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METALLIC PARTICLE COMPOSITIONS FOR MECHANICALLY JOINED ELECTRICAL CONDUCTORS

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Fig. I.

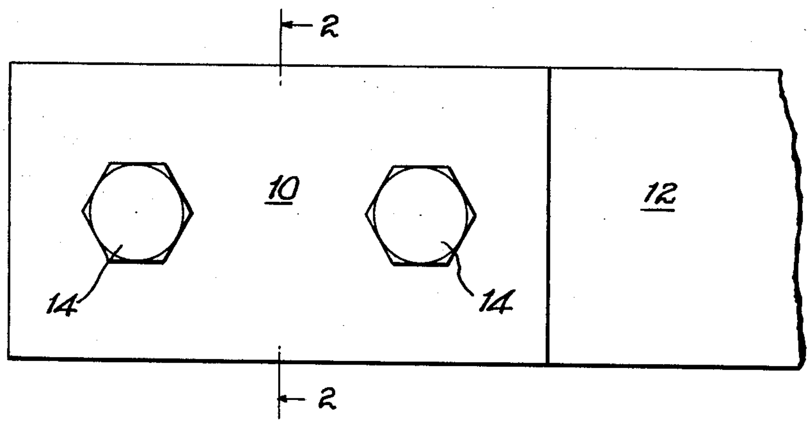
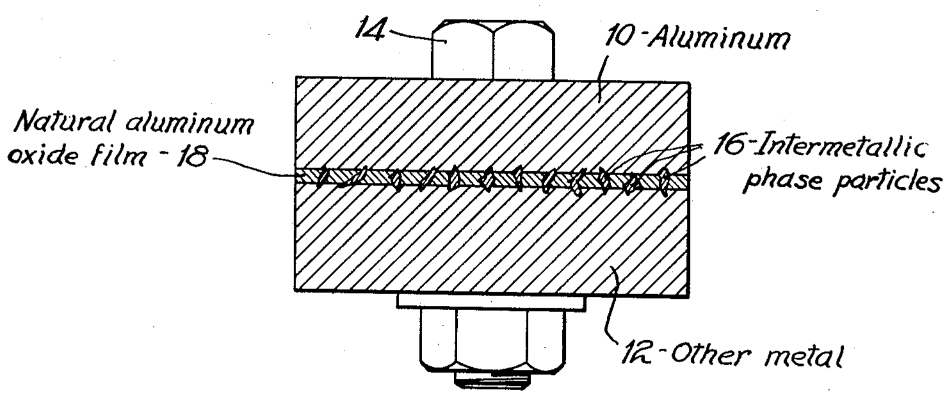


Fig. 2.



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METALLIC PARTICLE COMPOSITIONS FOR MECHANICALLY JOINED ELECTRICAL CONDUCTORS

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This invention relates in general to forming mechanical joints between electrical conductors as distinguished from soldered and welded joining of the same. The invention is more particularly concerned with mechanical joints between electrical conductors and conventional fittings employed therewith, in which juxtaposed superimposed surfaces of at least two electrically conductive members are secured under pressure in interfacial surface contacting relationship to form and constitute a mechanical joint therebetween. The mechanical practices thus contemplated include conventional bolt or clamp-secured lap joints between juxtaposed superimposed contacting surfaces of bus bar elements in electrical distribution systems, as well as joints in electrical transmission systems incorporating conventional compression sleeve and parallel groove connectors in pressure-exerting surface-contacting attachment on electrical conductors or cables.

The current carrying efficiency of any electrical system is inversely proportional to its resistance, and the joints in such a system can invariably increase the resistance to a level where electrical losses become quite appreciable. It is therefore a primary desideratum to provide joining practices in electrical systems which insure low initial and extended electrical contact resistance characteristics to avoid unnecessary voltage drop in the systems.

