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THESIS

****

ALLOYS OF ALUMINUM

by

Robert Dunn Howerton

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I. BIBLIOGRAPHY.

The following bibliography contains a short abstract of the more important references. used.

SCHNABEL: "GENERAL METALLURGY", VOL. II.

Aluminum alloys with almost all metals, and in all proportions with many of them.

MAGNESIUM. Up to 10% magnesium in aluminum alloys can be worked in every way. Greater than 15% magnesium has a tendency to cause brittleness. Magnesium-aluminum alloys, with less than 35% magnesium are usually designated as Magnalium.

ANTIMONY. Up to 5% antimony makes aluminum harder, tougher, and more easily forged than pure aluminum. Greater proportions increase hardness, but cause brittleness and raise melting point. Melting point of Magnalium raised by antimony up to 30%.

COBALT. Up to 5% cobalt permits rolling; 75% cobalt renders it hard as steel.

NICKEL. Alloys harder and tougher than aluminum. Alloy with 3% nickel easilymolded into plates. 18% of aluminum with 82% nickel gives alloy hard as steel, readly polished and easily worked with the hammer.

ZINC. Up to 3% renders aluminum harder but more brittle.

CADMIUM, BISMUTH, AND LEAD. These metals do not alloy readily with aluminum.

SILVER. Aluminum with 5% silver is easily forged. Alloys having two parts of aluminum to one part silver easier to coin than copper-silver alloys.

COPPER. Copper and aluminum alloy in all proportions. Copper, up to 10%, gives an alloy possessing hardness, toughness, and tenacity; more causes alloy to become brittle.

GOLD. An alloy having 22% aluminum and 78% gold has a ruby red color and is hard and brittle.

COPPER AND NICKEL IN MAGNALIUM.
Richards, ENG. & MIN. J., 1908, p. 715.

Magnalium admits of introduction of small quantities of copper and nickel without unduly raising the specific gravity.

specific gravity, giving greater tensile strenght and resistance to atmospheric and acid corrosion.

BARNETT, J. SOC. CHEM. IND., 1905, p. 832.
ALLOYS OF ALUMINUM.

METAL FOR TAPS, TUYERES, ETC.: 75% aluminum, 12% cadmium, 6% copper, 5% tin, 2% nickel.

FOR PEDESTALS: 45% aluminum, 14% antimony, 1.2% copper, 12% tin, 27% zinc, 0.8% lead.

BEARING AND TOOL METAL: Copper with 10% aluminum and 1% manganese makes very hard alloy.

~~Horse-shoes~~ HORSE-SHOES: 78% aluminum, 12% copper, 10% zinc, or 85% aluminum, 5% copper, 10% tin.

The addition of aluminum to brass (2.5% aluminum, 70% copper, 27.5% zinc) more than doubles the elongation and nearly doubles the tenacity.

Tin renders aluminum more fusible and more brittle. one hundred parts of aluminum to ten parts of tin, ace cording to Bourbose, gives a combination easily worked and soldered as easily as brass, less easily attacked by reagents than aluminum, suitable for optical instruments. Small amounts of aluminum (5, 7, and 9%) increase the hardness and tenacity of tin.

Aluminum combines in all proportions with cadmium forming fusible and malleable alloys.

Silver in small amounts increases the hardness and elasticity of aluminum, and lowers the melting point without increasing the brittleness.

Aluminum and nickel combine with incandescence when heated together. Under 3% nickel increases hardness, elasticity, and toughness, and lowers the melting point.

Alloys with bismuth are hard and brittle.

Those containing sodium are easily attacked both in the atmosphere and in water.

Aluminum unites with manganese and platinum, forming fusible alloys; with boron in varying proportions, forming among other combinations 'adamantine' and 'graphitic' boron.

CAMPBELL AND MATHEWS, J. AM. CHEM. SOC., 1902.

Addition of platinum to aluminum, up to 10%, renders no change in color; 30%-60% distinctly yellow.

