth in the following detailed description and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

55 [0010] Fig. 1 is a graph showing tensile strength versus electrical conductivity at 0.0320" diameter aged 725-975°F;
 [0011] Fig. 2 is a graph showing tensile strength versus electrical conductivity at 0.0177" diameter aged 725-975°F;
 [0012] Fig. 3 is a graph showing tensile strength versus electrical conductivity at 0.004" diameter aged 725-975°F;
 [0013] Fig. 4 is a graph showing tensile strength versus conductivity for improved C17510 aged 3 hours at 725-975°F;
 and

[0014] Fig. 5 is a graph showing tensile strength vs. electrical conductivity for Std. C 17510 aged 3 hours at 725-975°F.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0015] The Copper Development Association (CDA) nominal composition of alloy C17510 is listed in Table 1. This is a broad range of chemistry and if utilized allows for a wide range of properties. The alloy, however, is normally cast with a nominal composition of about 0.35% Be and 1.6% Ni or a Ni/Be ratio of 4.6. The alloy utilized in the above mentioned patents is similar to this chemistry having 0.38% Be and 1.66% Ni, a Ni/Be ratio of 4.4. If the broad range of chemistry listed for the alloy is utilized the Ni/Be range will vary from 2.3 to 11.

Table 1. Composition Range for C17510

Be, %	Ni, %	Cu	Impurities, % Max
0.20-0.60	1.4-2.2	Balance	0.10 Fe, 0.30 Co, 0.20 Si, 0.20 Al

[0016] High conductivity Be-Cu alloy C17510 contains a small amount of Be and a relatively larger amount of Ni. Ni readily reacts with Be forming beryllides. Ni beryllides mainly work as a grain refiner. Upon heat treatment (aging) of the normal chemistry of C17510, only a portion of the Be is combined with Ni to form beryllide leaving excess Be in elemental form. The free Be left in the copper matrix reduces electrical conductivity without substantially increasing strength of the alloy. Additionally, during the aging treatment the free Be can easily diffuse through silver plating to the surface of the wire causing a yellow discoloration. This discoloration is an unacceptable feature of the silver plated material.

[0017] Increasing the Ni/Be ratio in this alloy was found to increase the electrical conductivity of the alloy by reducing the remaining elemental beryllium. The improved alloy chemistry is defined by the ratio of Ni/Be to form nickel beryllide. Excess Ni beyond the amount needed to combine with Be will also reduce electrical conductivity of the alloy. Binary Ni-Be system shows two nickel beryllides, BeNi (γ) and Be₂₅Ni₅ (δ). BeNi is the beryllide forming in C 17510. Ni/Be weight ratio to form BeNi is 6.5. As stated previously, the range of Ni/Be with the permitted range of chemistry for C17510 is 2.3 to 11, with the typical ratio of 4.6.

[0018] In accordance with the present invention, there is described a copper nickel beryllium alloy where the Ni/Be weight ratio is close to 6.5, the stoichiometric ratio for NiBe. As a practical measure, the Ni/Be weight ratio can be in the range of from 5.0 to 8.0, but is preferably from 5.5 to 7.5, and most preferably from 6.0 to 7.0. The Be content of the alloy may be from 0.25 to 0.45 percent by weight and the nickel of the alloy content may be from 1.25 to 3.6 percent by weight. The alloy may have intentional or unintentional impurities which do not adversely affect properties of the alloy in particular electrical conductivity, such as up to 0.10 wt% iron, up to 0.30 wt% cobalt, up to 0.20 wt% silicon, and up to 0.20 wt% aluminum.

The alloy may be solution treated, cold worked and aged to provide electrical conductivity of at least 70% IACS with a tensile strength of at least 95 ksi. The alloy may also be solution treated, cold worked and aged to provide an electrical conductivity of at least 60% IACS and a tensile strength of at least 105 ksi. Typical solution treatment for the alloys is 1600°F to 1750°F for 15 minutes to 2 hours followed by the quench. The cold working may be performed in a single step using any suitable working device known in the art such as a drawing die. The cold working step should reduce the original dimension of the copper alloy material by an amount within the range of from at least 60% to 95%, preferably from 66% to 88%. Following cold working, the material may be age hardened at a temperature in the range of from 725°F to 925°F for a time period of up to 5.0 hours.

