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COPPER NICKEL ALLOYS

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ABSTRACT OF THE DISCLOSURE

A cupro-nickel alloy having high strength, high ductility and excellent resistance to corrosion and sea water, and a magnetic permeability of below 1.1 having the following compositions by weight: nickel, 15–32%; aluminium, 1.5–3%; manganese, 4–6%; iron, .5–2%; balance—copper. The cupro-nickel alloy may also contain up to 5% chromium, up to 3% columbium and up to 3% silicon.

This invention relates to copper-nickel alloys and in particular to alloys containing maganese, aluminium and iron and is a continuation-in-part of application Ser. No. 627,642, filed Apr. 3, 1967, now abandoned, which in turn is a continuation-in-part of application Ser. No. 362,454 filed Apr. 24, 1964, now abandoned.

An object of this invention is to produce cupro-nickel alloys having a magnetic permeability below 1.1 and which are highly resistant to corrosion by sea water and possess a high strength combined with excellent ductility and resistance to shock as measured by the Izod or Charpy Impact Value—a combination of properties much sought after in modern marine engineering practice.

Another object of this invention is to produce alloys which are easily hot worked, e.g. by rolling, forging or extrusion and which do not require critical control of the hot working temperature. Such alloys are in consequence of this, readily forgeable in, for example marine forge shops or repair shops where the control of the forging conditions may be considered inadequate for the forging of many other alloys of this nature.

A further object of this invention is to produce alloys of the type described above which although amenable to precipitation hardening heat treatments, do not necessarily require any heat-treatment, in order to achieve the combination of corrosion resistance, low magnetic permeability, high yield strength, high tensile strength, good ductility and high Izod Impact Value—another factor of importance when components in this alloy are required to be produced in inadequately equipped workshops.

A further object of the invention is to produce alloys which after hot working possess a combination of properties which may be still further enhanced by a subsequent precipitation hardening treatment.

For many years cupro-nickels (copper-nickel alloys containing up to about 40% nickel) have been regarded as the most suitable types of alloy for handling many corrosive liquids and, in particular sea water, and they have been extensively used for items such as condenser tubes.

Considerable research has been carried out with a view to improving still further the properties and, in particular, the corrosion resistance of these alloys.

However, the cupro-nickels used to date are generally of comparatively low strength although possessing extremely good ductility.

The following is a typical example of the mechanical

properties of a standard alloy composed of 70% copper, 30% nickel, after hot working and annealing:

EXAMPLE A

Proof stress (0.5%)	tons/sq.inch	10
Tensile strength	tons/sq.inch	28
Elongation	percent	45
Izod Value	ft. lbs.	80

There is now a growing demand for materials of this type which have the ability to withstand much higher stresses in service and consequently must possess higher strength and, in particular, appreciably higher yield strength or proof stress values, although the ability to withstand shock loads must not be too greatly reduced and hence the required alloys must retain a high degree of ductility particularly as measured by the Izod Impact Value.

The beneficial effects of aluminium as a strengthening agent in cupro-nickels has also been known for some considerable time and one of the highest strength alloys in this series is known as Hidurax (registered trade mark) Special—the typical composition of which is as follows:

EXAMPLE B

	Percent
Nickel	14.90
Aluminium	2.60
Iron	1.00
Manganese	0.15

Copper—remainder.

The alloy of Example B possesses the following mechanical properties in the hot rolled condition:

Proof stress (0.1%)	tons/sq.inch	42.4
Tensile strength	tons/sq.inch	58.4
Elongation	percent	13.5
Izod Value	ft. lbs.	10

It will be noted that the alloy, Example B, possesses a proof stress and tensile strength far higher than the alloy of Example A, but the ductility as measured by elongation and Izod Impact Value is appreciably lower.

Hidurax Special responds to precipitation hardening, and because of this the ductility is reduced still further if the alloy is heated within the Precipitation Hardening range 400° C.–600° C. and consequently it is not considered suitable for services within this range of temperature, particularly if subjected to shock loading. This embrittlement at elevated temperatures may also impair the weldability of the alloy.

In the past, it has been considered that in order to achieve the best combination of properties in such copper-nickel-aluminium alloys, the ratio of nickel to aluminium should be in the region of 5:1.