Addition of tin gradually lowers the freezing point of aluminum to 570° at 74% tin; sudden fall to 490° at 80% tin; rises to 550° with 85% tin; then falls gradually to the eutectic point with 99.92% tin.

RICHARDS, J. AM. CHEM. SOC., 1902.

Two classes of aluminum alloys.

1. Those in which small amounts of ~~aluminum~~ other metals are added to aluminum.

2. Those in which small amounts of aluminum are added to othermetals.

Other metlas in the smaller proportions do not generally exceed 15%, and in these alloys maximum improvement is generally obtained with much smaller amounts than 15%.

Aluminum forms inter-metallic compounds more readily than any other metal, except perhaps the alkalies. However, it will neither combine nor give homogeneous mixtures with lead, bismuth, or cadmium, and perhaps a few others. Various workers have found one or more compounds with antimony, chromium, cobalt, ~~and~~ copper, nickel, gold, manganese, magnesium, mercury, molybdenum, platinum, titanium, tungsten, and other metals. (Recent work has, however, disaffirmed certain of these compounds.)

Nickel (2%-5%) is used for hardening aluminum; sometimes used with other hardeners; as, copper, tungsten, etc. With 7%-10% of combined hardeners alloy casts well and is exceedingly tough.

Tin tends to lower the melting point but increases brittleness.

MOISAN, J. AM. CHEM. SOC., 1895.

Action of water on aluminum alloys.

Presence of sodium in aluminum or its alloys tends to render them easily decomposable and easily destructible in water. Aluminum-tin alloys of certain proportions are easily attacked by water. Also, certain other metals in different proportions.

GUILLET, J. AM. CHEM. SOC., 1908.

Aluminum-iron and aluminum-manganese alloys.

When aluminum and ferric oxide are heated together, the alloy FeAl is formed. If the mixture be heated previously at 800° the compound $FeAl_4$ is the result. Other iron-aluminum compounds may be isolated. These facts hold true, practically in their entirety, for manganese and aluminum.

ABS. J. AM. CHEM. SOC.,1903.

Alloys of copper and magnesium.

The melting points of a series of alloys of copper and magnesium containing from 10%-90% of copper have been obtained. Three maxima (555°, 585°, and 915° 892°) and three minima (475°, 540°, and 890°) were observed; the three maxima corresponded with $CuMg_2$, CuMg, and Cu_2Mg, respectively; alloys were white with less than 80% copper. Alloy with 10% copper was malleable; addition of copper increases brittleness, 70% being so brittle it can be broken with the fingers. There is a close analogy between these alloys and those of aluminum and gold.

BOUDUARD, ABS. J. AM. CHEM. SOC., 1903, Aii, p. 480.

Alloys of copper and magnesium.

$CuMg_2$, CuMg, Cu_2Mg were confirmed to exist by microscopic examination. Alloy prepared by the addition of magnesium to copper, fused under salt. Alloy CuMg also prepared in impure state by similar treatment.

ABS. J. AM. CHEM. SOC., 1904, 86ii, p. 618.

Aluminum-magnesium and aluminum-antimony alloys.

The aluminum-magnesium alloys containing less than 65% aluminum obtained by fusing the two metals together in sealed tubes out of contact with the air.

Van Aubel: alloy SbAl obtained melting at 1080°; Guillet: obtained SbAl, $SbAl_3$, $SbAl_4$, and $SbAl_{10}$; Gautier has examined the melting points of the two metals alloyed together. Hector Pecheux has prepared the following alloys: $SbAl_{30}$ with sp. gr. 2.736 at 23°; $SbAl_{35}$, sp. gr. 2.70; $SbAl_{36}$, 2.662; $SbAl_{40}$, 2.598; all melting between 730° and 760°; expand on solidifying, slightly sonorous, brittle and bend readily. Stable in air at fusion, do not decompose cold water, but $SbAl_{30}$ decomposes water at 100°. Attacked by most acids and alkalies.

J. W. RICHARDS, J. AM. CHEM. SOC.,1904.

Light alloys of aluminum.

Effects of alloying aluminum with chromium, manganese, copper, nickel tin silver, tin tungsten, zinc described.

