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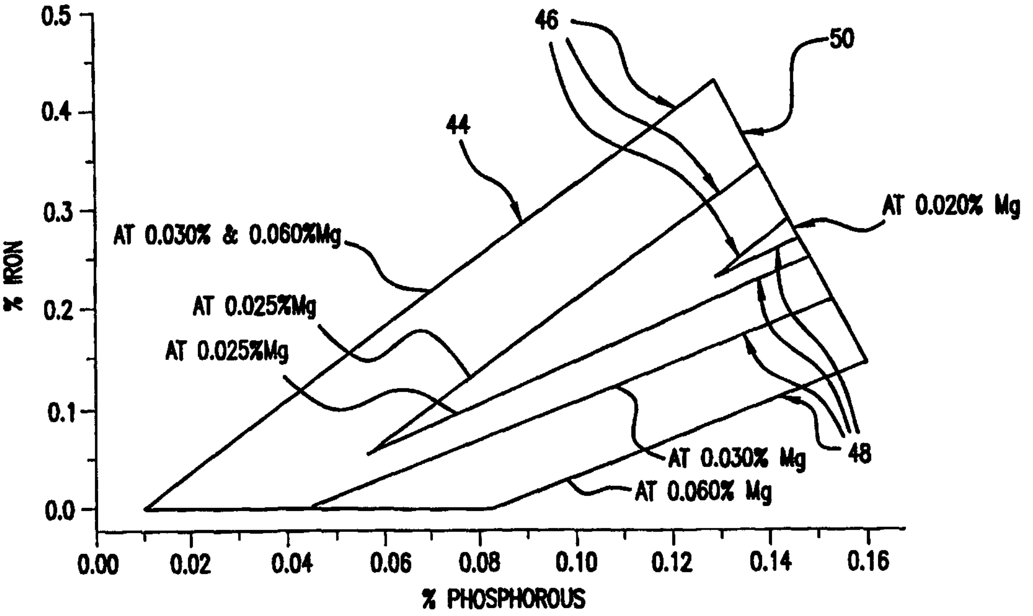

(57) Abstract

A copper alloy having improved resistance to stress relaxation and good stampability contains controlled additions of iron, phosphorous and magnesium. Free magnesium, in solid solution with the copper, increases the alloy's resistance to stress relaxation. Coppre alloys of the invention retain at least 70% of the initial stress following exposure to a temperature of 105 °C for 3000 hours, making alloys particularly useful for electrical connector components.

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COPPER ALLOY HAVING MAGNESIUM ADDITION

This invention relates to a copper alloy having high strength, high electrical conductivity and a resistance to stress relaxation at elevated temperatures. More particularly, the resistance to stress relaxation is enhanced by the presence of magnesium in solution with the copper.

Elemental copper has a very high electrical conductivity and relatively low strength and poor resistance to stress relaxation. Stress relaxation is an important consideration when selecting a copper alloy for an application where the product will be subjected to external stresses, such as when used for a spring or an electrical connector component.

Stress relaxation is a phenomenon that occurs when an external stress is applied to a piece of metal. The metal reacts by developing an equal and opposite internal stress. If the metal is restrained in the strained position, the internal stress decreases as a function of time. The gradual decrease in internal stress is called stress relaxation and happens because of the transformation of elastic strain in the metal to plastic, or permanent, strain. The rate of decrease of internal stress with time is a function of alloy composition, alloy temper, orientation and exposure temperature. It is desirable to reduce the rate of decrease, i.e. to increase the resistance to stress relaxation, as much as possible for spring and connector applications.

In the manufacture of an electrical connector, a sheet of copper alloy may be deformed into a hollow, generally cylindrical shape for use as a socket. Metal adjacent to an open end of the cylinder is externally stressed, such as by bending, to develop an opposing internal stress effective to cause the ends of the copper strip to bias inward and tightly contact a mating plug. This tight contact insures that the electrical resistance across the connector components remains relatively constant and that, in extreme conditions, the plug resists separation from the socket.

Over time, and more rapidly at higher temperatures, stress relaxation weakens the contact force between the socket and the plug and may eventually lead to connector failure. It is a primary objective of electrical connector design to maximize the contact force between the socket and the plug to maintain good electrical conductivity through the connector.

One copper alloy used to manufacture electrical connector components is designated by the Copper Development Association (CDA, Greenwich, CT) as copper alloy C19700. Copper alloy C19700 has the nominal composition, by weight, of 0.3%-1.2% iron, 0.1%-0.4% phosphorous, 0.01%-0.2% magnesium and the balance copper and unavoidable impurities.

Copper alloy C19700 has a resistance to stress relaxation that is marginal for many applications at exposure temperatures of 105°C or higher, particularly in the transverse orientation and for stronger tempers. It has been determined that after 3000 hours at an exposure temperature of 105°C, a copper alloy C19700 connector in the hard temper, typically has about 64% stress remaining in the longitudinal direction and 56% stress remaining in the transverse direction.

The resistance to stress relaxation can be improved by a relief anneal. After the copper alloy sheet is rolled to final gage, it may be relief annealed for a hard temper by bell annealing at a strip temperature of from 200°C to 400°C for from 30 seconds to 4 hours. Strip annealing at corresponding higher temperatures and shorter exposure times is also useful. A connector formed from copper alloy C19700 in the hard/relief anneal temper typically has a longitudinal value of 72% stress remaining and a transverse value of 65% stress remaining after the same exposure to 105°C for 3000 hours.

Directionality is defined with reference to Figure 1. A sheet 10 of a desired copper alloy is reduced in thickness by passing through the rolls 12 of a rolling mill. The copper alloy sheet 10 then has a longitudinal axis 14 along the rolling direction that is perpendicular to an axis 16 about which the rolls 12 rotate. The transverse axis 18 of the copper alloy sheet 10 is perpendicular to the longitudinal axis 14. Spring contacts formed from the copper alloy sheet and oriented parallel to the rolling direction are referred to as having a longitudinal (or good-way) orientation while spring contacts having an orientation transverse to the rolling direction are referred to as having a transverse (or bad-way) orientation.

United States patents that disclose a copper alloy containing iron, phosphorous and magnesium include United States Patent No. 4,305,762 to Caron et al. and United States Patent No. 4,605,532 to Knorr et al.

The Caron et al. patent discloses a copper alloy containing 0.04%-0.20% of magnesium, phosphorous and iron. The Knorr et al. patent discloses a copper alloy containing 0.01%-0.20% magnesium, 0.1%-0.4% phosphorous, 0.3%-1.6% iron and the balance copper. Published Japanese patent application No. JP 58-199835 by Sumitomo Electric discloses a copper alloy that contains 0.03%-0.3% magnesium, 0.03%-0.3% iron, 0.1%-0.3% phosphorous and the balance copper.

To be useful in commercial applications such as to be formed into leadframes or electrical connectors, copper is alloyed with various other elements, and combinations of elements, to increase strength. The alloying additions frequently impact other alloy properties. If the alloying additions are in solid solution with the copper, conductivity is frequently reduced. If the alloying additions result in large, hard, second phase particles, the surface finish of the copper alloy after cold rolling to sheet form may be marred by voids around these second phase particles. These voids can adversely affect the quality of an electrolytically deposited coating on the alloy. It is, therefore, an objective to maximize the strength of a copper alloy without significantly degrading other desirable properties, such as uniform etching (in leadframe manufacture) and limited tool wear during stamping (in connecter manufacture).

Common alloying additions to copper include iron and phosphorous. Copper alloy C19400 has the composition, by weight, of 2.1%-2.6% iron, 0.05%-0.20% zinc, 0.015%-0.15% phosphorous and the balance copper. Alloy C19400 has excellent stampability and an electrical conductivity of about 60% IACS (IACS stands for International Annealed Copper Standard and defines the conductivity of "pure" copper at 20°C as 100%). Another alloy, designated by the CDA as alloy C19210, has the composition, by weight, of 0.05%-0.15% iron, 0.025%-0.04% phosphorous and the balance copper. Alloy C19210 has an electrical conductivity of about 80% IACS, but relatively poor stampability.

Magnesium is sometimes added to copper-iron-phosphorous alloys. The magnesium combines with phosphorous to form a magnesium phosphide that precipitates from the copper matrix as a discrete second phase particulate. A dispersion of magnesium phosphide particulate throughout the copper alloy increases the strength of the copper alloy and, by effectively removing phosphorous from solid solution with the copper, increases electrical conductivity.

While copper alloys containing magnesium, phosphorous and iron are known, there remains a need for a copper alloy with an improved combination of electrical conductivity, strength, stampability and resistance to stress relaxation.

Accordingly, it is an object of the invention to provide a copper alloy having an improved resistance to stress relaxation at temperatures of 105°C and above. It is a feature of the invention that the copper alloy contains controlled amounts of iron, phosphorous and magnesium with an effective amount of magnesium remaining in solution with the copper to favorably affect stress relaxation performance.

Among the advantages of the copper alloy of the invention are that in excess of about 70% of the applied stress remains, in both the transverse and longitudinal directions, following exposure to 105°C for 3000 hours. The alloy has an electrical conductivity on the order of 80% IACS and is particularly suitable for use as an electrical connector.

In accordance with the invention, there is provided a copper alloy. The copper alloy contains, by weight, 0.05%-0.1% phosphorous, 0.05%-0.3% iron and the balance is copper and unavoidable impurities. The copper alloy further contains at least 0.06 weight percent of free magnesium in solution with the copper. The free magnesium effectively improves resistance to stress relaxation at elevated temperatures.

The above stated objects, features and advantages will become more apparent from the specification and drawings that follow.

Figure 1 schematically illustrates the transverse and longitudinal axes of a strip of copper alloy.

Figure 2 shows in cross-sectional representation an electrical connector formed from the copper alloys of the invention.

Figure 3 schematically illustrates an apparatus for stamping a copper alloy.

Figure 4 illustrates in cross-sectional representation an evaluation of stampability.

Figures 5 and 6 graphically illustrate the criticality of magnesium content.

Figure 7 illustrates the critical relationship between the percent phosphorous and the percent iron in a first alloy of the invention.

Figure 8 illustrates the critical relationship between the percent phosphorous and the percent iron in a second, tin containing, alloy of the invention.

