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PROCESSES OF TREATING MAGNESIUM-BASE CASTINGS AND IMPROVED MAGNESIUM-BASE ALLOYS PRODUCED THEREBY

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1

The invention relates to alloys, and particularly to alloys having a magnesium base. The invention also includes improvements in processes of treating magnesium-base castings to produce the improved alloys.

This application on said invention is a continuation-in-part application of my pending application Serial No. 586,024, filed March 31, 1945, now abandoned, on Magnesium-base alloys and process of treating the same, and my pending application Serial No. 18,858, filed April 3, 1948, now abandoned, on Processes of treating magnesium-base castings and improved magnesium-base alloys produced thereby.

Primarily, the invention comprises improvements in aging magnesium-base castings by continuous heating at stepped temperatures whereby the ultimate strength, elongation, yield strength, and hardness are improved.

Insofar as I am informed, known processes of heat-treating magnesium-base alloy castings consists in giving them a solution heat treatment immediately followed by an air quenching, and then aging them by heating at about 350° F. for about sixteen (16) hours, and then removing them from the heat treatment furnace and letting them air-cool at room temperature.

It has long been well recognized in commercial practice that, although a difference of 2000 p.s.i. in tensile strength between the solution-heat-treated and the solution-heat-treated and aged conditions of the commercial magnesium casting alloys such as AZ63 and AZ92 is indicated by the specifications to be feasible, there is a persistent inability to maintain this difference. However, the increase in yield strength and the decrease in elongation do correspond in commercial practice to those of the specifications. The commercial magnesium casting alloys AZ63 and AZ92 are, respectively, those in which aluminum constitutes about 6 and 9%, zinc about 3 and 2%, with from 0.15 to 0.20% maganese, and traces of other foreign elements such as silicon, iron, etc., the remainder of the casting alloy being magnesium. Manganese is added to all commercial magnesium alloys to improve the corrosion resistance and is, therefore, disregarded herein.

Because in commercial practice the specified properties are relatively low, there has been encountered little difficulty in meeting the properties specified for AN-M-36, in either the heat-treated or the heat-treated and aged condition. AN-M-36 is an Army-Navy aeronautical specification, one type of which known as composition "A" contains substantially, 6% aluminum, 3% zinc, and 0.20% manganese, with traces of other foreign elements. It is the specification hereinbefore referred to as AZ63. Although, as stated, little difficulty has been encountered in meeting the properties specified for AN-M-36, the difference of 2000 p.s.i. in tensile strength which is specified for the aged condition over the heated condition has not been maintainable. On the contrary, the average tensile strength found in a large number of foundry-produced composition "A" magnesium alloys tested was some 500 p.s.i. lower for the aged condition than for the heated condition only. This average for the aged condition was about 39,000; whereas, the expected differential should have produced an average of about 41,500 p.s.i.

2

It has been found that test bars cast under close laboratory control yield a tensile strength of approximately 41,000 p.s.i. and an elongation of substantially 16% for the solution-heat-treated condition, while the tensile strength is approximately 42,500 p.s.i. and the elongation 7% after the bar had been aged for sixteen hours at 350° F. However, less rigidly controlled castings of test bars in commercial practice yield a tensile strength of approximately 40,000 p.s.i. for the heat treated metal, and 39,000 p.s.i. for the metal aged for sixteen hours at 350° F., with respective elongations of approximately 14 and 5%. This discrepancy between tensile strengths of the laboratory specimen and the commercial practice specimen is explained by the respective differences in elongation. The two heat treatments, viz., the solution heat treatment and the aging heat treatment, are characterized by well defined stress-strain curves, and the cast quality of a test bar does not affect the shape of the curve but only determines its terminal point. This terminal point has coordinates which represent the elongation and the tensile strength. Therefore, the elongation of 16% in the laboratory bars corresponds to a p.s.i. of 41,000, and the commercial elongation of 14% produces a p.s.i. of 40,000, which is only 1000 p.s.i. lower than the laboratory value. For the laboratory bar, in the aged condition, the elongation of 7% determines a tensile strength of 42,500 p.s.i., and for the commercial bar, the elongation of 5% produces a tensile strength of 39,000 p.s.i., which is 3500 p.s.i. lower than the laboratory value. Therefore, defects in or a decrease in the casting quality reduces the tensile strength of the aged condition considerably more than that of the solution-heat-treated condition. However, the allowance

made by the specifications in commercial practice for an inferior casting is considerably larger for the heat-treated condition than for the condition both heat-treated and aged. It is evident that these specifications should set a minimum tensile strength of the aged condition at an equal or smaller value than that of the solution-heat-treated condition. The stepped aging treatment herein presented eliminates this necessity, and also produces improved characteristics of the resultant casting alloys. It also effects a great saving in total heat-treatment time.