PECHEUX, ABS. J. AM. CHEM. SOC., 1906, 86ii, p. 404.

Zinc-aluminum alloys.

Form nine well-defined alloys; namely, Zn_3Al, Zn_2Al, $ZnAl$, $ZnAl_2$, $ZnAl_3$, $ZnAl_4$, $ZnAl_6$, $ZnAl_{10}$, $ZnAl_{12}$, with specific gravity varying between 5.704, and 3.040 at 16°, as the proportion of aluminum increases. Melting points increase with the proportion of aluminum. All brittle, first two hardest, last three softest. Most of them attacked by most acids and by concentrated potassium hydroxide.

G. GRUBE, ABS. J. AM. CHEM. SOC., 1905, 86ii, p. 523.
Magnesium-aluminum alloys.

(Certain combinations cause rapid decomposition of water, evolving hydrogen.) The melting point curve of these two metals has four branches, intersecting at the eutectic points corresponding with 451.6°, with 35% magnesium, and 439.9°, with 68% magnesium. Maximum point of 462.7° indicates compound Al_3Mg_4. Alloys of aluminum and magnesium containing from 5% to 30% of magnesium are called Magnalium; hardness increases with the percentage of magnesium; alloys with high percentage of magnesium, while hard, are brittle and easily oxidizable in air.

R. E. BARNETT, J. AM. CHEM. SOC., 1906, 88ii, p. 536.
Magnalium and other light alloys.

ALUMINUM-MAGNESIUM ALLOYS. Thre varieties, x, y, and z. Have greater tendency to oxidation when hot than aluminum, but have greater tensile strength, much better adapted to turning, rolling, etc. Alloy x contains copper 1.76%, magnesium 1.60%, nickel 1.16%, and antimony and iron in smaller proportions. Alloy, intermediate between x and z as regards nickel, contains copper,manganese, tin, lead, small amount of iron, and a trace of antimony. z (soft sheet metal) contains tin 3.15%, copper 0.21%, magnesium 1.58%, lead 0. 72%. and about 0.3% iron.

ZISIUM (sp. gr. 2.95) contains aluminum with small amounts of zinc, tin, copper, and traces of antimony and bismuth. ZISKON (sp. gr. 3.35) contains aluminum 75% and zinc 25%. Both are silver-white metals used in instrument making.

GWYER, ABS. J. AM. CHEM. SOC., 1906, Aii, p.544.

ALUMINUM-TIN reach maximum hardness at 30% tin and again at 50%.

ALUMINUM-ZINC alloys reach maximum hardness at 30% zinc, an alloy which is very similar to one of the fol-
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lowing composition: 72% aluminum, 24% zinc, 4% copper.

GOV. PUBL., J. IND. & ENG. CHEM., 1918, p.998.

Ternary alloys of aluminum, magnesium, and copper.

Increased in tensile strength after heating to about 500° and cooling rapidly to ordinary temperatures. Are apt to form compounds of magnesium and aluminum and of copper and aluminum, which crystallize and become a detriment to the alloy by causing brittleness.

EDITORIAL, QUEENSLAND MIN. J., 1918.

CALCIUM alloys with aluminum forming metal of superior quality, lighter than aluminum. Castings machine well and are free from brittleness; take minutest impression of the mold. Calcium neutralizes the tendency of aluminum alloys to oxidize in air. Alloy does not decompose water; can be remelted as readily as pure aluminum.

MERICA, GOV. PUBL., J. IND. & ENG. CHEM., 1920, p.99.

Three ternary series of alloys.

Alloys of aluminum-magnesium-manganese, aluminum-magnesium-copper, and aluminum-magnesium-nickel were rolled out into sheets and tested as to tension when cold-rolled, after annealing, and also after heat-treatment, consisting of quenching from about 500°, and aging at ordinary temperatures. Alloys of magnesium-aluminum-copper series found to,be superior, their tensile strength being increased by the proper heat-treatment. Magnesium-aluminum- nickel series also improved by the heat-treatment, but the other series was not. Alloys were exposed to salt corrosion for six or eight weeks; magnesium-aluminum-manganese resisted best, but heat-treated specimens of the magnesium-aluminum-copper series were found to be very little inferior. However, the annealed and cold-rolled ~~series~~ specimens of the same series were least resistant to corrosion. Types of aluminum metal did not compare favorably with the alloys.