[0019] The alloy can be silver plated using any suitable plating treatment known in the art. By silver plating, it is meant that the silver plating can be a plating of pure silver or a silver alloy. One of the advantages to the present invention is that the resulting material does not discolor upon final heat treatment.

[0020] The following examples demonstrate advantages of the new improved chemistry.

Example 1.

[0021] A sample of alloy C 17510 was obtained with the Ni/Be weight ratio of 6.0. Chemistry of this alloy is listed in Table 2.

Table 2. Chemical composition for Improved C17510

Be, %	Ni, %	Cu
0.32	1.93	Balance

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[0022] Performance of this alloy was compared with C 17510 having "standard" or typical chemistry for this alloy. Chemical composition of material used for comparison is listed in Table 3. Ni/Be ratio for the standard chemistry sample is 4.4.

Table 3. Chemical composition for standard C17510

Be, %	Ni, %	Cu
0.36	1.57	Balance

[0023] Both the standard and improved wires were obtained in the solutionized condition at 0.0508" diameter following identical processing. Mechanical properties and electrical conductivity of the as received wires are listed in Table 4. Both versions of the alloy have the same tensile strength and elongation while improved C 17510 shows higher electrical conductivity.

Table 4. Mechanical properties and electrical conductivity of the solution annealed 0.0508" wire

Material	Tensile Strength, ksi	Elongation, % in 10"	Conductivity, %IACS
Standard C17510	55.8	27.5	35.9
Improved C17510	55.2	26.2	40.5

[0024] The two alloys shown in Tables 2 and 3 were plated with silver and drawn to 38 AWG (0.004" diameter). The silver plating thickness at 38 AWG was 40 micro-inches. This is the silver plating thickness required for most conductors. Using these single end wires, unilay stranded conductors consisting of 19 ends were made. This is a common conductor construction. The two conductors were heat treated to provide a minimum of 6% elongation as required by such conductors. Annealing was conducted in a typical box furnace under protective atmosphere of nitrogen. Following this heat treatment the conductor manufactured with the improved chemistry was bright with silver color. In contrast, the conductor with the standard chemistry was discolored showing an unacceptable yellow hue.

[0025] Additionally the properties of the improved chemistry were superior to those of the standard chemistry. The properties obtained following heat treatment of the two conductors are listed in Table 5. Electrical conductivity of the improved alloy is 10% greater than that of the standard alloy. The improved alloy also has a greater tensile strength and elongation.

Table 5. Tensile strength and electrical conductivity of 19/38 Unilay C17510 Conductor

Property	Improved Alloy	Standard Alloy
Tensile Strength, ksi	100.2	96.2
Elongation, %	12.4	11.4
Conductivity, %IACS	72.6	62.2

Example 2.

[0026] The wires of example 1 having the chemistries shown in Tables 2 and 3 were drawn in three steps to 38 AWG (0.004" in diameter), a typical conductor diameter. As expected, both alloys showed good drawability and could be easily drawn to greater than 99% reduction in area. Properties of the as-drawn wires as a function of cold reduction are listed in Table 6.

Table 6. Mechanical properties and electrical conductivity of as-drawn C17510

% Cold	Improved Alloy		Standard Alloy	
Work	Tensile Strength, ksi	Conductivity, %IACS	Tensile Strength, ksi	Conductivity, %IACS
0.0	55.2	40.5	55.8	35.9
20.8	74.3	40.5	74.0	36.3
35.5	77.6	39.5	79.0	34.9

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(continued)

% Cold	Improved Alloy		Standard Alloy	
Work	Tensile Strength, ksi	Conductivity, %IACS	Tensile Strength, ksi	Conductivity, %IACS
49.5	78.8	40.7	82.9	35.3
60.8	80.5	40.8	85.5	36.0
87.8	94.6	38.3	99.8	35.5
99.3	117.2	39.4	126.9	33.6

[0027] The standard chemistry shows a higher work hardening rate but at a lower electrical conductivity. At the highest cold reduction of 99.3% (38 AWG) tensile strength for the standard chemistry is about 10 ksi higher than that of improved C 17510

[0028] The wires drawn to 0.0320", 0.0179" and 0.004" diameter were aged at various temperatures for three (3) hours to determine their aging response. Tensile strength, elongation and electrical conductivity of these wires are listed in Tables 7-9.