Figure 9 illustrates a leadframe stamped from the copper alloys of the invention.

Figures 10-12 graphically illustrate the effect of free magnesium on the percent stress remaining in the copper alloys of the invention.

Figure 13 graphically illustrates the criticality of the magnesium content for good stampability.

Figure 14 graphically illustrates exemplary alloys superimposed over the composition box of Figure 10.

Figure 2 illustrates in cross-sectional representation an electrical connector assembly 20 utilizing the copper alloys of the invention. The connector assembly 20 includes a socket 22 and a plug or jack 24. The socket 22 is formed from a strip of the copper alloy and bent into a desired shape, typically with a flat 26 for contacting the plug 24. To maintain consistent contact with the plug 24, a bend 28 generates an internal stress in the copper alloy strip drawing the flats 26 against the plug 24. When the connector is exposed to temperatures above room temperature (nominally 25°C), and more notably when the temperature is in excess of 100°C, this internal stress gradually dissipates and contact between the flats 26 and plug 24 deteriorates.

The alloys of the invention better resist elevated temperature stress relaxation and produce an improved electrical connector.

The iron content of the alloys of the invention is similar to that specified for copper alloy C19700, by weight, 0.05%-1.5% iron. The phosphorous content, 0.05%-0.17%, by weight, phosphorous, is at the low end of the range specified for copper alloy C19700 to retain magnesium in solid solution with the copper.

Excess iron in solution with the copper reduces electrical conductivity below the target of 80% IACS and, preferably, the iron content is between about 0.3% and 0.7% and most preferably, between about 0.35% and 0.50%. Preferably, the phosphorous content is between 0.1% and 0.15%.

Up to 50% of the iron may be substituted with another transition metal such as manganese, cobalt, nickel and alloys thereof as a 1:1 substitution, by weight.

Good resistance to stress relaxation, is accomplished by the presence of magnesium in solution with the copper. Magnesium in solution with the copper is referred to as "free magnesium" and is distinguished from magnesium in the form of magnesium phosphides (Mg_3P_2) that precipitate from the alloy matrix during processing. Magnesium that combines with phosphorous as phosphide particles has little or no effect on stress relaxation.

In the copper alloys of the invention, iron, phosphorous and magnesium interact to determine the free magnesium content. During processing of copper alloy strip from cast ingots, iron phosphides precipitate from the alloy matrix before the magnesium phosphides. If there is any magnesium left in solution after the phosphorous is completely precipitated as Fe_2P and Mg_3P_2, this magnesium will favorably influence stress relaxation performance.

The free magnesium content is calculated by first determining the amount of phosphorous available to combine with magnesium.

$$X = 1.18(P-Fe/3.6) \tag{1}$$

if X is negative, then the free magnesium content equals the magnesium content of the alloy. If X is equal to zero or a positive number, then the free magnesium content is equal to

$$Y = Mg-[1.18(P-Fe/3.6)] \qquad (2)$$

Y is the free magnesium content and is a value greater than 0. While even trace amounts of free magnesium will increase the resistance to stress relaxation, to consistently obtain at least 70% stress remaining in a relief anneal (RA) temper after an exposure of 3000 hours at 105°C, at least about 0.03%, by weight of free magnesium should be present.

Excess magnesium may cause cracking and sliver defects during hot rolling and the maximum magnesium content should be less than about 0.1%, by weight. For an alloy containing between 0.3% and 0.7%, by weight of iron and between 0.1% and 0.17%, by weight of phosphorous, the magnesium content will typically be between about 0.03% and 0.08%.

In an alternative embodiment, the phosphorous content is maintained below 0.1 percent, by weight and the iron content maintained below 0.3 percent, by weight. Higher amounts of magnesium may then be included in the alloy without a severe loss of hot workability. In this embodiment, the minimum amount of free magnesium is at least 0.06 weight percent, and preferably the free magnesium content is at least 0.07 weight percent. The total amount of magnesium in the alloy is less than 0.25 percent, by weight, and preferably less than 0.15 percent by weight. A most preferred magnesium content is between 0.1 weight percent and 0.15 weight percent.

When the copper alloy sheet is to be stamped into an intricate structure, such as a leadframe, one consideration is the stampability of the copper alloy sheet. Stampability may be rated by the percentage of break (fracture) versus shear at a stamped edge for a given punch to die clearance. Materials having good stampability exhibit relatively large values of percentage break over a broad range of tool clearances and increasing the percentage of break is associated with both reduced tool wear and reduced burr height.

A method to evaluate stampability is schematically illustrated in Figure 3. A copper alloy strip 30 is supported by a die 32. A punch 34 reciprocates between the illustrated position and that indicated by the broken line 34', piercing the copper alloy strip 30. Both the die 32 and the punch 34 are formed from a material that is considerably harder than the copper alloy strip 30, such as tool steel. A clearance 36 is disposed between the punch 34 and die 32. Typically, the width of the clearance 36 is on the order of 10% of the thickness of the copper alloy strip 30.

Figure 4 illustrates in cross-sectional representation an edge 38 of the copper alloy strip 30 following stamping. A first portion 40 of the edge 38 exhibits fracture, while a second portion 42 exhibits a sheared surface indicative of tool to strip contact. A measurement of the percent of thickness of the first portion 40 (A) to the overall thickness (B) of the copper alloy strip 30, provides the percentage of break:

3 $$A/B \times 100\% = \% \text{ break}$$

When the stamping tool has a clearance width of 10% of the strip thickness, copper alloy C19400 has about 25% break while copper alloy C19210 has only about 15% break.

Figure 5 graphically illustrates a critical magnesium content for the alloys of the invention when good stampability is desired. Within the composition box 44, the alloys of the invention have both good stampability, approximately equivalent to or greater than C19400, and an electrical conductivity in excess of about 70% IACS. Below the stampability limit lines 46, sufficient phosphorous is present to react with the available magnesium to form phosphides for good stampability. Above the stampability limit lines 46, insufficient phosphorous is present and poor stampability results.

Below the conductivity limit lines 48, the electrical conductivity is below 70%. Within the composition box 44, the electrical conductivity is above about 70%.

Increasing the magnesium content from 0.02% to 0.03%, by weight, significantly opens the composition box of alloy compositions with good stampability. Increasing the magnesium content beyond 0.03% does not appear to provide any further benefit to stampability. So while 0.025% of magnesium provides some benefit, a preferred critical minimum magnesium content for the alloys of the invention is 0.03%, by weight. The maximum acceptable magnesium content of about 0.1%, by weight, beyond which cracking and sliver defects develop during hot rolling of the ingot.

A preferred magnesium content of the alloys of the invention is, by weight, from 0.03% to 0.1% and a most preferred magnesium content is from 0.03% to 0.06%.

While the phosphorous content of the alloys of the invention is described in detail below, the phosphide particulate size limit line 50 identifies that content of phosphorous above which large phosphide particles form.

Figure 6 graphically illustrates the criticality of the magnesium content. Along the stampability limit line 46, stampability is equivalent to copper alloy C19400. Above the line 46 is an excellent stampability region 54. Below the line 46, is a poor stampability region 56.

The vertical axis of Figure 6 is expressed, in weight percent, as:

$$\%P - \%Fe/3.6. \tag*{4}$$

Equation (4) was selected for the vertical axis because iron and phosphorous combine in approximately that ratio to form iron phosphide. It is desirable that there is sufficient phosphorous to combine with all the iron because iron remaining in solution in the copper matrix will reduce conductivity.

When

$$\%P - \%Fe/3.6 = 0, \tag*{5}$$

there is stoichiometric balance between the phosphorous and the iron. Stoichiometric balance is not desirable. It is preferred that there is an excess of phosphorous to form magnesium phosphide. The duplex nature of the second phase of the alloys of the invention, a combination of magnesium phosphide and iron phosphide, is believed to contribute to the high strength and excellent stampability.

When the magnesium content is in the most preferred range of 0.03% to 0.06%, the iron and phosphorous contents are defined by the composition box 58 graphically illustrated in Figure 7. When the phosphorous content is less than 0.07%, the ultimate tensile strength of the alloy is less than about 517.1 MPa (75 ksi). This is because a fine dispersion of both iron phosphide and magnesium phosphide particles are required to promote both high tensile strength and good stampability. Below the ultimate tensile strength limit line 60, insufficient phosphorous is available to form the requisite phosphides. The maximum phosphorous content is defined by the phosphide particulate size limit line 50. When the phosphorous content exceeds the limit defined by line 50, large, in excess of about 4 microns in diameter, particles form. These particles in the alloy microstructure may cause irregularities in the electroplated layers when the particles appear at the surface of the alloy material. The plating irregularities, such as blisters, are typically not acceptable for electrical applications.

Exceeding the stampability limit line 46, reduces stampability by the failure to provide an adequate number of magnesium phosphide particles. Below the conductivity limit line 48, excess phosphorous remains in solid solution with the copper and electrical conductivity is below 70% IACS.

From Figure 7, the phosphorous content of the high stampability alloys of the invention is, by weight, from 0.07% to 0.16% and the iron content from 0.05% to 0.43% with the further restriction that the phosphorous and iron contents fall within a composition box defined by the weight percent coordinates of (0.05% Fe, 0.07% P), (0.21% Fe, 0.07% P), (0.21% Fe, 0.16% P) and (0.43% Fe, 0.13% P).

More preferred iron and phosphorous contents are defined by the composition box 64, centered around a target 66 of 0.115% phosphorous and 0.25% iron and defined by the coordinates (0.14% Fe, 0.1% P), (0.27% Fe, 0.1% P), (0.23% Fe, 0.14% P) and (0.37% Fe, 0.13% P).

While the alloys of the invention are disclosed as containing iron, it is within the scope of the invention for up to 50% of the iron to be replaced with another transition metal, such as manganese, nickel, cobalt or mixtures thereof, on a 1:1 basis by weight.

Increasing the sulfur content of the alloys improves stampability but also leads to an increase in plating defects in the form of nodules. If the alloy is to be electrolytically coated, such as with silver, then the sulphur content of the alloy should be less than about 10 ppm, and preferably less than 7 ppm.