It is an accepted fact that metallic conductors, and conventional fittings regularly employed therewith in mechanically joining the same, exhibit natural oxide surface films in their as-fabricated condition. Aluminum and its alloys, widely used in electrical transmission and distribution systems are no exception, although the readily formed natural oxide surface films formed thereon are microscopically thin and are beneficial in the sense that they protect the underlying base metal against the self-consuming oxidation associated with many other metals and alloys. Regardless of these facts, many metallic oxides are practically electrically non-conductive and joints incorporating contacting surfaces, at least one of which is aluminum bearing its natural oxide surface film, the latter film in the dry state being an accepted electrical insulator, by nature exhibit higher electrical contact resistance than obtains if the effect of the natural oxide film can be eliminated or reduced.

By the term "aluminum," as used herein and in the appended claims to define a metallic conductor or electrically conductive surface thereof, is meant commercially pure electrical conductor (EC) grade aluminum and commercially available aluminum base alloys in which the elemental metal aluminum is present in amounts of at least 50 percent by weight.

Attempts to improve the electrical contact resistance of mechanical joints in electrical transmission and distribution systems have included the use of various types of particles between the interfaces of the juxtaposed contacting surfaces in restraining pressure assembly constituting such mechanical joints. In all such instances, the particles thus employed have been selected from commercially pure elemental metals, alloys thereof, and nonmetallic abrasive materials, the latter being recognized as non-conductive from an electrical standpoint, and the former metals and alloys exhibiting such inherent malleability that they deform and flatten under the pressures employed in making mechanical joints to actually provide metallic interlayer surface areas in superimposed relationship on the underlying non-conducting natural oxide surface films borne by the as-fabricated conductors and fittings employed therewith, without displacing the complained of non-conductive films.

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The present invention is predicated upon the determination and discovery that all particulates between the juxtaposed contacting surfaces of electrical conductors, and conventional fittings employed therewith, neither respond in the same manner nor to the same degree in providing low initial and extended low electrical contact resistance of mechanical joints in electrical transmission and distribution systems. It is to this end that the present invention is addressed in its provision of a particular class of electrically conductive metallic particles for use between juxtaposed pressure-restrained as-fabricated contacting surfaces of electrical conductors and conventional fittings employed therewith, such that the effects of the natural oxide surface films, giving rise to initial and extended high electrical contact resistance, are greatly reduced to the point of substantial elimination.

The general class of particles determined to be productive of the superior results and advantages attributable to the present invention are irregular in shape and are herein and hereinafter in the appended claims defined by the expression "intermetallic phases containing aluminum" by which expression is meant particles having a composition consisting in major proportion of intermetallic phases containing aluminum and a minor proportion, if any, of element or elements in excess of that entering into the formation of the composition of said intermetallic phases. In this connection, it is an accepted understanding that a true intermetallic compound is an intermediate phase in an alloy system, having a narrow range of homogeneity and relatively simple stoichiometric proportions, in which the nature of the atomic binding can vary from metallic to ionic. The particles responding to the present invention, and defined in their composition by the aforesaid expression "intermetallic phases containing aluminum," include not only those particles having a composition consisting in major proportion of true intermetallic compounds containing aluminum, satisfying the above-accepted definition, but the variants thereof, which may or may not be isomorphous therewith.

The particulate or particles of the invention composed of the intermetallic phases containing aluminum have been determined to exhibit a minimum hardness which permits alloys productive thereof to be readily fragmentized or fractured in conventional grinding and hammer mill equipment to produce a frangible or friable aggregate, without the difficulty associated with the malleable metals and alloys heretofore employed in electrical conductor mechanical joining practices. In addition, the particles themselves are irregular in shape and of such brittleness that they are readily reduced in particle size under the pressures normally employed in mechanical joining practices to provide further disintegration of the individual particles in situ in the formation of a mechanical joint employing the same. The irregularity in the shapes of the individual particles, and again referring to their minimum hardness, has been found to provide and insure the existence of innumerable pressure points in the plane of the juxtaposed contacting surface areas constituting the mechanical joints herein contemplated, with the end result that the interposed particles of the invention compensate for any inherent irregularities and non-uniformities in the as-fabricated exposed surface areas in juxtaposed contacting surface assembly in the mechanical joints.

The irregular shape and hardness of the particles have also been observed to react on the natural oxide film carried on the surfaces of as-fabricated aluminum conductors, and conventional fittings employed therewith, to fracture the natural oxide films in the areas of the pressure points developed in the mechanical joints, with individual particles entering the fissures in the so-fractured natural oxide film and penetrating into the underlying aluminum of the conductors and fittings to displace metallic aluminum along the axes of the individual particles and thus form innumerable oxide-free aluminum conductors between the superimposed contacting surfaces constituting a mechanical joint therebetween.