Table 7. C17510 Properties drawn 60% to 0.0320" diameter and aged

Aging Temperature °F	Improved C17510			Standard C17510		
	Tensile Strength, ksi	Elongation, % in 10"	Conductivity %IACS	Tensile Strength, ksi	Elongation % in 10"	Conductivity %IACS
As Cold Worked	80.5	1.2	40.8	85.5	1.2	36.0
725	127.4	11.3	50.0	141.8	11.3	46.9
775	136.6	11.1	55.9	144.2	11.4	49.4
825	136.5	10.3	59.8	143.7	11.5	52.7
875	128.7	8.7	64.3	136.2	10.2	56.0
925	113.7	8.5	69.8	125.2	9.2	58.0

Table 8. C17510 Properties drawn 88% to 0.0179" diameter and aged

Aging Temperature °F	Improved C17510			Standard C17510		
	Tensile Strength, ksi	Elongation, % in 10"	Conductivity %IACS	Tensile Strength, ksi	Elongation % in 10"	Conductivity %IACS
As Cold Worked	94.6	1.2	38.3	99.8	1.3	35.5
725	130.9	8.9	49.2	146.5	10.0	46.4
775	142.2	8.9	56.3	148.6	10.0	51.4
825	133.0	7.6	63.3	143.5	9.0	53.9
875	116.7	6.4	68.2	136.2	8.3	56.4
925	81.0	7.5	77.1	117.3	7.0	59.8

Table 9. C17510 Properties drawn 99.3% to 0.004" diameter and aged

Aging Temperature °F	Improved C17510			Standard C17510		
	Tensile Strength, ksi	Elongation, % in 10"	Conductivity %IACS	Tensile Strength, ksi	Elongation % in 10"	Conductivity %IACS
As Cold Worked	117.2	1.7	39.4	126.9	1.6	33.6
725	121.2	1.1	52.9	141.5	1.2	48.6
775	113.0	3.2	63.3	128.9	1.5	55.6
825	93.5	4.5	73.5	117.1	5.3	58.9
875	76.0	8.0	78.6	104.5	5.3	61.2
925	70.1	13.8	80.4	87.5	7.7	63.8

[0029] In order to be able to compare combination of properties for these samples, tensile strength for each size wire is plotted versus electrical conductivity, Figures 1-3. The alloy with superior combination of properties would lie to the top and right part of the graph. The most important property for a conductor is its electrical conductivity. A higher electrical conductivity at an equivalent tensile strength shows an improved product. Minimum electrical conductivity specified for this conductor is 60% IACS.

[0030] Figures 1 - 3 show that in the region of interest, i.e., electrical conductivity greater than 60% IACS the improved chemistry has a greater electrical conductivity at equivalent tensile strength, or conversely has a higher tensile strength at the same electrical conductivity. The improved electrical conductivity is about 10% IACS, a substantial improvement. This clearly shows that the improved C 17510 is a preferred chemistry in conductor applications. As figures 1 - 3 show, in all cases above 60% IACS improved C17510 has a superior combination of properties indicating that improved C 17510 is the preferred chemistry for this application.

[0031] The above mentioned patents (US patent numbers 4,594,116, 4,727,002 and 4,838,959) for an ultra high strength conductor are based on a minimum of 99% reduction as an essential step to obtain the required properties. Figure 4 shows that improved C 17510 provides the required combination of properties with lower reductions (for example 60% reduction at 0.0320" and 88% reduction at 0.0177" diameters.) Figure 5 shows tensile strength vs. electrical conductivity for Std. C17510 aged 3 hours at 725-975°F.