The size and frequency of plating nodules decreases with decreasing sulphur content. Nodules smaller than 0.05 millimeter are considered acceptable in most applications, thus requiring that the sulphur content be held to below about 10 ppm.

Tin is a preferred addition to the alloys of the invention. The addition of tin increases strength, but typically reduces electrical conductivity as well. Preferably, the tin content is, by weight, from 0.05% to 0.35% and more preferably from 0.10% to 0.20%.

As illustrated in Figure 8, the addition of 0.15% of tin narrows the composition box 68 to the coordinates of (0.05% Fe, 0.02% P), (0.05% Fe - 0.033% P), (0.35% Fe, 0.14% P) and (0.43% Fe, 0.13% P).

Other additions that may be made to the alloys of the invention include aluminum, antimony and zinc. Preferably, the total cumulative content of these other additions is less than about 1%, by weight, such that the desired properties of the alloy, notably conductivity, are not detrimentally affected.

While the copper alloys of the invention are suitable for a variety of applications, particularly where high electrical conductivity and strength are required, the alloys are particularly suited for the manufacture of a stamped leadframe. As illustrated in Figure 9, a leadframe 70 is stamped from a sheet of copper alloy, typically having a thickness of between 0.13 mm (0.005 inch) and 0.25 mm (0.01 inch) to form features such as leads 72 and die paddle 74. The lead to lead pitch is on the order of the thickness of the sheet mandating the use of a copper alloy with good stampability.

The advantages of the alloys of the invention will become more apparent from the Examples that follow.

EXAMPLES

Example 1

Copper alloys having the compositions specified in Table 1 were cast as 4.5 kg (10 pound) ingots and rolled to a final gage of 0.51 mm (0.02 inch). A hard/relief anneal temper was obtained by the process steps of hot roll, diffusion anneal at 600°C, cold roll, anneal at 525°C, roll to final gage and then relief anneal at 250°C for from 2 to 8 hours.

The resistance to stress relaxation of the strips was then evaluated by constraining a cantilever beam formed from the copper alloy to a fixed deflection and measuring the load exerted by the beam on the constraint as a function of time at temperature. The initial stress at the surface of the test sample was set to 80% of the room temperature 0.2% offset yield strength.

As illustrated in Table 1, the percent stress remaining in both the longitudinal and transverse directions increases as a function of the free magnesium content. When the free magnesium content exceeds about 0.03%, by weight, at least 70% stress remains after 3000 hours exposure at 105°C in both the longitudinal and transverse directions.

Sample H586 illustrates the unique properties of the alternative embodiment disclosed above. The alloy has an iron content of 0.14 weight percent, a phosphorous content of 0.07 weight percent and a free magnesium content of 0.073 weight percent. The alloy is readily hot workable, has a high electrical conductivity, 88% IACS and good resistance to stress relaxation.

Figure 10 illustrates the percent stress remaining following exposure at 105°C for 3000 hours for copper alloys of the invention in the hard/relief anneal temper as a function of the free magnesium content. The steeper slope for the percentage of stress remaining along the transverse direction indicates that the free magnesium has a greater effect on resistance to stress relaxation for connector components oriented in that direction than on connector components oriented in the longitudinal direction. This is believed due to the interaction of the free magnesium with the dislocation microstructure such that the crystallographic texture becomes less significant. The enhanced benefit in the transverse orientation is particularly beneficial since most components are stamped transverse to the rolling direction of the copper strip.

Figure 11 illustrates that increasing the amount of free magnesium also improves the stress relaxation resistance at the higher temperature of 125°C following a 3000 hour exposure.

TABLE 1

Stress Relaxation Properties for Hard/RA Temper

Sample Identification	Composition Fe/P/Mg	Free-Mg+	G.S., um	Tensile, YS/UTS/%El MPa	Tensile, YS/UTS/%El ksi	%IACS	%SR @ 105°C Long	%SR @ 105°C Trans	%SR @ 125°C Long	%SR @ 125°C Trans
H441	0.29/0.15/0.047	0.000	7	441/455/6	64/66/6	83	74	63	63	49
H365	0.24/0.13/0.044	0.000	6	435/448/6	63/65/6	81	73	63	65	51
H367	0.48/0.14/0.012	0.004	9	421/435/5	61/63/5	90	72	54	64	44
RN271680	0.57/0.19/0.045	0.008	5	455/469/6	66/68/6	87	79	69	69	56
RN282813	0.36/0.10/0.022	0.022	7	421/435/5	61/63/5	90	79	65	68	52
H588	0.27/0.14/0.100	0.023	9	427/441/5	62/64/5	90	74	63	66	51
H369	0.39/0.11/0.032	0.030	10	421/441/6	61/64/6	85	79	69	72	59
H587	0.41/0.16/0.105	0.051	11	435/462/6	63/67/6	87	83	74	73	61
H366	0.49/0.13/0.053	0.053	7	441/455/5	64/66/5	82	85	76	75	64
H406	0.41/0.09/0.055	0.055	9	421/441/6	61/64/6	72	85	78	76	68
H586	0.14/0.07/0.110	0.073	9	421/435/6	61/63/6	88	84	77	80	64
H589	0.48/0.15/0.116	0.096	8	441/462/6	64/67/6	81	87	83	77	71
H590	0.41/0.15/0.170	0.127	8	455/476/6	66/69/6	80	88	85	78	71

\+ If 1.18 (P-Fe/3.6) is negative, **free-Mg** equals Mg content; otherwise, **free-Mg** equals Mg-[1.18(P-Fe/3.6)].
G.S. = grain size in microns.
YS = room temperature yield strength.
UTS = room temperature ultimate tensile strength.
EL = room temperature elongation.
SR = stress remaining.
Long = longitudinal orientation and trans = transverse orientation.

TABLE 2

Stress Relaxation Properties for Hard Temper

Sample Identification	**Composition Fe/P/Mg**	**Free-Mg+**	**G.S., um**	**Tensile, YS/UTS/%El**		**%IACS**	**%SR @ 105°C**	
				MPa	**ksi**		**Long**	**Trans**
H365	0.24/0.13/0.044	0.000	6	421/434/3	61/63/3	84	59	49
RN271680	0.57/0.19/0.045	0.008	5	441/455/4	64/66/4	88	64	56
RN282813	0.36/0.10/0.022	0.022	6	414/427/3	60/62/3	89	65	58
H366	0.49/0.13/0.053	0.053	5	427/441/3	62/64/3	81	68	63

*Extrapolated to 3000 Hrs from 2000 Hrs.

+If 1.18 (P-Fe/3.6) is negative, **free-Mg** equals Mg content; otherwise, **free-Mg** equals Mg-[1.18(P-Fe/3.6)].

Example 2

Copper alloys of the compositions specified in Table 2 were cast and rolled to strip having a final gage of 0.51 mm (0.02 inch). The alloys were imparted with a hard temper by the process steps of hot rolling, cold rolling, annealing at 500°C - 600°C, cold roll, anneal at 450°C - 525°C, then cold roll to gage with a minimum total reduction following the last anneal of about 30%.

Table 2 illustrates that the presence of free magnesium improves the resistance to stress relaxation of the copper alloys in the hard temper.

As shown in Figure 12, the enhancement to resistance to stress relaxation is again more pronounced in the transverse direction as compared to the longitudinal direction. However, the inclusion of free magnesium improves the resistance to stress relaxation in bends formed along either axis.

Example 3

Copper alloys containing magnesium, phosphorous and iron were cast as 4.5 kg (10 pound) ingots and provided with an extra spring/ relief anneal temper by casting a bar having the approximate dimensions of 4.4 cm x 10.2 cm x 12.7 cm (1.75 inches x 4 inches x 5 inches), homogenizing by heating to 930° C for 1.5 hours and then hot rolling to a thickness of 12.7 mm (0.5 inch). The 12.7 mm (0.5 inch) strip was then annealed at a temperature of between 300° C and 650° C and surface milled to remove oxides. The annealed strip was then cold rolled to a finished gage of 0.15 mm (0.006 inch) and relief annealed at 300° C. The copper alloy strips were then stamped using a die having a clearance width of 10% of the strip thickness and the percentage of break measured.

Figure 13 illustrates the percentage of break by the numerical value next to each point and shows that when the magnesium content exceeds 0.03% and an excess of phosphorous is present, excellent stampability is achieved. When the magnesium content is less than 0.03%, progressively more phosphorous is required to achieve good stampability. Increasing the phosphorous content leads to the risk of both large phosphide particles and phosphorous remaining in solution and deteriorating electrical conductivity.

Example 4

A number of copper alloys were cast and processed as described for Example 3. Properties of the alloys were then evaluated at room temperature (20°C) and recorded in Table 3.

TABLE 3

Alloy	Composition (Fe/P/Mg) balance copper	Ultimate Tensile Strength MPa	ksi	Conductivity (% IACS)	Percent Break	Phosphide Size (microns)
A	.22/.10/.070	538	78	91	31	less than 4
B	.14/.10/.043	545	79	77	33	less than 4
C	.28/.11/.057	538	78	91	40	less than 4
D	.22/.11/.031	558	81	78	30	less than 4
E	.24/.13/.044	552	80	79	40	less than 4
F	.41/.09/.055	545	79	73	22	less than 4
G	.12/.11/.025	552	80	65	31	less than 4
H	.52/.13/.047	552	80	78	14	greater than 4
I	.20/.15/.020	558	81	59	33	less than 4
J	.17/.05/.019	510	74	94	12	less than 4
K	.29/.15/.047	565	82	81	39	greater than 4

Figure 14 graphically illustrates the alloys of Table 3 superimposed on composition box 58 of Figure 7. Alloys A-E, the alloys of the invention, are within the composition box 58 and have an ultimate tensile strength, percent conductivity, percent break and phosphide size within the preferred ranges specified above. Alloys F-K are outside the composition box 58 and have one or more properties that do not meet the preferred ranges. Those values outside the preferred ranges are underlined in Table 3.

It is apparent that there has been provided in accordance with the invention a copper alloy that fully satisfies the objects, means and advantages set forth hereinabove.

While the invention has been described in combination with embodiments thereof, it is apparent that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications and variations as fall within the spirit and broad scope of the appended claims.