It has now been found that the aluminium content should never exceed a value determined by this ratio and that increasing this ratio still further so that the aluminium content is less than one-sixth of the nickel content, results in an alloy possessing considerably higher ductility, as measured by elongation and Izod Impact Value although the proof stress and tensile strength are only slightly reduced if the nickel and aluminium contents are correctly selected, as shown by the following Example 1.

	Percent
Nickel	16.1
Aluminium	1.71
Iron	1.47
Manganese	0.25

Balance substantially all copper.

MECHANICAL PROPERTIES WHEN HOT ROLLED FROM THE TEMPERATURE RANGE 1000° C.–1050° C.

Proof stress (0.1%)	tons/sq. in.	35.2
Tensile strength	tons/sq. in.	47.2
Elongation	percent	21
Izod value	ft. lbs.	30

Therefore the present invention provides a cupronickel having a nickel content in the range of 15% to 32% and an aluminium content in the range of 1.5% to 3.0% and less than one-sixth of the nickel content.

A further improvement in the mechanical properties of such alloys has now been effected by making a substantial addition of manganese. By this means it is possible to produce alloys in the hot worked condition possessing an excellent combination of proof stress, tensile strength, ductility and Izod Impact Value, but in order to achieve this, the manganese content must be controlled between 4% and 6% and the manganese content must be less than one half of the nickel content, and is preferably less than one-third of the nickel content.

The use of manganese in alloys of this type is not unknown, but examples of such alloys have usually contained more than 9% manganese with the manganese and nickel contents being present in substantially equal proportions, and these known alloys have always to be subjected to heat treatment if adequate strength is to be achieved.

The following Table I shows the properties of two alloys, the first according to the present invention, the other of similar composition with the exception that the manganese content is 10.35% and more than half the nickel content.

It will be seen that the proof stress and tensile strength of the high manganese alloy are considerably less than those obtained on the alloy according to this invention, in spite of the fact that the rolled bar was produced in an identical manner.

Alloys according to this invention, i.e. containing between 1.5% and 3.0% aluminium, possess far superior proof stress and tensile strength in the hot worked condition without resorting to further heat treatment.

Such alloys containing between 1.5% and 2.1% aluminium possess an excellent combination of proof stress, tensile strength, ductility and Izod Impact Value as shown by Examples 6, 7, 8, 9, and 10 on Table III, this combination of properties being achieved by "Self-Precipitation Hardening" which takes place during cooling from the hot working operation.

Alloys within these limits of aluminium content may, if considered necessary, be subjected to a further precipitation hardening treatment following the hot working operation which results in a further substantial increase in proof stress and tensile strength (compares Tables III and V below which show a series of alloys of the same composition, differently treated).

Increasing the aluminium content still further has the effect of increasing the degree of "Self-Precipitation Hardening" during natural as opposed to induced cooling from the hot working process with a resulting further increase in proof stress and tensile strength, and Examples 11, 12, 13 and 14 in Table III show the properties which have been obtained on the rolled bar produced from alloys containing between 2.1 and 3.0% aluminium without resorting to further heat treatment. It will be noted that in all cases the 0.1% proof stress in this condition is greater than 40 tons/sq. inch.

However, because of the high degree of "Self-Precipitation Hardening" which takes place during natural cooling from the hot working operation, when the alloy contains between 2.1 and 3.0% aluminium, they show little response to subsequent precipitation hardening.

Alloys falling within this range of aluminium content therefore, should on no account be subjected to further precipitation hardening since this results in only a very slight increase in proof stress, but may result in appreciable reduction in the Izod Impact Value, as will be obvious from the results of precipitation hardening Examples 20, 21, 22 and 23 shown in Table V.

TABLE I

Example	Ni, Percent	Al, Percent	Mn, Percent	Fe, Percent	Condition	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., Percent	Izod Impact Value, ft./lbs.
2	18.2	1.86	4.77	1.32	1" sq. hot rolled bar. NOT heat treated	29.6	45.6	30	70
3	16.9	1.89	10.35	1.01	do	17.6	35.2	30	107
		Balance substantially copper							

The aluminium content of alloys according to this invention is particularly important since this determines the degree of precipitation hardening occurring during cooling from the hot working process. It consequently determines the mechanical properties of the hot worked product and in order to achieve the object of this invention it is important that the aluminium content should be controlled within the range of 1.5% to 3.0%.