[0032] The beryllium-copper conductor of the present invention provides an increased electrical conductivity and bright annealing with silver plating. The conductor of the present invention may take the form of a single end wire or a stranded wire.

[0033] It is apparent that there has been provided in accordance with the present invention a beryllium-copper conductor which fully satisfies the objects, means, and advantages set forth hereinbefore. While the present invention has been described in the context of specific embodiments thereof, other unforeseeable alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing detailed description. Accordingly, it is intended to embrace those alternatives, modifications, and variations as fall within the broad scope of the appended claims.

Claims

1. An age hardened wire for use as an electrical conductor, said wire being formed from a copper base alloy consisting of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy, said nickel and beryllium being present in said copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0, said wire being in a cold worked and aged hardened condition so as to have an electrical conductivity of at least about 60% IACS.
2. The age hardened wire of claim 1, wherein said wire has a tensile strength of at least 95 ksi and at least 70% IACS.
3. The age hardened wire of claim 1, wherein said wire has a tensile strength of at least 105 ksi.
4. The age hardened wire of claim 1, wherein said nickel to beryllium ratio is in the range of from 5.5 to 7.5.

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5. The age hardened wire of claim 1, wherein said nickel to beryllium ratio is in the range of from 6.0 to 7.0.
6. The age hardened wire of claim 1, wherein said impurities consist of up to 0.10 wt% iron, up to 0.30 wt% cobalt, up to 0.20 wt% silicon, and up to 0.20 wt% aluminum.
7. The age hardened wire of claim 1, further comprising a silver plating over said copper base alloy.
8. A process for forming an age hardened wire for use as an electrical conductor comprising the steps of:
 - providing a copper base alloy material consisting of from 1.25 to 3.6 wt% nickel, from 0.25 to 0.45 beryllium, and the balance copper and impurities which do not affect the properties of said alloy, said nickel and beryllium being present in said copper base alloy in a ratio of nickel to beryllium from 5.0 to 8.0, cold working said material in a single step; and
 - age hardening said cold worked material in a single step to form a wire in a cold worked and aged hardened condition having an electrical conductivity of at least about 60% IACS.
9. The process of claim 8 wherein said copper base alloy material providing step comprises providing a copper base alloy material having an original dimension and said cold working step comprises reducing said copper base alloy material by an amount less than 95%.
10. The process of claim 9 wherein said cold working step comprises drawing said copper base alloy material into a wire.
11. The process of claim 8, wherein said age hardening step comprises heating said cold worked material at a temperature in the range of from 725°F to 925°F for a time period up to 5.0 hours.
12. The process of claim 8, further comprising solution treating said material prior to said cold working step.
13. The process of claim 8, further comprising silver plating said material.
14. The process of claim 13, wherein said plating is performed prior to said cold working step.