IN THE CLAIMS:

1. A copper alloy consisting essentially of:
from 0.05 to 0.17 weight percent phosphorous;
from 0.05 to 1.5 weight percent iron; and
the balance copper and unavoidable impurities wherein said copper alloy further contains magnesium in solid solution with said copper in an amount effective to improve resistance to stress relaxation at elevated temperatures, said free magnesium content, Y, being equal to Y = Mg-X where X is the amount of phosphorous available to combine with magnesium and X = 1.18(P-Fe/3.6) and with X being equal to or greater than zero and Y being greater than 0.06.

2. The copper alloy of claim 1 characterized in that the phosphorous content is from 0.1 to 0.17 weight percent; the iron content is from 0.1 to 1.5 weight percent; and Y is greater than 0.3.

3. The copper alloy of either claim 1 or claim 2 characterized in that a total magnesium content is less than 0.25 weight percent.

4. The copper alloy of claim 3 characterized in that the total magnesium content is between 0.1 and 0.15 weight percent.

5. The copper alloy of claim 4 characterized in that up to 50% of the iron is substituted with another transition element on a 1:1 replacement basis, by weight,

6. The copper alloy of claim 5 formed into a sheet (10) by passing through a rolling mill (12), said sheet (10) having a longitudinal axis (14) that is parallel to a rolling direction and a transverse axis (18).

7. An electrical connector component (22) formed from said sheet (10) of claim 6.

8. The electrical connector component (22) of claim 7 having an orientation (18) transverse to said rolling direction (14).

9. A copper alloy consisting essentially of:
from 0.025 to 0.1 weight percent magnesium;
from 0.1 to 0.14 weight percent phosphorous;
from 0.14 to 0.37 weight percent iron; and
the balance copper and unavoidable impurities wherein the phosphorous and iron contents fall within a composition box defined by the weight percent coordinates (0.14% Fe, 0.1% P), (0.27% Fe, 0.1% P), (0.23% Fe, 0.14% P) and (0.37% Fe, 0.13% P).

10. The copper alloy of claim 9 characterized in that said magnesium content is from 0.03 weight percent to 0.06 weight percent.

11. The copper alloy of claim 10 characterized in that up to 50% by weight of said iron is replaced with another transition metal on a 1:1 weight basis.

12. The copper alloy of either claim 10 or claim 11 characterized in that said alloy has a maximum sulfur content of 10 ppm.

13. A copper alloy consisting essentially of:
from 0.025 to 0.1 weight percent magnesium;
from 0.02 to 0.14 weight percent phosphorous;
from 0.05 to 0.43 weight percent iron;
from 0.05 to 0.35 weight percent tin; and
the balance copper and unavoidable impurities wherein the phosphorous and iron contents fall within a composition box defined by the weight percent coordinates (0.05%Fe, 0.02%P), (0.05%Fe, 0.033%P), (0.035%Fe, 0.14%P) and (0.43%Fe, 0.13%P).

14. The copper alloy of claim13 characterized in that said magnesium content is from 0.03 weight percent to 0.06 weight percent.

15. The copper alloy of either claim 13 or claim 14 characterized in that said tin content is between 0.1% and 0.2%, by weight.