From the foregoing description it will be apparent that a prime desideratum to provide a material in fragmented particle form for disposition between the contacting mechanically-restrained surfaces of joints in electrical transmission and distribution systems, which is capable of insuring direct metal-to-metal contact across such joints, is achieved by the provision of the particles composed of intermetallic phases containing aluminum above described.

It will be further observed that the particles of the invention, through their inclusion in a mechanical joint of the type herein contemplated, have overcome the disadvantages arising out of the presence and non-conductive property of the natural oxide film carried on the exposed surfaces of as-fabricated aluminum conductors and conventional fittings employed therewith.

Additional advantages will be more fully understood and appreciated by those skilled in the art to which the invention appertains on consideration of the following more detailed description.

FIG. 1 is a plan view of a joint employing the joint composition of the invention.

FIG. 2 is a sectional view taken along lines 2—2 of FIG. 1.

Extensive development and testing in establishing the particular class of particles of the invention as being composed of intermetallic phases containing aluminum

has revealed that the particles are in themselves better than average electrical conductors and that they are characterized by exhibiting a minimum Vickers Microhardness Number of 240. This minimum hardness is most favorable to the production of the particles from aluminum alloys productive of the particles by conventional impact crushing and grinding practices. The stated minimum hardness factor is also beneficial in the reaction of particles under conventional pressures employed in making mechanical joints of the type herein contemplated to cause fracture of the natural oxide film on aluminum surfaces and establish metal-to-metal conductive bridging between underlying aluminum and aluminum alloy conductors and fittings, in which condition the embedded particles themselves are electrically conductive.

Particle size is a desirable, but not necessarily a limiting factor to insure optimum interfacial low electrical contact resistance across a joint between superimposed pressure-restrained electrical conductors in accordance with the present invention. In this regard particles falling within the Tyler Standard Screen Sieve range 28 to 235, and more specifically the Sieve range 80 to 170, have performed to give excellent low initial and extended electrical contact resistance values in mechanical joints between as-fabricated aluminum conductors and cables having conventional mechanically-applied aluminum connectors attached thereto.

Table No. 1 is representative of particles comprising intermetallic phases containing aluminum, together with determined Vickers Microhardness Numbers therefor, which have been found to fulfill and satisfy the requirements of the invention.

Table No. 1

Identity of Intermetallic Phases Containing Aluminum	Composition of Particles Composed of 100% by Weight Intermetallic Phases Containing Aluminum	Total Composition of Particles Composed of 74% by Weight Intermetallic Phases Containing Aluminum and 26% Uncombined Aluminum	Vickers Microhardness Numbers for Intermetallic Phases Containing Aluminum
$CuAl_2$	54% Cu-46% Al	40% Cu-60% Al	438
$CrAl_7$	22% Cr—78% Al	16.5% Cr-83.5% Al	335
$FeAl_3$	41% Fe-59% Al	31% Fe-69% Al	727
Mg_2Al_3	35% Mg-65% Al	26% Mg-74% Al	246
$NiAl_3$	42% Ni-58% Al	31% Ni-69% Al	400
βAl-Cu-Fe	32% Cu-17% Fe-51% Al	24% Cu-13% Fe-63% Al	625
Al-Cu-Mn	14% Cu-22% Mn-64% Al	10.5% Cu-16.5% Mn-73% Al	397
βAl-Fe-Si	28% Fe-15% Si-57% Al	21% Fe-11% Si-68% Al	747
Al-Cu-Fe-Mn	10% Cu-15% Fe-15% Mn-60% Al	7.5% Cu-11% Fe-11% Mn-70.5% Al	569

It will be observed that 100 and 74 percent by weight particle compositions have been included in Table No. 1, the first five listed intermetallic phases containing aluminum being true binary intermetallic compounds, whereas the remaining four phases are variants thereof. The designated 74 percent by weight compositions are representative of the preferred lower limit of intermetallic phases containing aluminum in the composition of particles falling within the scope of the invention which have been determined to be productive of the superior results expressed in terms of low initial and extended electrical contact resistance in mechanical joints including the irregular shaped particles.