W. A. McADAMS, MET. & CHEM., 1914, p.352.

Two new white metals of aluminum and silver,'argental' and 'macadam', said to possess properties "superior for certain purposes" ; take high polish, do not tarnish or corrode, can be cast or rolled.

7.

EDITORIAL, MET. & CHEM., 1921.
"ORMISTON METAL".

A certain London company has placed a new alloy on the market, containing 97.5% aluminum, which can be produced directly from bauxite clay, with the addition of the proper compounds, or by alloying with pure aluminum directly. Will take polish equal to nickel or silver, which it holds permanently; not corroded by sea, the atmosphere, nor food acids. Conductivity greater than that of copper and of any alloy known. Tensile strength, 16 to 20 tons per square inch. Can be soldered with itself or with other metals, with ordinary soldering iron; can be brazed or welded without difficulty.

A. A. READ & R. H. GREAVES, MET. & CHEM., 1914, p.595.
Nickel in copper-aluminum alloys.

5% of aluminum and 10% of aluminum, respectively. increased hardness, necessity of increased rolling temperatures; other properties practically indentical with those of copper-aluminum alloys.

1. Alloys with 5% aluminum. Nickel has little effect on hardness until 5% is present. Ductility greatly increased by 1%; with less than 5% nickel, alloys are homogeneous solid solutions. A second constituent separates with over 5%.

2. Alloys with 10% aluminum. Nickel up to 10% in chill castings increased maximum stress and yield point, lowering elongation and area. 5% nickel gave maximum hardness, improved annealed metal and diminished detrimental effect of annealing on 10% nickel alloy.

Presence of nickel in small propertions makes little material difference in the specific gravity of the alloys. Melting points are raised and conductivity for electricity greatly diminished.

W. N. NAYLOR & S. P. HUTTON, MET. & CHEM., 1916, p. 546.
Aluminum-magnesium alloys.

A percentage of magnesium and of phosphor tin is added to an aluminum metal, so treated as to increase strength. Phosphor copper may be added to increase tensile strength for certain purposes. The amount of magnesium generally exceeds that of tin, and is varied according to the purposes for which the alloy is to be used. Forinstance , the magnesium is reduced if the metal is to be rolled or drawn. For dental purposes, a small amount of sodium may be added.

An alloy of the following composition may be used in sea-water: 1.5 lb. of aluminum, 1.25 oz of magnesium, 3 gms. phosphor tin, 2 gms. phosphorous.

For drawing metal: 4 lb. of aluminum, 0.5 oz. of magnesium, 2 gms. phosphor tin.

For increased tensile strength: 1.5 lb. of aluminum, 1.25 oz. magnesium, 1.25 oz phosphor copper, 3 gms., phosphor tin.

II. USES AND GENERAL PROPERTIES OF ALUMINUM ALLOYS.

Physical and chemical properties of metallic aluminum:

Aluminum is asilver white metal having a melting point between 654.5°C. and 657.3°C., depending upon the purity of the metal; (also, to acertain extent upon the "personal equation" of the men who have made researches along this line). The cast metal has a specific gravity of 2.66; the molten metal, of 2.54; the specific gravity is increased by rolling. Aluminum resembles silver very closely in hardness; the pure metal is softer than the slightly impure metal generally offered on the market. Aluminum has an atomic weight of 27.1. Conductivity of heat at 0°C.: 0.3435; at 100°C.: 0.3619. Conductivity for electricity (copper, 100): 98.5% pure: 55; 99.0% pure: 59; 99.5% pure: 61; 100% pure: 66. Elasticity (i. e., load in kilograms per square mm., divided by alteration in length): 7462, as compared with copper, 11,350. Expansion coefficient: 0.00002313 at 40.0°C.; 0.00003150 at 600°C. Tensile strength, upward of 13,000 pounds per sq. in., varying with different treatment of the metal; claimed by some to attain a tensile strength as high as 31,000 pounds per sq. in., after being properly tempered. Ductility: capable of being drawn into awire 1/250 in. in cross-section. Malleability: can be rolled or beaten to a thickness of 1/40,000 inch.