16. The copper alloy of claim 15 characterized in that said alloy has a maximum sulfur content of 10 ppm.

17. A leadframe formed from the copper alloy of either claim 9 or claim 13.

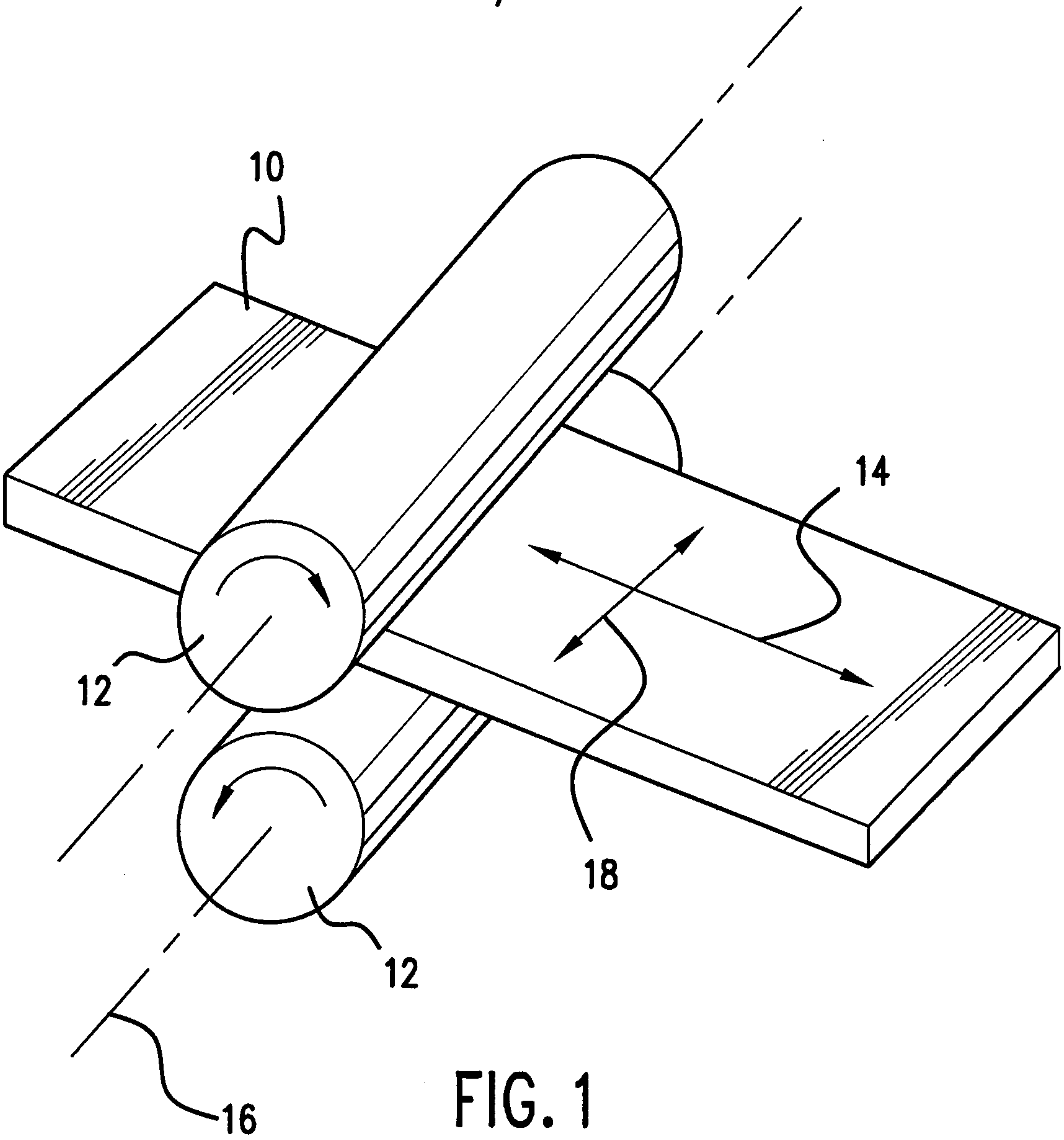


FIG. 1

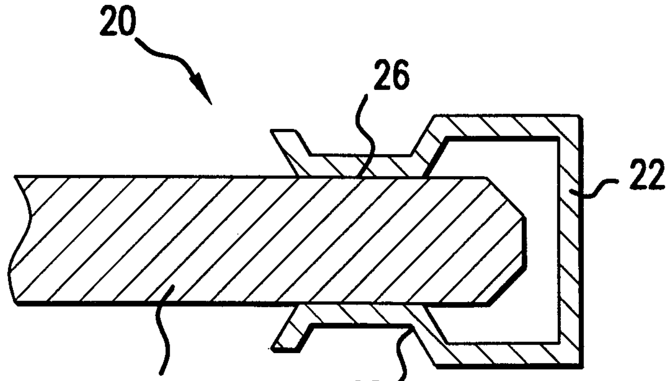


FIG. 2

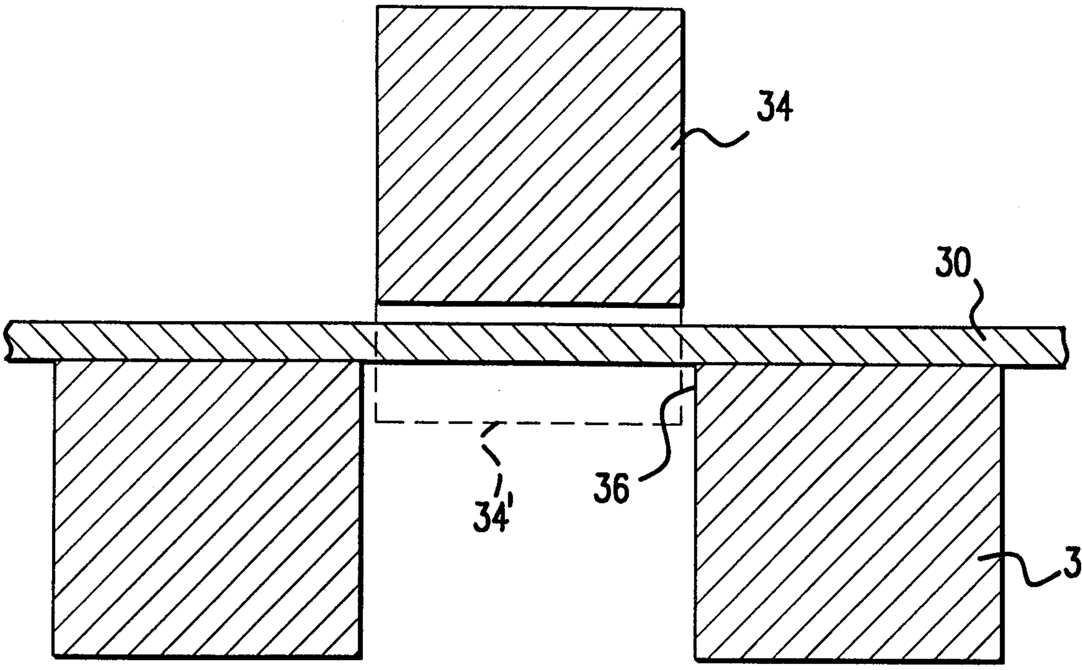


FIG. 3

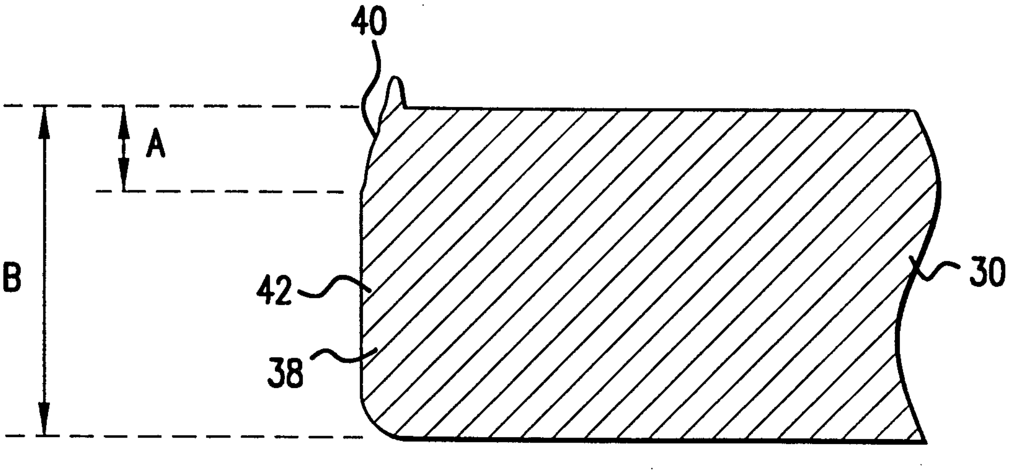
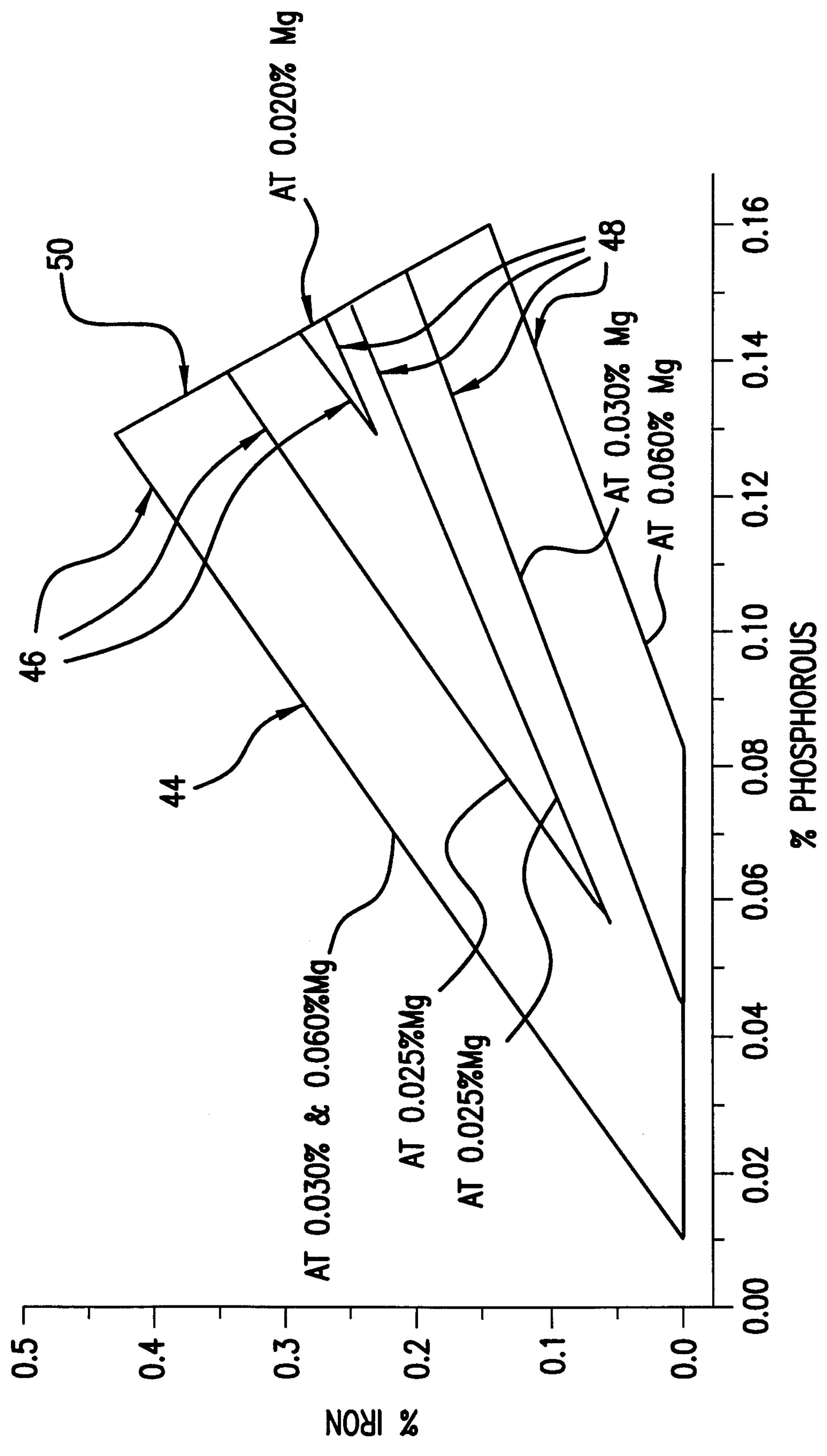


FIG. 4



50
AT 0.020% Mg
48
46
44
AT 0.030% Mg
AT 0.060% Mg
AT 0.030% & 0.060%Mg
AT 0.025%Mg
AT 0.025%Mg
% IRON
0.5
0.4
0.3
0.2
0.1
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
% PHOSPHOROUS

FIG. 5

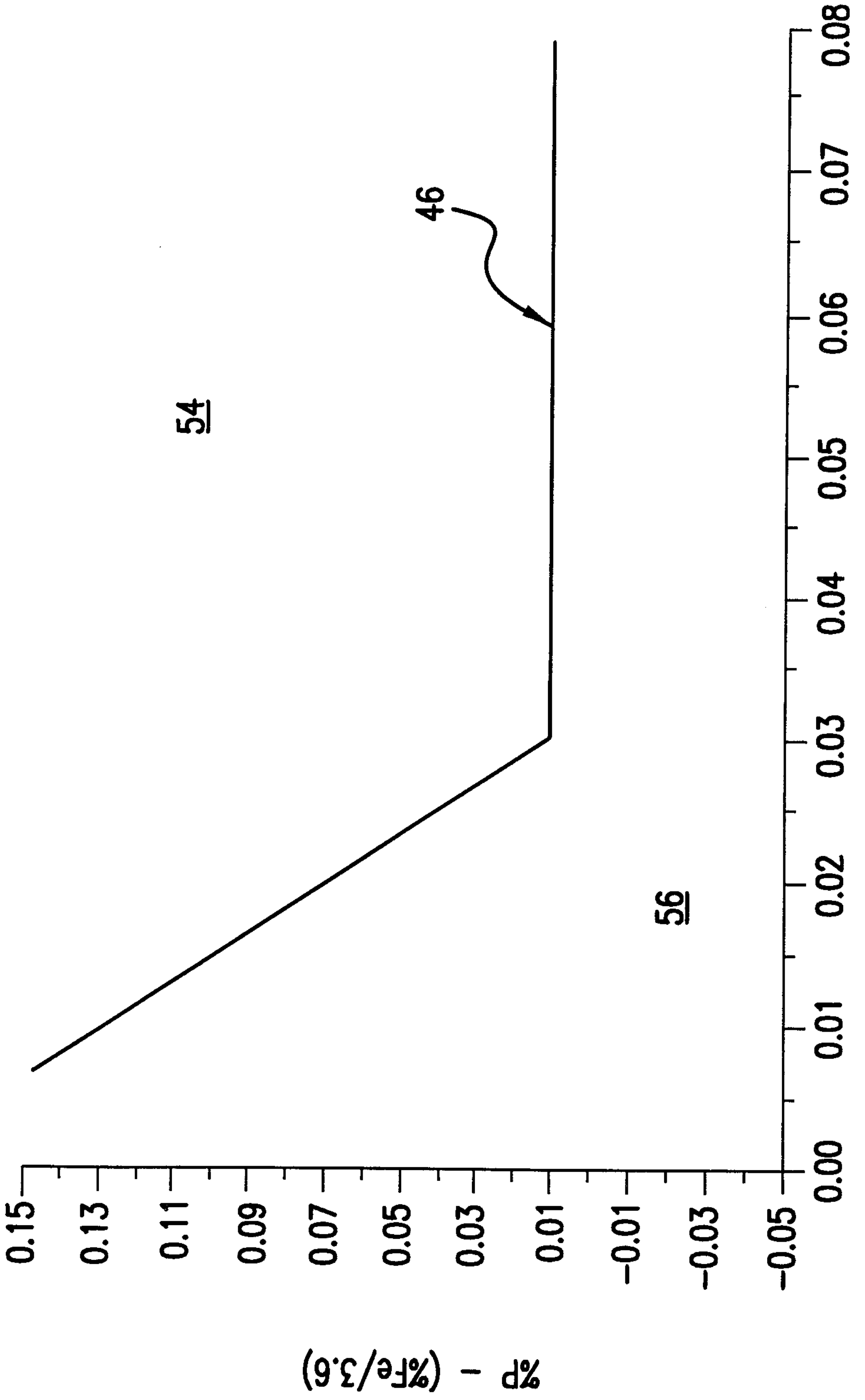

%P - (%Fe/3.6)
0.15
0.13
0.11
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
% MAGNESIUM
46
54
56