Table No. 2 is included to illustrate Vickers Microhardness Numbers for typical wrought aluminum conductors and cast and wrought aluminum accessories, such as compression type and bolt-secured conductor and cable connecting accessories, regularly employed in electrical transmission and distribution systems, between the interfacial contacting surfaces of which the particles of the invention have been successfully employed to provide low initial and extended electrical contact resistance joints.

Table No. 2

Aluminum Base Alloy Designation	Product Type, Nominal Composition, and Temper	Vickers Micro-hardness Numbers
356-T4	Permanent mold casting—7.0% silicon, 0.3% magnesium, balance substantially aluminum. Temper T4—Solution heat treatment followed by natural aging at room temperature.	69
356-T6	Permanent mold casting—7.0% silicon, 0.3% magnesium, balance substantially aluminum. Temper T6—Solution heat treatment followed by artificial aging.	93
A100-F	Die Casting—Commercially pure 99.0% aluminum. Temper F—As die cast condition	30
1100-0	Wrought material—Commercially pure 99.0% aluminum. Temper 0—Annealed condition	34
1100-H12	Wrought material—Commercially pure 99.0% aluminum. Temper H12—20% cold reduction	35
6062-T6	Extruded clamp—0.25% copper, 0.6% silicon, 1% magnesium, 0.06% chromium, balance substantially aluminum. Temper T6—Solution heat treatment followed by artificial aging.	91
EC-H19	Wrought material—Commercially pure 99.6% aluminum electrical conductor grade. Temper H19—Cold worked extra hard	41

It will be observed that the Vickers Microhardness Numbers determined for the materials and products listed in Table No. 2 are considerably lower and are actually mere fractions of the Vickers Microhardness Numbers established for the intermetallic phases containing aluminum, constituting 100 and 74 percent by weight of the composition of particles falling within the scope of the invention listed in Table No. 1.

Extensive tests were conducted which include electrical energization and resistance determinations of mechanical joints incorporating as-fabricated aluminum sleeve type terminals compressibly attached to the bare ends of identical electrical conductor (EC) aluminum stranded cable. The tubular bores in one set of the sleeve terminals had been filled with an unctuous material or grease containing particles composed by weight of a 50 percent copper-50 percent aluminum alloy, having a Tyler Standard Screen Sieve particle size range between 100 to 150, before compressive assembly of the sleeves on the cables. An equal number of the terminal sleeves had their tubular bores filled with a commercial joint compound comprising an unctuous material or grease containing metallic zinc dust, before their compressive assembly on the cables, the same tool and exerted pressures being employed to assemble both sets of terminal joints.

Each set of compressively assembled cables and sleeve terminals thus prepared was installed in a 330 ampere heat cycling circuit and the current in each was permitted to flow for one-hour intervals with a one-hour interruption in the current flow at the end of each hour flow period. Resistance ratio values were calculated from Kelvin bridge measured electrical resistance and dimensional measurements for each individual test assembly, the resistance ratio values reported in Table No. 3 being average values of the apparent resistance of a joint assembly exclusive of its conductor beyond its sleeve terminal, divided by the resistance of an equal length of

the same conductor incorporated in each joint assembly up to and including 1050 hours of repeated heat cycling.

Conventional sleeve type service entrance connectors having their as-fabricated tubular bores filled with four different joint compounds comprising unctuous material or grease in admixture with particles of intermetallic phases containing aluminum identifiable as $CuAl_2$, $NiAl_3$, βAl-Cu-Fe and βAl-Fe-Si, the intermetallic phase in each instance being present in an amount at least equal to 74 percent by weight of the particles, are presently undergoing repeated heat cycling test in compressive assembly on stranded bare aluminum cables. The resistance ratio values initially and at the end of 165 hours heat cycling are quite comparable to the resistance ratio values reported in Table No. 3 for the terminal sleeve cable joint incorporating 50 percent copper-50 percent aluminum particles, thereby establishing full equivalency for the class of particles defined in terms of intermetallic phases containing aluminum.