Aluminum will absorb its own volume of hydrogen, expelling it in heating in a vacuum. Pure metal unacted on by water, but the introduction of sodium causes some action, more or less violent according to the proportion; several other metals, in certain proportions, cause varying action of aluminum alloys on water. The halogen elements or acids act readily upon aluminum; hot concentrated sulfuric acid and the alkalies act upon it; the action of organic acids is inconsiderable. Aluminum may be detected in compound or in combination as follows: when heated, and moistened with cobalt nitrate solution, and re-heated again on charcoal under the blow-pipe, a sky-blue color results.

Aluminum is alloyed with various other metals, and is being more and more used in alloys every day, due, first, to its readiness to alloy; secondly, to its tensile strength; and third, to its low specific gravity.

The alloys of aluminum may be divided generally into three classes; namely, bronzes, rolling alloys and casting alloys. This classification is based chiefly on the general uses of aluminum alloys, the class being determined by the use for which its own peculiar physiaal properties fit it, tough partly by the chemical composition.

BRONZES. True (aluminum) Bronze contains approximately 88% copper and 12% aluminum. Also, ternary alloys of aluminum, copper, and some other metal, or a binary alloy of aluminum and some other metal, possessing the peculiar physical properties, may be termed a bronze. Gold Bronze is a binary alloy, containing from 3% to 5% of aluminum. Steel Bronze contains 8.5% aluminum and a trace of silicon. Copper Bronze may contain from 2% to 12% of aluminum, the proportion depending on the properties desired. Bronzes are very homogeneous; are free from crystallization; possess great hardness and tensilestrength. Manganese is sometimes added in small proportions to increase ductility (less than 1.5%); large amounts increase hardness and tensile strength, but cause formation of compounds which, crystallizing, cause brittleness, and decrease the ductility.

ROLLING ALLOYS. Good examples of this class would be alloys containing a small percentage of copper (3-4%) or of nickel (1.5-5%). Others may be prepared with numerous other metals. Rolling alloys possess tensile strength and workability.

CASTING ALLOYS. By far the greater proportion of aluminum alloys fall under this classification, generally speaking. Zinc, copper, magnesium, tin, silver, gold, manganese, cadmium, and many other metals may be alloyed with aluminum, in almost any proportion, either in binary, ternary, or even quaternary alloys to form casting alloys. The metals to be used and the ptoportions must be determined by the properties desired.

It must not be thought that the composition of aluminum alloys is final in determining the specific properties of that alloyx. The method of preparation, temperatures used, heat-treatment, allx play an important part in determing these factors. No attempt will be made below to give a full description of all aluminum alloys, their, properties, uses, or methods of preparation, since it is neither within the scope of this thesis nor its purpose to do so. A short sketch only will be given of work already done by others with those metals to be treated in the original research work of this thesis. The bibliographical sketch has been made very full purposely that it may fulfill this part, at least so far as this thesis may be expected to go.

MAGNESIUM. Aluminum alloys with magnesium readily, alloys having been prepared and fully investigated containing from 5% to 35% of magnesium; such alloys are called Magnalium as a class. These alloys have a very low specific gravity, considerable hardness and tensile strength, as compared with the constituent metals. Up to 10% can be worked in every way; over 15% causes brittleness. Various compositions under certain treatments form compounds; some decompose water. Most of them tarnish more easily than aluminum metal itself.

NICKEL. Nickel alloys with aluminum in all proportions, forming metals which are hard and tough, possessing great tensile strength. Certain proportions of nickel with aluminum form alloys which are very brittle; the nickel should, as a general rule, be kept under 10%, to avoid brittleness; nickel alloys have a very high melting point, as compared with the pure aluminum.