In the aforementioned known alloys of copper-nickel-aluminium-manganese and iron, the published data discloses alloys containing 0.5%, 1.0% and 1.5% aluminium.

It has been found that alloys containing low proportions of aluminium do not develop the required proof stress and tensile strength in the hot worked condition.

Table II shows the properties of two allows containing 1.34% aluminium and 1.17% aluminium, and hence outside the scope of this invention.

These two alloys which fall outside the scope of this invention possess very inferior proof stress and tensile strength.

Alloys according to this invention may be melted in many types of melting furnace although it is an advantage of the preferred alloys, i.e. those containing 15–20% nickel that they are readily melted in fuel fired crucible furnaces, although of course they may be melted in many other types of furnace such as high frequency or low frequency induction electric furnaces.

When all the ingredients are thoroughly alloyed and the molten alloy has been heated to the necessary casting temperature, it is ready for casting into suitable moulds for subsequent hot working.

Alternatively, the molten alloy may be deoxidized with an addition of up to 0.25 oz. of lithium per 100 lb. of molten alloy. This addition not only has the effect of producing a high quality cast billet but also promotes improved weldability in the finished wrought products. The molten alloy may be cast into billets by any conventional method but the preferred technique is to cast these billets

TABLE II

Example	Ni, Percent	Al, Percent	Mn, Percent	Fe, Percent	Condition	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., Percent	Izod Impact Value, ft./lbs.
4	16.5	1.34	4.50	1.40	1" sq. hot rolled bar. NOT heat treated	18.0	36.5	51	118
5	17.4	1.17	4.90	0.70	do	18.5	36.0	26	49
					Balance substantially all copper.				

by the Durville method, referred to on page 5 of the Metals Handbook 1948 published by the American Society for Metals of Cleveland, Ohio (see also the article by P. H. G. Durville entitled "Still Casting of Metals" Amer. Inst. Min. Met. Eng. Proc. Inst., Metals Div. 1927, 343).

This non-turbulent method of casting billets is particularly desirable for an alloy of this type since it ensures freedom from aluminium oxide inclusions which may be formed by more turbulent methods of casting.

Billets free from aluminium oxide inclusions are also readily obtained by utilizing the continuous or semi-continuous casting processes.

Unlike many other copper-nickel alloys and in particular those containing more than 9.0% manganese, the alloys according to this invention are readily hot worked by rolling, forging, extrusion or any other hot working process over the wide temperature range 900° C.–1040° C.

After such hot working, alloys according to this invention possess the desired combination of mechanical properties without the necessity for solution treatment and precipitation hardening as shown by the examples given in the following Table III.

TABLE III

Example	Ni, Percent	Al, Percent	Mn, Percent	Fe, Percent	Condition	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., Percent	Izod Impact Value, ft./lbs.
6	17.3	1.59	4.87	1.14	Hot rolled bar. NOT heat treated	34.4	46.4	29	60
7	23.8	1.65	4.4	0.80	do	28.8	45.0	26	109
8	19.0	1.75	4.25	0.80	do	29.4	45.6	33	88
9	29.2	1.81	5.0	1.01	do	25.2	41.8	42	103
10	18.2	1.86	4.77	1.32	do	29.6	45.6	30	69
11	17.1	2.22	5.45	1.11	do	40.5	57.5	24	27
12	19.5	2.32	4.55	1.0	do	43.0	57.6	20	39
13	23.1	2.37	4.55	0.88	do	43.2	59.2	21	32
14	27.5	2.81	4.55	0.95	do	48.0	64.4	18	17.5

The balance is substantially all Copper in all Examples 6 to 14.

Unlike other cupro-nickel alloys and in particular those containing more than 6% manganese which require critical control of the hot working temperature, the alloys according to this invention can be successfully forged without the necessity for close temperature control and in fact the judgement of temperature by eye is sufficient to achieve an excellent combination of properties in the finished product.

The following table is a typical example of the properties which have been obtained by forging from 2" dia. to 1" sq. The forging being commenced respectively at 1040° C., 1000° C., 950° C. and 900° C.