It will be manifest that the lower initial and extended resistance ratio values exhibited in Table No. 3, which are comparable to the results being obtained in the tests in progress at the end of 165 hours repeated heat cycling, clearly establish the superiority of mechanical joints employing particles comprising intermetallic phases containing aluminum. Table No. 3, under the heading "Repeated Bending of Cable at Joint," lists calculated resistance ratio values following bending of the cable of each joint several times through an approximate angle of 45° to simulate vibration and whipping action experienced in actual practice of the invention.

The unctuous material or grease hereinabove referred to is a conventional carrier and medium for facile application of the particles between the contacting surfaces of joints in electrical transmission and distribution systems. It will be apparent that other well-known and suitable carriers may be employed for this purpose, such as adhesives, lacquers, and the like, and the particles may, if desired, be sprayed in a suitable liquid adhesive directly on one or more of the as-fabricated interfaces to be incorporated in a mechanical joint of the type herein contemplated. Regardless of the particular unctuous material selected, it should be non-toxic, water-repellant, pliable and usable within the temperature range −10° to 300° F., and exhibit non-corrosive characteristics in its intended environment.

Although the invention has been described with particular reference to mechanical joints incorporating aluminum conductors and aluminum alloy fittings, it is intended and it should be understood that the particles of the invention comprising intermetallic phases containing aluminum will function with equal success with other conductive metals and alloys. In the preferred practice of the invention, however, it is recommended for optimum results that at least one of the members or elements of the mechanical joints present an interfacial contacting surface of aluminum.

The Vickers Microhardness Numbers included hereinabove were calculated from the formula

$$H=\frac{1854.5\times P}{d^2}$$

where P=load in grams, d=the length of the diagonals of the diamond indentation in microns, and H=Vickers

Table No. 3

Terminal Sleeve Cable Joint Including	Resistance Ratio Values					
	Initial	100 hours Heat Cycling	500 hours Heat Cycling	1,000 Hours Heat Cycling	Repeated Bending of Cable at Joint	1,050 Hours Heat Cycling
Unctuous Grease and 50% Cu—50% Al Particles	.94	1.38	1.38	1.42	1.62	2.00
Unctuous Grease and Zinc Dust	1.06	2.92	3.14	3.24	8.72	11.63

Microhardness Number kg./mm.^{2}, a 25 gram load having been employed in measuring and establishing the Vickers Microhardness Numbers appearing in the preceding Tables Nos. 1 and 2.

FIGS. 1 and 2 are representative of a low electrical contact resistance joint falling within the scope of this invention. Therein FIG. 1 is a top plan view of a pressure-restrained joint between the overlapped ends of two substantially rectangular electrically conductive metallic bus bar members 10 and 12, and FIG. 2 is a transverse section through the joint taken on the plane 22 of FIG. 1, to enlarged scale, restraining means, such as the bolts 14, being provided to secure the joint.

At least one of the bus bar members 10 or 12 is an aluminum member bearing a natural oxide film 18, dimensionally exaggerated on the faying joint surface of bus bar element 10, and the layer 16 between the overlapped faying surfaces of the metallic bus bar members 10 and 12 is composed of electrically conductive intermetallic phase particles, described above and asserted in some of the claims, preferably, but not necessarily, in admixture with an unctuous or equivalent carrier.

Having thus described the invention and certain embodiments in support thereof, what is claimed is:

1. Metallic particles for disposition between contacting interfaces of electrical conductors in a pressure-retrained joint therebetween, which particles serve to reduce initial and extended electrical contact resistance of the joint, said particles being frangible and irregular in shape and consisting of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, and said particles exhibiting a Tyler Standard Screen Sieve particle size range between 28 to 235 and a minimum Vickers Microhardness Number of 240.

2. Electrically conductive metallic particles for disposition between contacting interfaces of electrical conductors, at least one of which conductors presents an aluminum surface bearing a natural oxide film, in a mechanical pressure-restrained joint therebetween, which particles serve to reduce initial and extended electrical contact resistance of the joint, said particles being frangible and irregular in shape and consisting of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, and said particles exhibiting a Tyler Standard Screen Sieve size range between 80 to 170 and a minimum Vickers Microhardness Number of 240.