FIG. 6

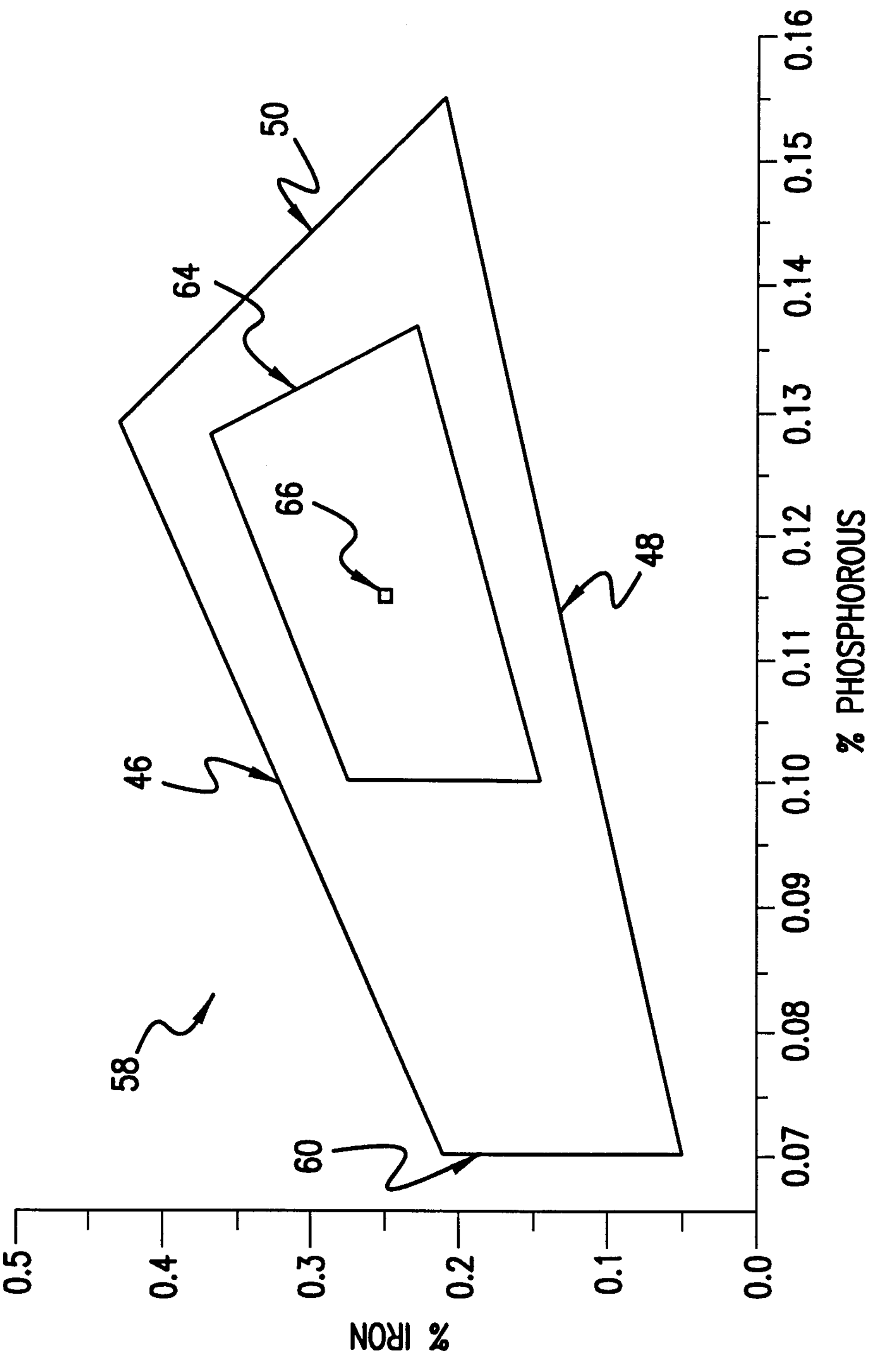

% IRON
0.5
0.4
0.3
0.2
0.1
0.0
% PHOSPHOROUS
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
50
64
66
48
46
58
60

FIG. 7

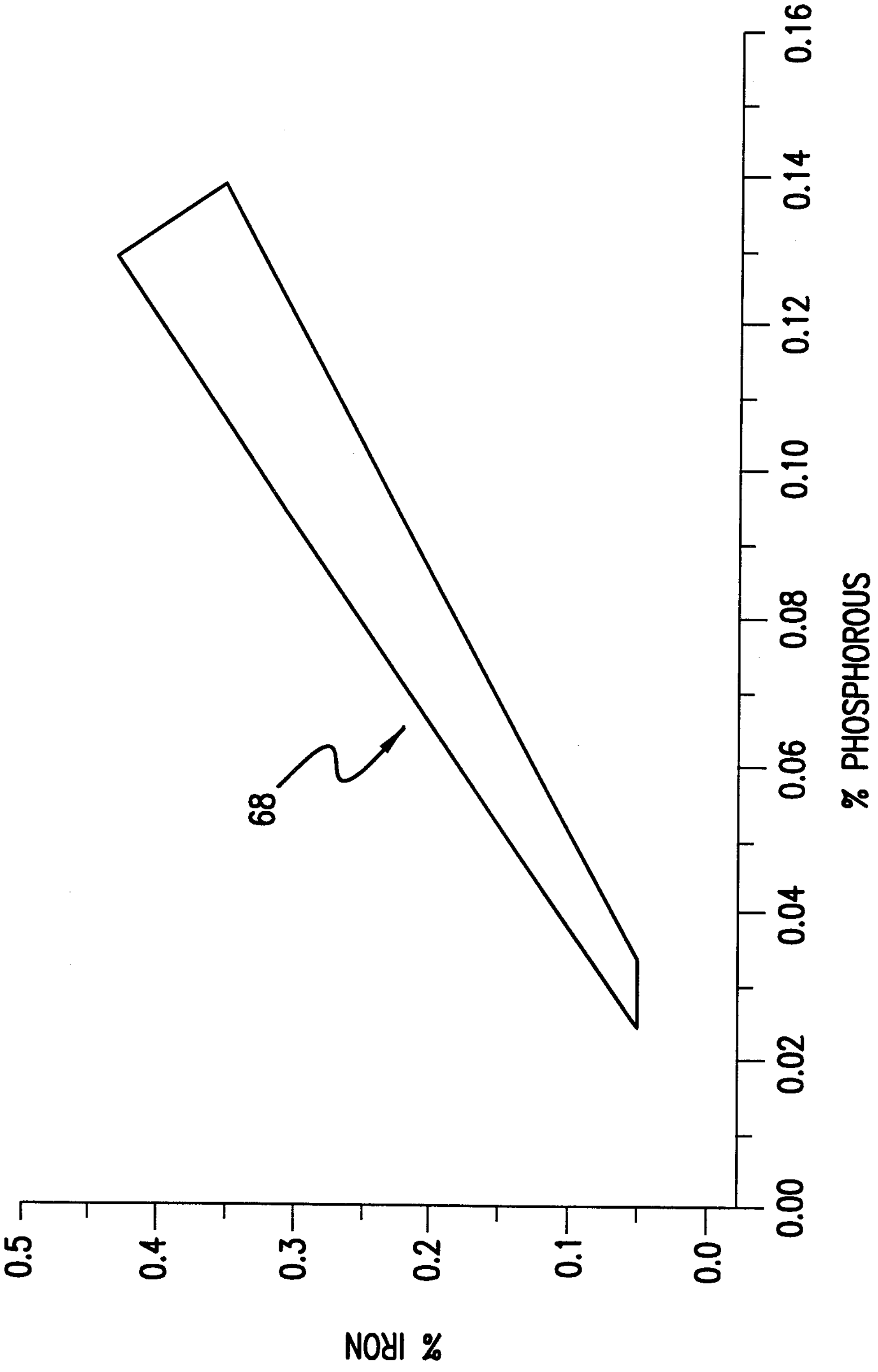

68
0.5
0.4
0.3
0.2
0.1
0.0
% IRON
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
% PHOSPHOROUS