TIN. Tin alloys easily with aluminum in all proportions; its chief quality lies in the fact that it makes the resulting alloy more fusible. Otherwise, unless the proportion is kept very low, hardness is diminished and brittleness is increased.

MANGANESE. The results of very little research work om alloys of aluminum containing manganesex have been found availablefor study. It has been noted, however, that small percentages of manganese are beneficial in that the hardness and ductility are materially incresed. Larger proportions destroy ductility.

CHROMIUM. Practically no material has been found desribing the effect of chromium on aluminum alloys. However, it may be noted that it has been used in some aluminum alloys, presumably to increase hardness.

CADMIUM. The chief value of cadmium lies in the fact that it will lower the melting points of most alloys.

III. ORIGINAL RESEARCH WORK.

A. Purpose and Scope.

We may state the original purpose of this thesis, in general, as being an attempt to find an aluminum alloy of low specific gravity, having tensile strength and hardness, without being brittle.

More specifically, a magnesium-aluminum alloy was to be taken as a starting point; the proportion of aluminum to magnesium was to be varied, according to material found in the bibliography based on the original research work of others. Secondly, two metals, one of a low melting point and the other of a high melting point, tin and nickel, respectively, were to be tried separated in the differently made up samples of Magnalium. Also, manganese and chromium were to be tried in several of the alloys prepared in the compositions as described above. In other words the following compositions were to be made in the furnace and tested (the proportions of each constituent being varied): aluminum-nickel-magnesium, aluminum-magnesium-nickel-chromium, aluminum-magnesium-nickel-manganese, aluminum-magnesium-tin-chromium, aluminum-magnesium-tin-manganese. These alloys were to be tested for tensile strength, hardness, and resistance to atmospheric corrosion; also for exact chemical composition.

The work was naturally very limited in its general scope and extent, due first to the limited time and, second to the lack of metallurgical equipment at hand. The best that has been hoped for has been to find the general effects of alloying the above-mentioned metals with aluminum, that they might prove of some value in other research work along the same lines.

B. Experimental

1. Work done in the muffle furnace. (Temperatures ranging between 1000° and 1300°, approximately).

Samples were weighed out into graphite crucibles as follows:

A.	Aluminum (turnings)	37.5 gms.
	Magnesium (turnings)	7.5
	Nickel (plates)	5.0
B.	Aluminum (turnings)	40.0
	Magnesium (turnings)	5.0
	Nickel (plates)	5.0
C.	Aluminum (turnings)	42.5
	Magnesium (turnings)	5.0
	Nickel (plates)	2.5
D.	Aluminum (turnings)	40.0
	Magnesium (turnings)	7.5
	Nickel (plates)	2.5
E.	Aluminum (turnings)	41.5
	Magnesium (turnings)	4.5
	Nickel (plates)	4.0
F.	Aluminum (turnings)	42.5
	Magnesium (bars)	5.0
	Tin (crystals)	2.5
G.	Aluminum (turnings)	42.5
	Magnesium (bar)	6.0
	Tin (crystals)	1.5
H.	Aluminum (turnings)	42.0
	Magnesium (bar)	5.0
	Nickel (plate)	2.5
	Manganese	0.5
I.	Aluminum (turnings)	42.5
	Magnesium (turnings)	4.5
	Tin (crystals)	2.5
	Manganese	0.5
J.	Aluminum (turnings)	41.5
	Tin (crystals)	3.5
	Magnesium (bar)	4.5
	Chromium	0.5
K.	Aluminum (turnings)	40.0
	Magnesium (bar)	5.0
	Nickel (plate)	4.0
	Chromium	1.0

(Note: Chromium and Manganese were prepared in the laboratory from chromium trioxide and pyrolusite respectively, by the Goldsmith method, which will be described below).