3. Electrically conductive metallic particles for disposition between contacting interfaces of electrical conductors in a mechanical pressure-restrained joint therebetween, one of which conductors presents as fabricated aluminum interfacial surface bearing a natural oxide surface film, said particles consisting of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging in nature from metallic to ionic and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, said particles serving to reduce the initial and extended electrical contact resistance of the joint between the conductors, and said particles exhibiting a Tyler Standard Screen Sieve particle size range between 80 to 170 and a minimum Vickers Microhardness Number of 240.

4. Metallic particles for disposition between the contacting interfaces of electrical conductors adapted to be assembled in pressure-restrained interfacial contacting relationship, at least one of said conductors presenting an interface of aluminum bearing a natural oxide surface film, which particles serve to reduce the initial and extended electrical contact resistance of the joint, said particles being frangible under pressure and irregular in shape and composed of an aluminum-copper alloy in which the aluminum and copper are each present in the amount of 50 percent by weight, the particles falling within the particle size Tyler Standard Screen Sieve range of 80 to 170, and the particles being further characterized by having a Vickers Microhardness Number of 438.

5. A low electrical contact resistance joint composition for use between contacting interfaces in mechanical pressure-restrained joints between electrical conductors, at least one contacting interface in a joint presenting an aluminum surface bearing a natural oxide surface film, said joint composition comprising an unctuous carrier in admixture with irregular shaped frangible metallic particles composed of a composition consisting of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, and said particles exhibiting a Tyler Standard Screen Sieve particle size range of 80 to 170 and a minimum Vickers Microhardness Number of 240.

6. A low electrical contact resistance joint composition for use between contacting interfaces in a mechanical pressure-restrained joint between electrical conductors at least one of which conductors presents an aluminum surface bearing its natural oxide film, said joint composition comprising an unctuous carrier material in admixture with irregular shaped frangible particles composed of an aluminum-copper alloy in which the aluminum and copper are each present in the amount of 50 percent by weight, the particles having a particle size Tyler Standard Screen Sieve range between 80 to 170 and exhibiting a minimum Vickers Microhardness Number of 240.

7. A low initial and extended electrical contact resistance joint composition for disposition between interfacial contacting surfaces in a pressure-restrained joint between electrical conductors at least one of which conductors presents an interfacial as fabricated contacting surface of aluminum bearing its natural oxide film, said joint composition comprising an unctuous material in admixture with irregular shaped frangible electrically conductive particles consisting of at least 74 percent by weight of at least one intermetallic compound, said intermetallic compound being binary and consisting essentially of aluminum and one of the elements selected from the group consisting of Cu, Cr, Fe, Mg and Ni combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one of said stipulated elements present in the intermetallic compound in excess of that required to form the compound, and said particles exhibiting a Tyler Standard Screen Sieve particle size range between 28 to 235 and a minimum Vickers Microhardness Number of 240.

8. A low electrical contact resistance joint between pressure-restrained contacting surfaces of two or more electrically conductive metallic members, at least one of which members presents a contacting surface composed of aluminum bearing a natural oxide film, metallic par-

ticles disposed between the contacting surfaces, said metallic particles being selected from and composed of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, and said particles exhibiting a Tyler Standard Screen Sieve particle size range between 80 to 170 and a minimum Vickers Microhardness Number of 240.

9. A low electrical contact resistance joint between pressure-restrained contacting surfaces of two or more electrically conductive metallic members, at least one of which members presents a contacting surface composed of aluminum bearing a natural oxide film, an electrical joint compound disposed between the contacting surfaces of the joint, said compound comprising an unctuous carrier in admixture with metallic electrically conductive particles, the particles being selected from a composition composed of at least 74 percent by weight of at least one intermetallic phase, said intermetallic phase consisting essentially of aluminum and at least one metal combined therewith by an atomic bond ranging from metallic to ionic in nature and the balance of said composition of said particles being composed of up to 26 percent by weight of at least one element present in the intermetallic phase in excess of that required to form the phase, and said particles exhibiting a Tyler Standard Screen Sieve particle size range between 28 to 235 and a minimum Vickers Microhardness Number of 240.

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