Forging Temperature, ° C.	0.1% Proof Stress, Tons/sq. in.	Tensile Strength, Tons/sq. in.	Elong., Percent	B.H.N.	Izod Impact Value, ft./lbs.
1,040	25.4	43.0	37.5	187	66, 65, 67
1,000	32.0	45.0	32.0	201	66, 69, 70
950	26.8	44.0	32.0	197	64, 63, 62
900	30.0	43.8	30.0	201	63, 65, 64

It will be noted that the proof stress in all cases was 25 tons/sq. inch or more but the most remarkable feature of these examples is the excellent consistency of the Izod Impact Value; all values lying between 62 ft. lbs. and 70 ft. lbs.

As further proof of the excellent behaviour of alloys according to this invention when forged under conditions of inadequate control, the following examples demonstrate that the percentage reduction in area during the forging operation, has little effect on the properties of the final forged product.

Two lengths of a 4½" dia. billet were reheated to 1000° C. Having attained the temperature, one length was forged to 3" sq., a reduction in area of 44.0%, and the second length was forged to 2" sq. a reduction in area of 75.0% and the mechanical properties obtained without any further heat treatment were as follows:

	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., percent	B.H.N.	Izod Impact Value, ft./lb.
3" sq	28.3	48.3	30.5	201	53, 53, 54
2" sq	28.4	48.0	31.0	207	48, 49, 49

The majority of known copper-nickel alloys are susceptible to sulphur embrittlement when re-heated in furnaces fired by fuels of high sulphur content and, consequently, special reheating equipment is necessary for the successful forging of such alloys.

It has been found that alloys according to this invention are not susceptible to such sulphur embrittlement as demonstrated by the following example.

A 3" dia. section of rolled bar was heated in an oil fired furnace at a temperature of 950–1000° C. for a period of 8 hours. The sulphur content of the fuel oil being 3.2% by weight maximum.

During the period of heating the furnace door was closed most of the time except for the withdrawal of other work for forging. The furnace atmosphere would therefore be slightly reducing, this producing conditions more conducive to sulphur embrittlement.

After heating under the above conditions, the 3" dia. section was forged at a temperature of 980° C. to 1" square. The metal forged satisfactorily, no cracking occurred during the forging operation. Tensile and Izod tests taken from the 1" square bar gave the following results in the as-forged condition.

Proof stress (0.1%) _____tons/sq. inch__ 25.0
Tensile strength _____tons/sq. inch__ 42.5
Elongation _____percent__ 42.0
Izod Impact value, 51.5, 48.5, 45.5 ft. lbs.

The fact that the material did not crack after prolonged heating at its forging temperature demonstrates that alloys according to this invention are not susceptible to sulphur embrittlement. The absence of any embrittlement is also confirmed by the good tensile and impact properties.

The above examples clearly demonstrate that alloys according to this invention can be readily forged in a variety of conditions of temperature, furnace atmosphere, etc., whilst still achieving an excellent combination of properties without resorting to further heat-treatment.

It is however an established fact that copper-nickel-manganese-aluminium alloys are amenable to precipitation hardening, i.e. they may be softened by heating to a temperature in excess of 750° C. followed by quenching or rapid cooling, and subsequently hardened or strengthened by reheating to a temperature in the range 300° C.–600° C.

However, it is only by controlling the composition in accordance with this invention that such alloys will become "Self-Precipitation Hardening" during natural as op-

posed to induced cooling from the hot working process. The degree of such "Self-Precipitation Hardening" will of course be dependent on the rate of cooling and hence on the section of the finished product. But in the case of alloys according to this invention, it has now been found that the effect of such rate of cooling is comparatively small and if the alloy is produced exactly in accordance with this invention, an excellent combination of mechanical properties can be achieved in hot worked products of a very wide range of cross section as demonstrated by the following Table IV.

TABLE IV

Bar Size	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., percent	Izod Impact Value, ft./lb.
1" dia	27.5	47.0	37.0	64, 66, 68
2" dia	31.0	50.0	32.5	58, 59, 62
2⅛" dia	33.5	51.5	32.5	60, 61, 61
4" dia	29.0	49.0	31.0	54.5, 55, 56
5" dia	29.0	49.0	31.5	54, 54, 54.5

A most important feature of these examples is the fact that the proof stress shows no tendency to decrease with increasing section. This characteristic is invaluable to the designer of marine engineering equipment, since the majority of high strength corrosion resistant alloys available hitherto possess increasingly inferior tensile properties as the cross sectional area increases and the designer must therefore increase the cross section of his components still further to allow for such reduction in strength.