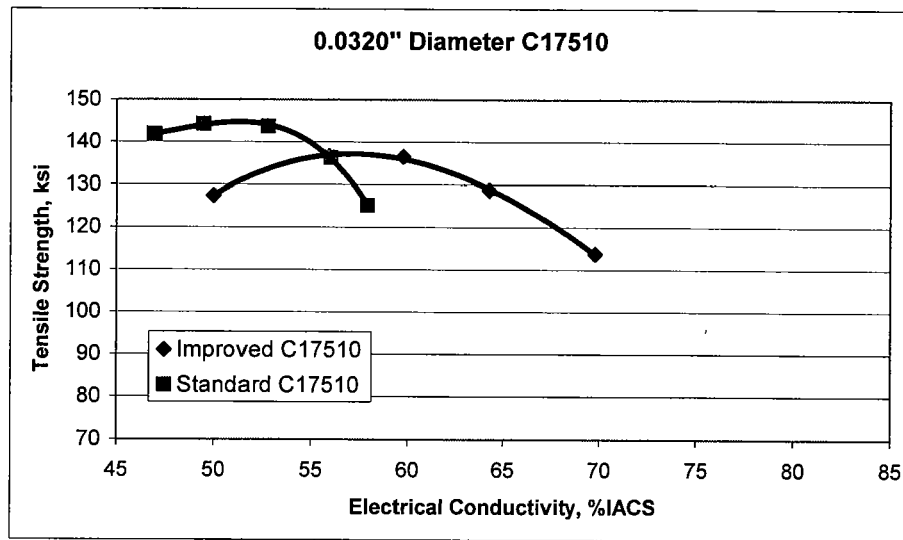


FIG. 1

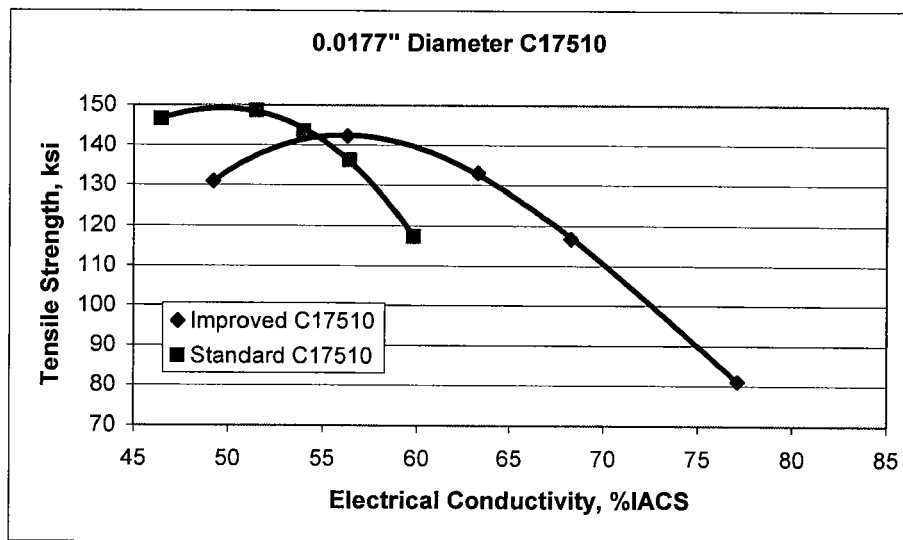


FIG. 2

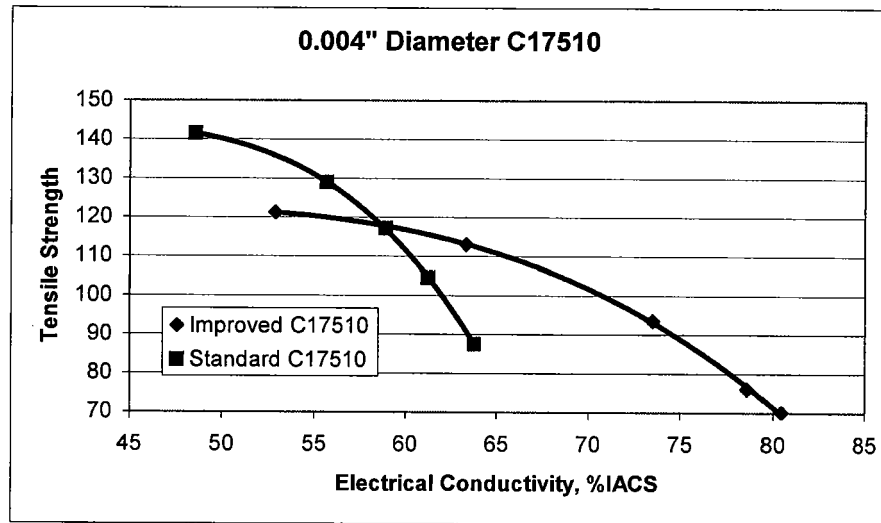


FIG. 3