I have discovered that the inability to maintain the 2000 p. s. i. difference in tensile strength between the two conditions of the alloy is caused by a premature termination in the stress-strain curve resulting from casting defects. This premature termination results in a greater loss in the tensile strength for the heat treated and aged condition casting than for the casting which has been heat treated only. Therefore, the invention disclosed herein comprises an improved aging treatment for which the curve indicating the stress-strain is not prematurely terminated, such improved aging treatment being effective to improve the characteristics of the resultant alloy such as its tensile strength, yield strength, elongation, and hardness.

Occasional difficulties with temperature control when producing the composition "A" magnesium alloy resulted in certain heats being subjected to a stepped aging such as at 250° F. for three hours and at 350° F. for thirteen hours. The product of these heats had a strength value greater than that resulting from the normal heating at a uniform temperature of 350° F. over the same total time. Therefore, the whole production was tentatively subjected to a stepped aging treatment. It was found that the tensile strength was decidedly higher than either the solution-heat-treated product or the normally aged product. Comparison of test bars subjected to solution heat treatment only showed identical properties; whereas, comparison of the aged test bars showed the increased strength values. Therefore, the benefits were attributable to the differential aging treatment.

Primarily, the improvements consist in a stepped aging treatment having different temperature and time factors. For instance, it has been ascertained by laboratory tests that an aging treatment which utilizes various times of heating at two temperatures with a total time equal to that of the regular commercial practice at one temperature results in a combination of tensile strength, per cent elongation, and yield strength which is superior to that obtained in regular commercial practice. Also, it has been ascertained that an aging treatment which utilizes two periods of heating time, employing a higher temperature in the second period of the aging treatment, results in properties which are equal to those obtained in commercial practice, even when the total time of the improved stepped aging treatment is only about 25% of the total time required by commercial practice at one temperature.

A part of the improvements presented herein consists in aging the magnesium-base castings, after the solution heat treatment including the air quenching, by heating them for about three (3) hours at 250° F., ±15°, and then continuing the heating for about thirteen (13) hours at 350° F., +30°—10°. The castings are then removed from the heat treatment furnace and air-cooled at and to room temperature. This improved aging treatment produces increased ultimate strength, hardness, and elongation characteristics of the alloy castings. Insofar as my tests have shown, the yield strength is substantially the same.

Another part of the improvement consists in aging the magnesium-base castings, after the solution heat treatment including the air quenching, by aging them over a total aging time of from about four hours to about eight hours, first at a temperature of from about 225° F. to 275° F., and then at a temperature of from about 350° F. to about 400° F., during which heating the aging time at the lower temperature does not exceed one-half the total aging time. Preferably, the total aging time is about four hours, during which the heating at the lower temperature is from about one to about one and one-half hours, and the heating at the higher temperature is from about two and one-half to about three hours.

All of the aging treatments comprehended by the part of the improvements last-described produce an improved combination of properties in the resultant alloys over those of similar alloys heated for the whole period at about 350° F. for about sixteen (16) hours, the particular properties improved being hereinafter designated for certain of the 2-stage heating procedures which will be hereinafter described.

Reference to the results which have been obtained by a 2-stage aging treatment of about three (3) hours at 250° F., ±15°, and then a continued heating for about thirteen (13) hours at 350° F., +30°—10°, for which results there have been treated a magnesium-base casting containing 6% aluminum, 3% zinc, about 0.15% manganese, and the balance magnesium; and also a casting containing 9% aluminum, 2% zinc, 0.15% manganese, and the balance magnesium, shows that the ultimate strength by the improved 2-stage procedure had been increased by about 2000 p. s. i. over the ultimate strength produced in test-pieces from the same casting operation by an aging thereof for sixteen hours at 350° F.; and that the hardness, by the Brinell table, had been increased about four (4) hardness numbers, and the percentage of elongation in 2" gauge length test-pieces had been increased about 1.5.