Alloys according to this invention do not suffer this serious disadvantage.

Although these alloys possess an excellent combination of mechanical properties described above in the hot worked condition without the necessity for solution treatment and/or precipitation hardening, they may in certain circumstances be subjected to a precipitation hardening heat-treatment in order to effect a further increase in the proof stress and tensile strength. The following Table V shows the results obtained by such treatment when applied to the hot rolled bar examples previously shown in Table III.

As distinct from all other known alloys of this type the alloys according to this invention should on no account be subjected to a solution heat treatment after hot working unless the product is to be subjected to a subsequent cold working operation. Such a solution treatment of a hot worked product, even though followed by a precipitation heat treatment, cannot achieve a better combination of properties and frequently results in inferior properties to those which can be achieved according to this invention.

It will be obvious therefore that hot worked products produced according to this invention after finishing the hot working must be allowed to cool freely in air and must not be subjected to a more rapid rate of cooling, such as would be obtained by quenching in oil or water, since such treatment can only result in a reduction in the proof stress and hardness.

However, if the wrought products are inadvantently cooled more rapidly than desired, this would be immediately detected by a low result on hardness test and the required tensile properties could be readily achieved by subjecting the rapidly cooled wrought products to a precipitation hardening treatment as described above.

As stated above, hot worked products in alloys according to this invention do not require a solution heat-treatment in order to achieve the required combination of properties.

However, a solution heat-treatment following a hot working operation is desirable if the product requires subsequent cold working. For this purpose hot rolled bar, forged slabs, hot rolled sheet, etc. should be solution heat-treated by heating within the temperature range 750° C. to 1000° C. followed by rapid cooling in air, oil or water, when they will be in their softest condition and readily cold workable. After this cold working treatment the finished products which may be sheet, strip, rod, wire or cold extruded components, may be subjected to a further precipitation hardening treatment after which the products will possess extremely high tensile properties, combined with excellent ductility and Izod Impact Values. Table VI indicates typical properties obtained on rod which had been solution treated by heating to 920° C. quenched in water, cold drawn with various reductions in cross section as indicated in the table and finally precipitation hardened as stated in the table.

TABLE V

Example	Ni, Percent	Al, Percent	Mn, Percent	Fe, Percent	Condition	0.1% Proof Stress, Tons/sq. in.	Ultimate Tensile Strength, Tons/sq. in.	Elong., Percent	Izod Impact Value, ft./lbs.
15	17.3	1.59	4.87	1.14	Hot rolled bar precipitation hardening 4 hrs. at 550° C.	43.0	56.0	20	35
16	23.8	1.65	4.4	0.80	do	35.8	57.8	24	40
17	19.0	1.75	4.25	0.80	do	36.2	54.4	22	32
18	29.2	1.81	5.0	1.01	do	35.2	53.4	25	40
19	18.2	1.86	4.77	1.32	do	36.6	54.8	22	37
20	17.1	2.22	5.45	1.11	do	43.6	59.6	16	16
21	19.5	2.32	4.55	1.0	do	43.6	59.6	15	17
22	23.1	2.37	4.55	0.88	do	45.6	63.2	14	10
23	27.5	2.81	4.55	0.95	do	50.4	67.2	9	4.5

From Tables III and V it will be obvious that hot worked products showing the lowest proof stress in the hot worked condition exhibit the greatest response to precipitation hardening.

TABLE VI

Percent Reduction of area in cold drawing	Precipitation Hardening Treatment	0.1% Proof Stress, Tons/sq. inch	Ultimate Tensile Strength, Tons/sq. inch	Elongation, Percent	Reduction in Area, Percent	Izod Impact Value, ft./lbs.
10	4 hrs. at 500° C	38	52	22	40	55
20	do	45	55	18	37.5	55
30	4 hrs. at 450° C	48	58	16	37.5	55
50	do	55	62	14	37.5	52
70	4 hrs. at 425° C	58	65	11	27.5	44

Hot worked products showing a high proof stress in the hot worked condition should not be subjected to precipitation hardening since this results in little increase in strength but appreciable reduction in elongation and Izod Impact Value.