FIG. 8

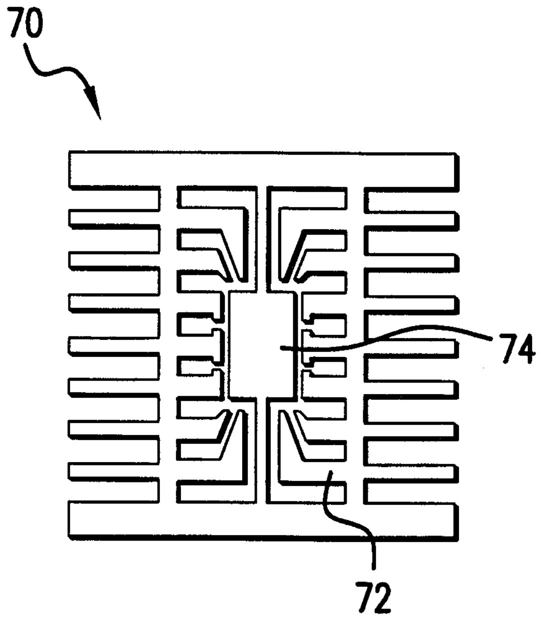


FIG. 9

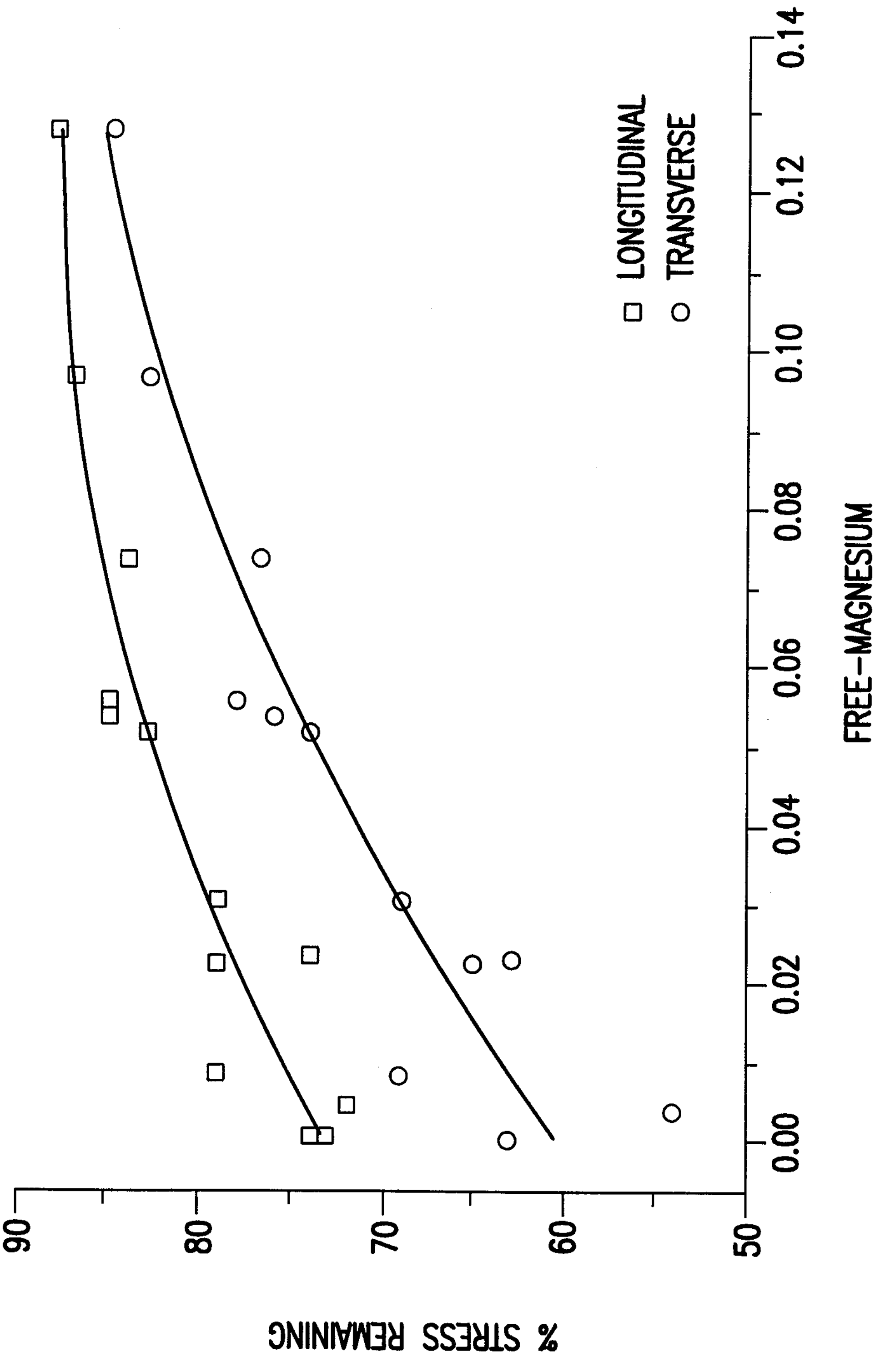

% STRESS REMAINING
90
80
70
60
50
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
FREE-MAGNESIUM
□ LONGITUDINAL
○ TRANSVERSE

FIG. 10

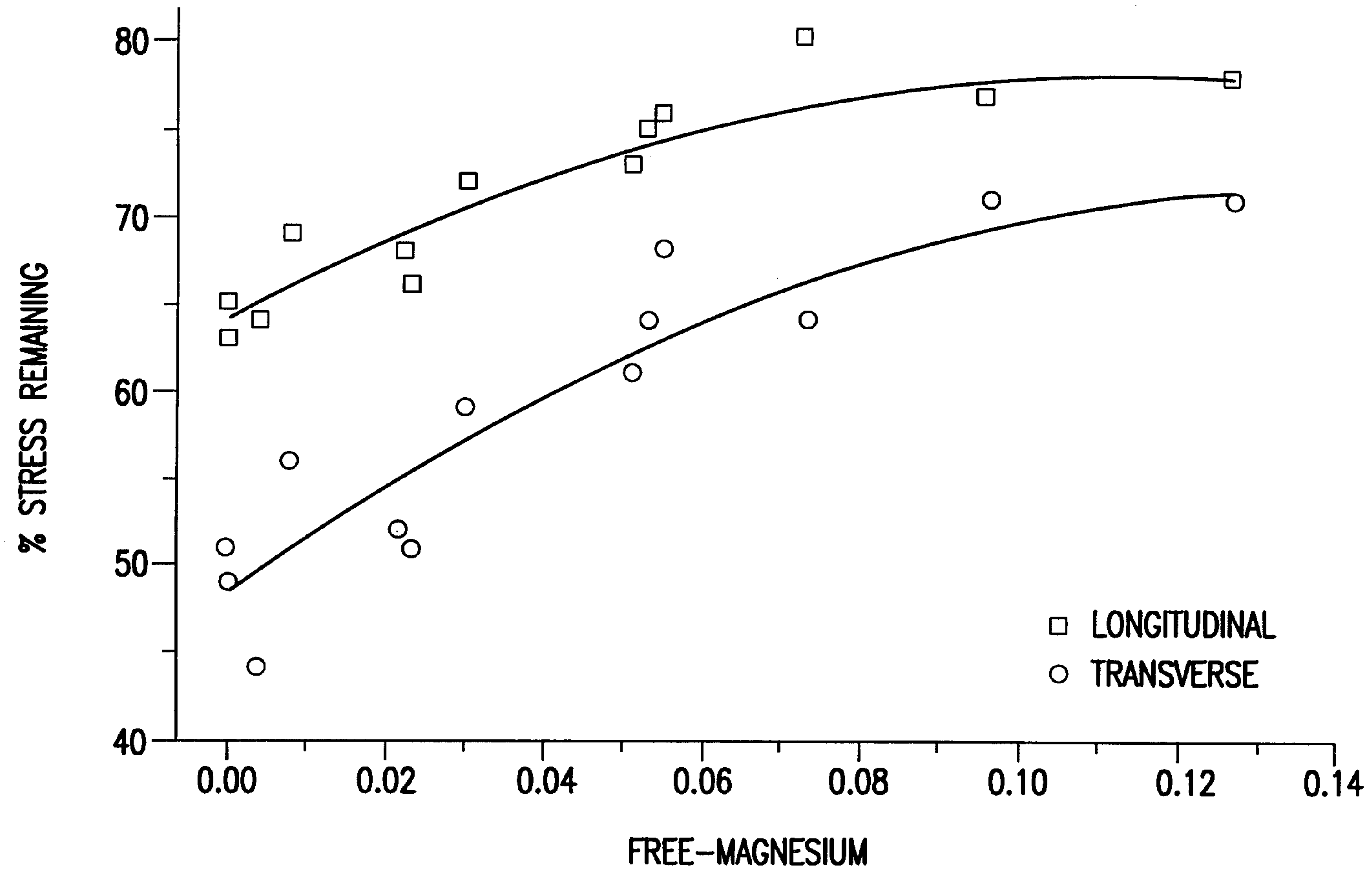

80
70
60
50
40
% STRESS REMAINING
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
FREE-MAGNESIUM
□ LONGITUDINAL
○ TRANSVERSE

FIG. 11

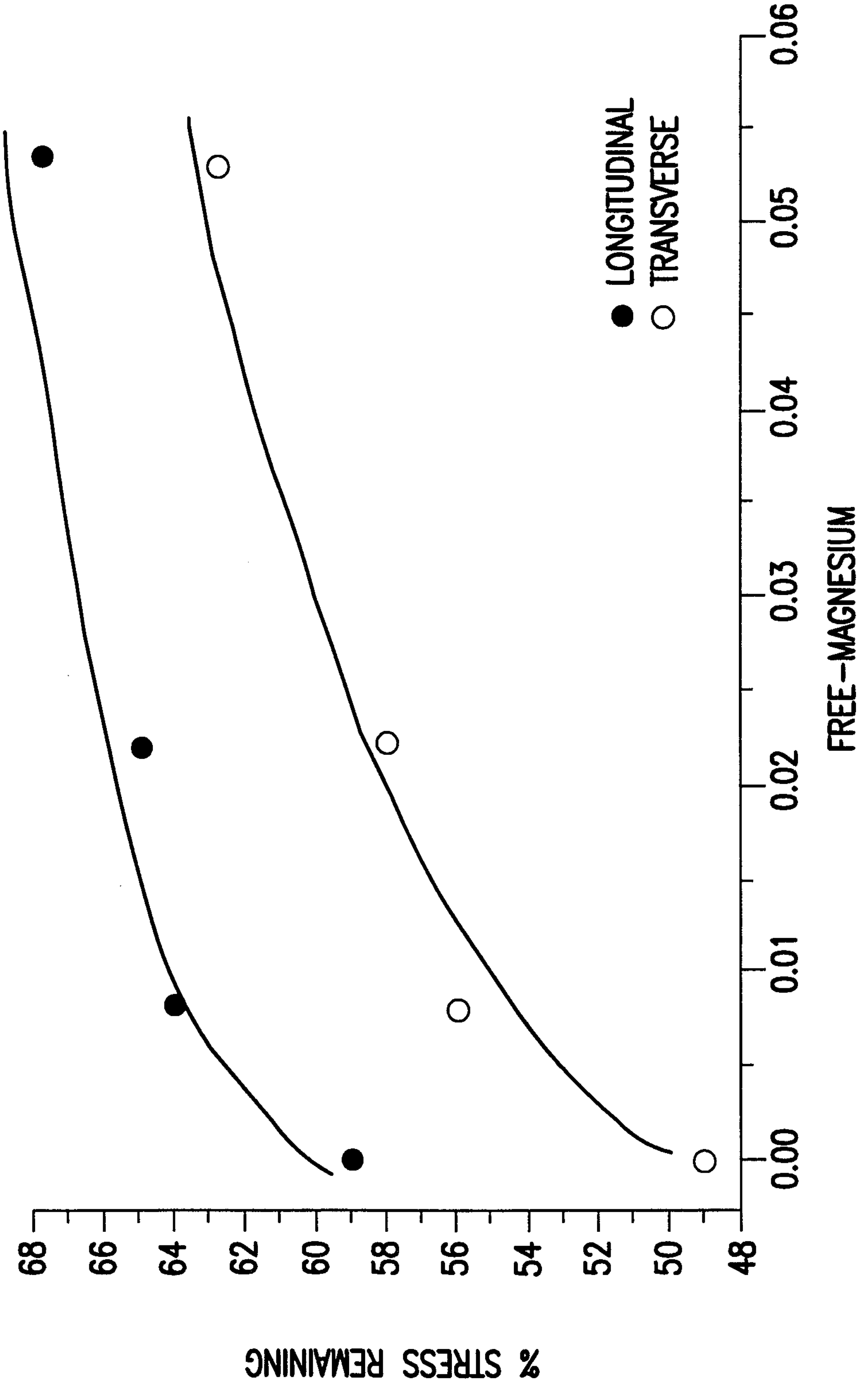

% STRESS REMAINING
68
66
64
62
60
58
56
54
52
50
48
0.00
0.01
0.02
0.03
0.04
0.05
0.06
FREE-MAGNESIUM
● LONGITUDINAL
○ TRANSVERSE