The furnace was fired to as great a heat as could be obtained and kept constantly at this heat. The charge within the crucible was covered, to about an inch thickness, with powdered charcoal, to prevent oxidation of the aluminum and magnesium. The crucibles were then placed in the muffle, after pre-heating, and allowed to remain there for periods varying from one-half hour to one and one-half hour. The first charges to be examined (after a half-hour heating) showed the aluminum turnings to be well coated with oxide, thus preventing it from melting readily; the magnesium had completely burned away. Hence, the charcoal cover was increased in thickness and a cover placed on the crucible. However, no better results were obtained than before.

T This trouble was attributed to two main facts; namely, the aluminum and magnesium were so finely divided that they were too easily oxidizable, and, secondly, the muffle furnace was not suited to the work because the charge was kept at an oxidizing temperature before it attained a sufficient temperature to melt the charge.

To overcome these difficulties, it was decided to use bar metal in place of the turnings and to transfer the work to the pot-furnace, in which a temperature of approximately 1500° can be obtained, and in which the charge could be heated to a fusing temperature very rapidly, since the flame come in direct contact with the crucible.

2. FIRST RUN IN THE POT-FURNACE.

Aluminum bar metal, magnesium bar metal, nickel plate, tin crystals, and chromium and manganese prepared by the Goldsmith method, were used throuhout the pot-furnace runs.

Five samples were made up; each contained from 75% to 85% of aluminum; from 10% to 15% of magnesium; two contained from 3% to6% of tin; one of these latter contained about one percent of manganese and the other about the same percent of chromium; three contained from 3% to 9% of nickel, two of these having percentages of manganese and chromium, separately, in about the same proportions as in the tin samples above.

The procedure followed in this instance was to fuse the aluminum in a covered graphite crucible; the fused metal was then covered with a layer of powdered charcoal and the magnesium blocks dropped in from a sufficient height to break the crust formed on the top of the fused metal by the powdered charcoal. When this mass seemed sufficiently fluid to have formed a homogeneous melt the other constituents were dropped on the charcoal crust as the magnesium had been. It was necessary to stir these in with a charcoal stick; during this stirring a great deal of the molten metal seemed tobe oxidizing, but the burning ceased when more charcoal was poured in and the cover replaced. However, when the melt was poured into the mold (which was done when the crucibles had become somewhat pasty on the outside from the melting of some of the clay in them and appeared in danger of complete fusion) it was foud that the magnesium in the mass burned with great vigor and that none of the constituent metals having the higher melting points had either become fused or gotten into solution in the metals which had become molten. Thus five alloys were obtained, or it is better to say that two alloys and three impure bars of aluminum were obtained. The two alloys containing a small percentage of tin were not considered worth further examination, since both were softer than aluminum itself.

2. SECOND RUN IN THE POT-FURNACE.

(Materials and samples same as in above run).

This time it was considered more advisable to melt the magnesium first, under a thick layer of charcoal, and to add the other metals to the molten magnesium. This procedure however produced no better results than the above.

Two conclusions were to be drawn from these trials; the equipment at hand would not allow the preparation of an allow containing magnesium; the metals having a higher melting points had to be prepared or treated in some other way before they could be gotten into the alloy.

From this second run of the pot-furnace, however, a conglomerate mass was obtained made up mostly of aluminum, having pieces of nickel distributed throughout it, parts of which seemed to have melted away or dissolved into the mass; also, a small percentage of tin and about one gram of metallic chromium were contained therein. This mass, however, never attained sufficient fluidity to be poured in to the mold, and was partly melted into the crucible. This mass was used in the third run of the pot-furnace, as will come out below.

4. THIRD RUN IN THE POT-FURNACE

An alloy containing about 50% of aluminum, about 10% of tin, and about 15% each of nickel and of manganese, and a like alloy containing chromium to replace the manganese were made by the Goldsmith method, as follows:

The bottom of a fire-clay crucible was lined with powdered Cryolite; about twenty grams of aluminum metal was placed on top of this; then, ten grams of tin crystals; next, between fifteen and twenty grams of nickel; next, the proper proportion of prolusite or of chromite, for the manganese or chromium alloy, respectively, mixed with aluminum in large excess; several grams of magnesium turnings were placed on top of this charge, which was to be ignited to furnish the heat necessary to start the reaction between the oxides and the aluminum; a few grams of cryolite were placed over the top as a partial cover, and a magnesium ribbon was introduced into the magnesium turnings as fuse. When the mass was ignited, the folloing results were obtained: the the aluminum was oxidized by the oxides of manganese or of chromium, as the case might be, thereby yielding metallic manganese or chromium; the heat attained was sufficient to melt the metals together in the bottom of the crucible and to cause a part of the metallic manganese or chromium to run into the mass of molten metals.