This invention also envisages the use of other additional elements to enhance certain characteristics of these alloys and in particular, columbium, silicon, chromium and lithium have beneficial effects for special applications.

Columbium has the effect of developing a very high

tensile strength combined with good ductility in hot worked products, see Table VII.

TABLE VII

Example	Ni, percent	Al, percent	Mn, percent	Fe, percent	Cb, percent	Condition	0.1% Proof Stress, Tons/sq. inch	Ultimate Tensile Strength, Tons/sq. inch	Elong., percent	Izod Impact Value, ft./lb.
26	18.0	1.76	5.4	0.95	0.30	2" sq. hot rolled bar	34.0	52.8	23	35
27	18.0	1.76	5.4	0.95	0.30	2" sq. hot rolled bar+4 hrs. at 550° C	38.0	56.0	20	16
28	18.0	1.76	5.4	0.95	0.30	1" sq. hot rolled bar	33.5	52.5	32	40
29	18.0	1.76	5.4	0.95	0.30	1" sq. hot rolled bar+4 hrs. at 550° C	36.5	55.5	27	21
30	18.2	2.80	4.85	1.18	0.80	¾" sq. hot rolled bar	49.5	62.2	24	19
31	18.2	2.80	4.85	1.18	0.80	¾" sq. hot rolled bar+4 hrs. at 550° C	54.0	56.5	18	7

The addition of silicon to alloys according to this invention also results in hot worked products possessing extremely high proof stress and tensile strengths combined with good ductility. Such alloys also possess an excellent resistance to wear and abrasion.

Examples of the properties which have been obtained on hot rolled bar produced from alloys containing silicon without being subjected to further heat-treatment are shown in Table VIII.

TABLE VIII

Example	Ni, percent	Al, percent	Mn, percent	Fe, percent	Si, percent	Condition	0.1% Proof Stress, Tons/sq. inch	Ultimate Tensile Strength, Tons/sq. inch	Elong., percent
32	17.9	2.79	5.15	1.01	0.77	¾" sq. hot rolled bar	48.5	62.0	15.0
33	18.5	1.85	5.3	1.10	0.65	2¾" sq. hot rolled bar	43.5	59.5	19.5
34	18.5	1.85	5.3	1.10	0.65	1" sq. hot rolled abr	44.0	59.5	19.0

Chromium has little effect on the tensile properties of the alloys according to this invention, but it is beneficial in refining the grain size.

Alloys according to the invention may also be produced in the form of sand castings in which condition they possess an excellent combination of properties as shown by the following example.

An alloy of the composition:

	Percent
Nickel	17.3
Aluminium	1.96
Manganese	5.15
Iron	1.32

Balance substantially all copper, when cast into a sand mould possesses the following mechanical properties:

Proof stress (0.1%) tons/sq. inch	29.0
Tensile strength tons/sq. inch	43.0
Elongation percent	13
Izod Impact Value ft. lbs.	28

It will be recalled that the object of the present invention is to produce a high strength corrosion resistant copper nickel alloy which is nonmagnetic and which has a nickel content in the range 15% to 32%. Such an alloy is particularly required in marine engineering practice, in which art, where a non-magnetic alloy of the kind in question is called for, an alloy having a magnetic permeability in excess of 1.1 would be unacceptable. Indeed, in this field, for many uses, a magnetic permeability of 1.05 or more would be unacceptable. Accordingly, it is an object of this invention that the alloys should have low magnetic permeability by which we mean certainly less than 1.1 and preferably less than 1.05.

Magnetic permeability is a function of the nickel and iron contents, the iron being present in an amount of at least 0.5% to perform a useful grain refining function.

However, in a copper nickel alloy having a nickel content in the range 15% to 32% any significant addition of iron beyond say, 6% reduces the corrosion resistance properties of the alloy and it is preferred that the nickel:iron ratio should be as high as possible for any given nickel content, and should not be less than 6:1.

Moreover, in order to obtain in addition, the low magnetic permeability values discussed above, it is necessary to reduce the iron content still further and it has been found that the desired values can only be obtained if the iron content is maintained below 3% and can only be ensured, that is, taking into account reasonable manufacturing tolerances, if the iron content is maintained below 2%. Accordingly the alloy provided by this invention and having a nickel content in the range 15% to 32%, has an iron content in the range 0.5% to 2% and indeed, such an alloy will usually be found to have a magnetic permeability of less than 1.05.