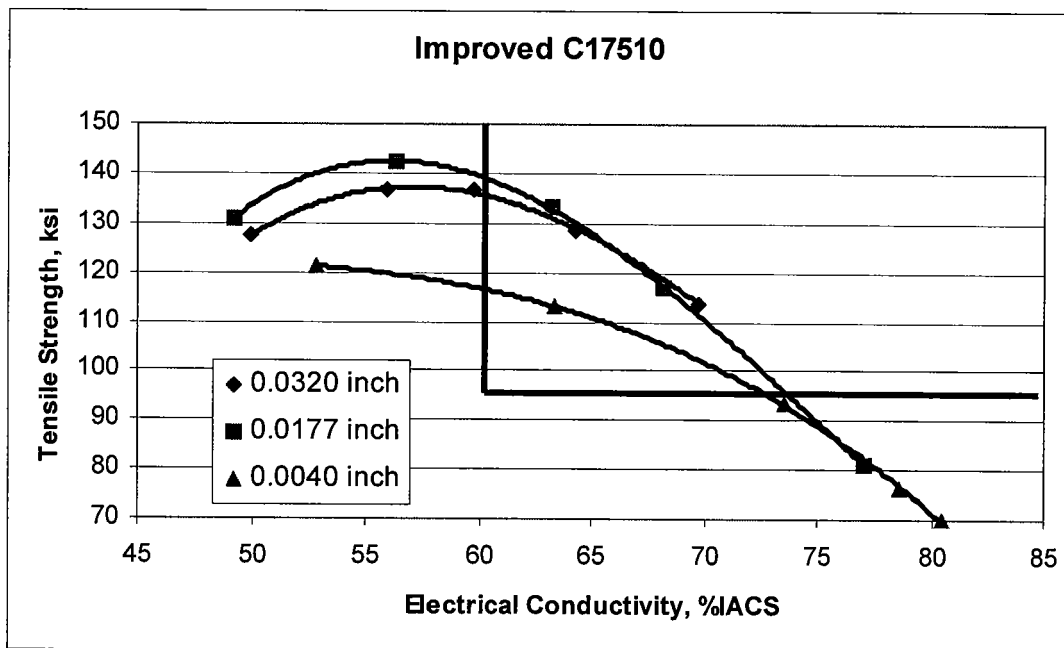


FIG. 4

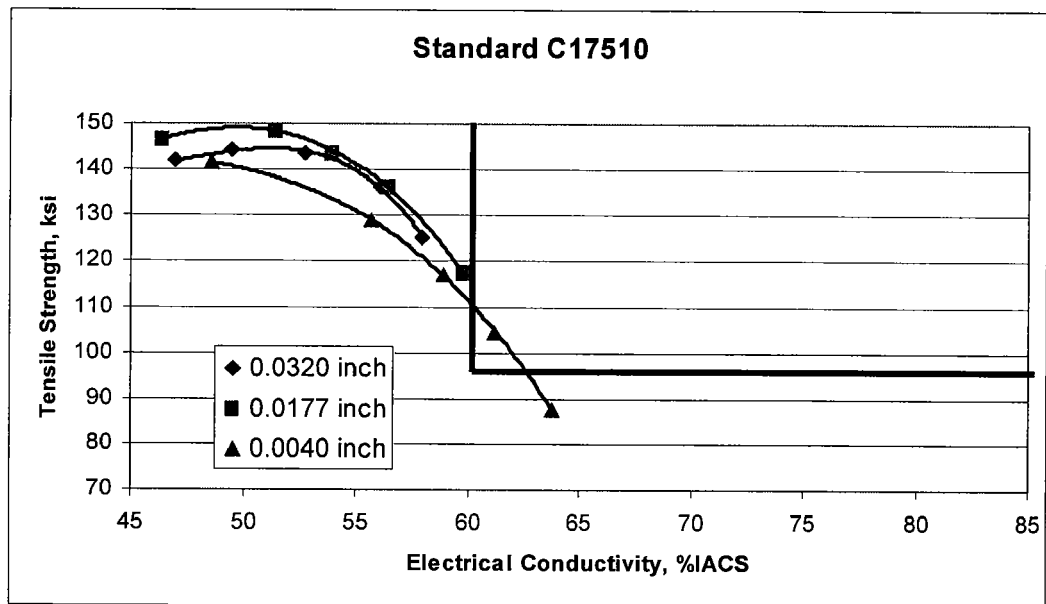


FIG. 5

REFERENCES CITED IN THE DESCRIPTION

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