Thus an alloy was obtained, rich in aluminum, nickel, tin, and manganese or chromium, which enabled us to get the higher melting point metals into the aluminum. By the same method, an alloy had been obtained, containing only aluminum, nickel, and manganese.

Charges of three compositions were then prepared, which, for the sake of convenience and clarity, we will call 'A', 'B', and 'C'.

'A'. The melt mentioned in the last paragraph of the description of the second run in the pot-furnace was used along with the alloy descrbed last above, containing aluminum, nickel, and manganese, and about ten grams of cadmium. Thus the melt obtained would be expected to be made up about as follows: aluminum over 80%, 1% to 2% of tin, less than 1% of chromium, between 5% and 6% of nickel, about 3% of manganese, and around 6% of cadmium. The alloy formed, melted far below the highest ~~melting~~ temperature of the furnace, poured well, did not stick to the mold; comparatively little dross was formed. The exterior surface of the cast bar had a very distinctly crystalline character, but the metal, when cut in two while cold, showed nothing of this crystalline character on the fresh surface. Strangely, the metal was not as hard as aluminum itself. The percentage of cadmium in the alloy was practically negligible; when dissolved in aqua regia (it would not dissolve in either nitric acid or hydrochloric acid, when treated with each separately, wholly), some insoluble matter was found to be present, probably silica and carbon; the aluminum was approximately 85%, or a little higher; chromium ran about 1%; nickel, about 6%; and about 2% tin, which had been added by mistake. The fact that the metal was much softer than would naturally be expected might be attributed to this latter constituent.

'B' and 'C' were made up of about 100 grams of aluminum each, and about 50 grams of the two alloys prepared by the Goldsmith method as described above, 'B' containing the sample with manganese, 'C', with chromium. They melted not very far above the melting point of aluminum itself, and did not stick to the mold (magnesite brick) as aluminum itself might be expected to do. Each contained about 85% aluminum, about 5% to 7% nickel, about 3% to 5% tin, and about 2% of manganese or of chromium. They possessed like properties: harder than aluminum, though not so hard as steel; neither was brittle to any noticeable extent; both could be hammered while cold to some extent, their malleability increasing rapidly with temperature; silver-white metals, not readily oxidizable in air or water, present very bright surfaces when polished which they hold very well; not wholly soluble in either nitric acid or hydrochloric acid, though attacked to some extent by either.

IV. CONCLUSION.

The equipment used in this work has been very crude and that to a very great extent limited. Then, too, this branch of metallurgy is very wide and an exhausting research terein might require a lifetime and more, and that be well-spent, This paper covers only the minuteest part of this field, however, and does not claim to have obtained in magnificent results in that. However, this work may be prove of some small value in the xxxxxx researches of someone else, and it is xx hoped that we may yet be able to carry it further.

We have noted several interesting general facts in the preparation of this paper. In the first place, Magnalium will always be hard to prepare and to alloy with other metals, due to the fact that magnesium oxidizes so readily, even after it has become dispersed through some other metal. Manganese hardens the metal considerably; in high percentages it causes brittleness, but this is not noticeable in small percentages. Likewise, small percentages of chromium harden the metal materially, without injury to the other properties. Nickel hardens and toughens the alloy. None of the above metals raise the specific gravity unduly, when their percentages are kept fairly low.

It is to be reasonably expected that an alloy of aluminum can be found someday which will have the hardness of steel, greater tensile strength than any aluminum alloy now known, and still maintaining its low specific gravity.

THE END