That the alloys provided according to this invention as described above, have low magnetic permeability is shown by Examples 35 and 36 of Table IX. Example 35 when produced in the form of a hot rolled bar possessed a magnetic permeability of 1.01 while Example 36 when cast into a sand mould and without further heat treatment, possessed a magnetic permeability of 1.005.

Example 37 although having an acceptably low magnetic permeability would require very accurate control of the nickel and iron contents for the value of 1.05 to be consistently achieved, since as shown in Example 38, a comparatively small decrease in the nickel content—from 16% to 15.5%—coupled with a small increase in the iron content—from 2.6% to 3.18%—is accompanied by a significant rise in the magnetic permeability value—of 1.05 in Example 37 to 1.3 in the case of Example 38.

Examples 39 to 45 show how magnetic permeability values rise significantly with increases in the iron content, of the nickel, aluminium and manganese contents of the alloy are maintained substantially constant.

TABLE IX

Example	Percent Aluminium	Percent Nickel	Percent Manganese	Percent Iron	Percent Copper	Condition	Magnetic Permeability
35	1.55	16.9	5.3	0.88	Balance	Wrought	1.01
36	1.80	19.4	4.7	0.95	do	Cast	1.005
37	1.81	16.0	5.6	2.6	do	Wrought	1.05
38	1.75	15.5	4.05	3.18	do	do	1.3
39	1.71	17.2	5.15	5.24	do	do	2.0
40	1.65	15.0	4.10	6.2	do	do	2.4
41	1.83	18.2	4.7	6.86	do	do	2.7
42	1.6	17.5	4.25	7.72	do	do	3.05
43	1.59	18.2	4.7	8.8	do	do	3.1
44	1.66	16.6	5.15	9.22	do	do	3.4
45	1.76	15.0	4.85	6.35	do	Cast	2.5

We claim:

1. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 25 tons per square inch, comprising:

	Percent
Nickel	15.0–32.0
Aluminium	1.5–3.0
Manganese	4.0–6.0
Iron	0.5–2.0

the aluminium content being less than one-sixth of the nickel content, and the balance being substantially all copper.

2. An alloy as defined in claim 1, including at least one of the following elements in the following proportions:

	Percent
Chromium	up to 5
Columbium	up to 3
Silicon	up to 3

3. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 25 tons per square inch, comprising:

	Percent
Nickel	15.0–25.0
Aluminium	1.5–2.1
Manganese	4.0–6.0
Iron	0.5–2.0

with the manganese content being less than one third of the nickel content and the aluminium content being less than one sixth of the nickel content, and the balance being substantially all copper.

4. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 35 tons per square inch, comprising:

	Percent
Nickel	15.0–25.0
Aluminium	>2 <3
Manganese	>4 <6
Iron	0.5–2.0

with the manganese content being less than one third of the nickel content and the aluminium content being less than one sixth of the nickel content and the balance being substantially all copper.

5. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 25 tons per square inch, comprising:

	Percent
Nickel	15.0–20.0
Aluminium	1.5–2.1
Manganese	>4 <5
Iron	0.5–1.5

Copper substantially the balance.

6. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 35 tons per square inch, comprising:

	Percent
Nickel	15.0–20.0
Aluminium	2.2–3.0
Manganese	4.5–5.5
Iron	0.5–1.5

Copper substantially the balance.

with the manganese content being less than one third of the nickel content and the aluminium content being less than one sixth of the nickel content and the balance being substantially all copper.

7. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.05 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 25 tons per square inch, comprising:

	Percent
Nickel	15–32
Aluminium	1.5–3
Manganese	>4 <5
Iron	0.5–2.0

Copper substantially the balance.

8. A corrosion resistant high strength ductile copper nickel alloy with low magnetic permeability of less than 1.1 which after hot working and without the necessity of subsequent solution treatment or precipitation hardening, possesses a 0.1% proof stress of at least 25 tons per square inch, comprising:

	Percent
Nickel	15–32
Aluminium	1.5–3
Manganese	>4 <6
Iron	0.5–2

Copper substantially the balance.

and including at least one of the following elements in the following proportions:

	Percent
Chromium	0.25–5
Columbium	0.25–3
Silicon	0.25–3

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