FIG. 12

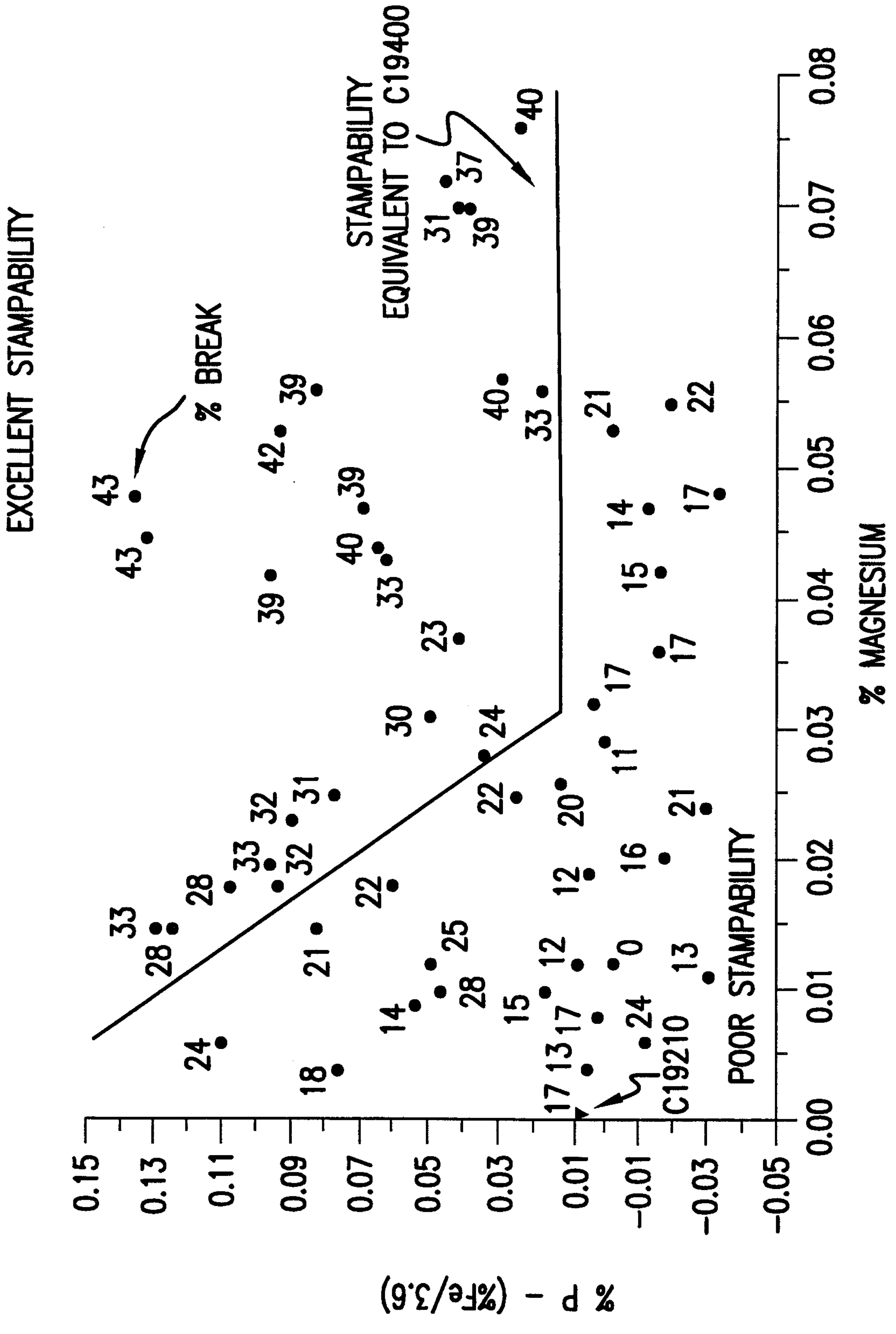

EXCELLENT STAMPABILITY
% BREAK
STAMPABILITY EQUIVALENT TO C19400
POOR STAMPABILITY
C19210
% P - (%Fe/3.6)
% MAGNESIUM
0.15
0.13
0.11
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
43
43
39
42
39
40
39
40
33
23
30
24
22
20
33
28
28
33
32
32
31
24
21
22
18
14
25
28
15
12
17
13
17
12
0
24
16
21
13
11
17
17
15
14
17
21
22
33
40
31
39
37
40

FIG. 13

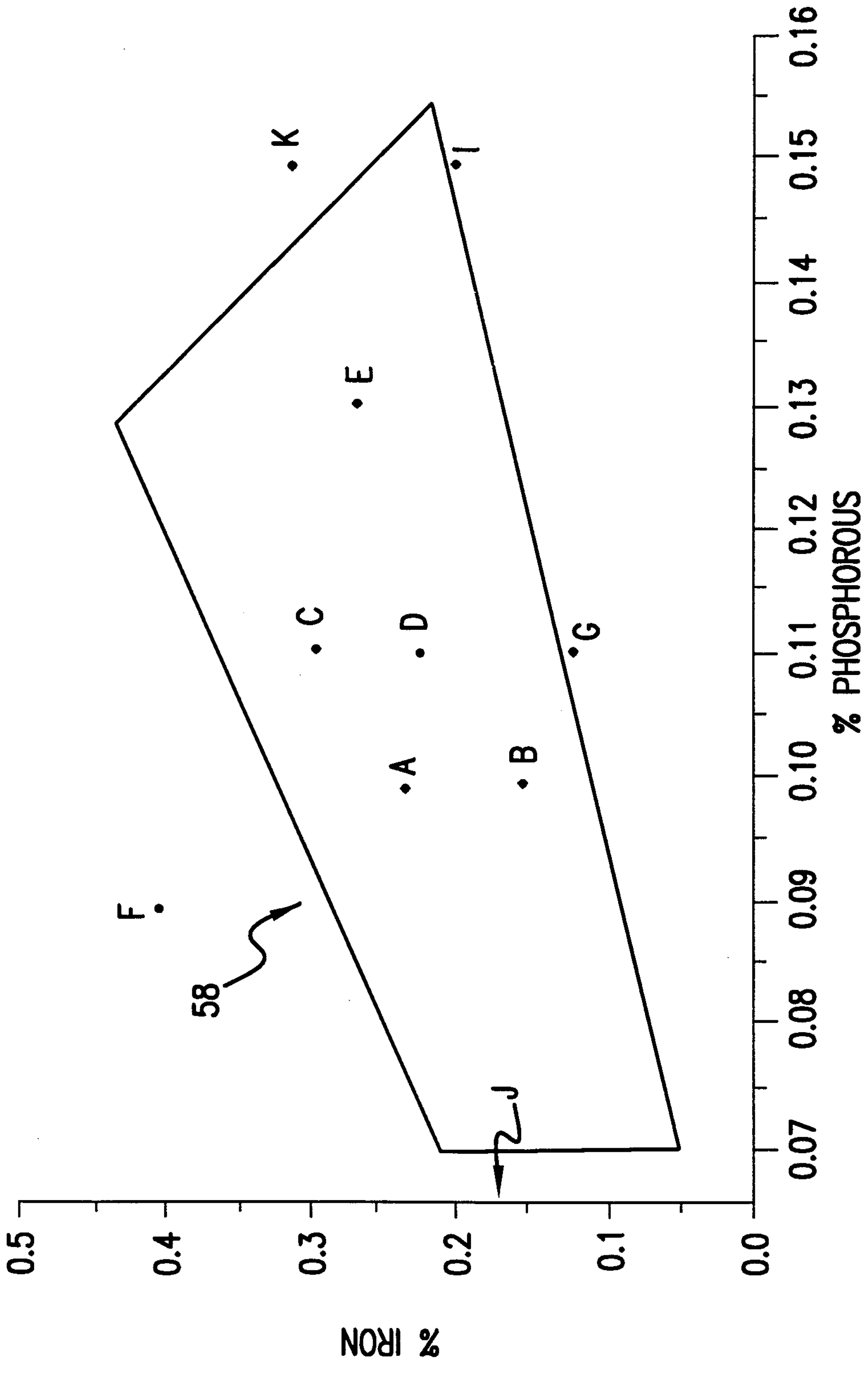

% IRON
0.0
0.1
0.2
0.3
0.4
0.5
% PHOSPHOROUS
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
A
B
C
D
E
F
G
H
I
J
K
58

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/13925

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C22C 9/00
US CL :148/432; 420/496, 499
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 148/432; 420/496, 499

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,334,346 A (KIM et al) 02 August 1994 (02-08-94).	1-17
A	US 4,605,532 A (KNORR et al) 12 August 1986 (12-08-86).	1-17
X	US 4,305,762 A (CARON et al) 15 December 1981 (15-12-81), col. 2, lines 6-10 and col. 6, Table IIA, Alloy Nos. 7.9.11.15.16 and 19	1-17
A	US 4,202,688 A (CRANE etal) 13 May 1980 (13-05-80).	1-17
A	US 3,778,318 A (FINLAY et al) 11 December 1973 (11-12-73).	1-17
A	US 3,677,745 A (FINLAY et al) 18 July 1972 (18-07-72).	1-17
X	JP 58-199385 A (SUMITOMO ELEC IND KK) 21 November 1983 (21-11-83), page 161, Table I, Alloy Nos. 1-5	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

08 OCTOBER 1998

Date of mailing of the international search report

30 OCT 1998

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