The temperature at which the first phase of the aging operation is effected, over a heating period of about three hours, is quite critical, viz., 250° F., as stated, but I have ascertained that a range of temperature within ±15° of 250° F. produces improved ultimate strength, hardness, and elongation characteristics. The temperature at which the second phase of the aging operation is effected, over a period of about thirteen (13) hours, viz., 350° F., is also quite critical, having, however, a permissible range within which the improved results are obtained, this range being +30° and —10° from 350° F.

In MgAlZn castings, as also in other magnesium-base castings, there will be traces of foreign elements other than those which enter into the compounds which are found concentrated in the alloys and which precipitate during the aging operation in pearlitic structures, such as manganese, silicon, iron, nickel, etc. Inasmuch as these other elements are not present in the pearlitic structures precipitated by the aging operation and, therefore, have no effect in the production of the improved characteristics, according to my theory of the production of the latter, no further reference to such other elements is made herein.

The results of the second part of my improvements which involve a shorter period of total aging time, viz., from about four to about eight hours at initial temperatures of from about 225° F. to about 275° F., and second heating temperatures of from about 350° F. to 400° F., were obtained by aging, and noting the improved results, the Army-Navy Aeronautical Specification AN–M–36, known as composition "A". This is the composition hereinbefore referred to as containing substantially 6% aluminum, 3% zinc, and 0.15% manganese, with traces of other foreign elements, the balance being magnesium. This specifica- is referred to as AZ63 and its maximum and minimum limits are: aluminum 5.3 to 6.7%, zinc 2.5 to 3.5%, manganese 0.15% minimum, and silicon 0.30% maximum, the balance being magnesium. This specification covers the most common heat-treated magnesium casting alloy. However, the improvements are applicable to and the improved characteristics obtained from the various magnesium casting alloys containing from 6 to 9% aluminum, 3 to 2% zinc, 0.15 to 0.20% manganese, with traces of silicon, iron, etc., the balance being magnesium.

Various closely-controlled laboratory tests of the conventional aging treatment have been conducted for different total times, and different temperatures. Conventional aging has been tested for various periods up to 500 hours and at temperatures from 250° F. to 400° F. For each variation of the aging treatment many specimens of the product have been tested for yield strength, tensile strength, elongation (per 2 inches), and Brinell hardness. For every test, a comparison of the results with results of similar tests using the stepped aging treatment produced a better combination of properties by the stepped aging treatment using different temperatures than by the conventional aging treatment over the whole period of time at a single temperature. It was also ascertained that for the given aging temperatures and total time there results from the stepped aging an almost constant or slightly increased yield strength and tensile strength and an elongation from 1 to 2% above the values obtained by aging for the entire period at the higher temperature. Thus, stepped aging temperatures of 250° F. and 350° F. over the usual total commercial time of sixteen hours has been tried; also, a total aging time of eight hours at 250° F. and 400° F.; and a total aging time of four hours at 250° F. and 400° F. The first aging time of 250° F. was tried in each series from zero hours to the total hours. For each series of tests, a better combination of properties than was obtainable by a single temperature aging was obtained by stepped aging in which a fraction of the aging time is consumed at 250° F. However, it was further ascertained that a reduction in yield strength, which cannot be tolerated, made it necessary that the lower temperature aging time, i. e., the aging time at which substantially 250° F. is utilized, while a substantial portion of the entire aging period, should not exceed one-half of the total time. Also, it is known that the aged condition improves with lower temperatures but a second-stage temperature materially below 350° F. is impracticable in standard practice because of the great length of time necessary for satisfactory aging. A practicable feasible aging time should not exceed twenty-four hours.

It has been further ascertained that the lowest combination of temperatures utilized, i. e., 250° F. and 350° F., for a total aging period of sixteen hours, yields the best combination of properties except that a total aging time of four hours with the use of temperatures of 250° F. and 400° F. yields an equal improvement or possibly slightly larger. For this stepped aging use of 250° F. and 400° F., a first aging treatment of 250° F. for one and one-half hours, and a second aging treatment of 400° F. for two and one-half hours is indicated, resulting, as compared with conventional aging at 350° F. for sixteen hours, in a tensile strength only slightly lower, in markedly increased elongation, and in an insignificant decrease (readily tolerated) in yield strength. However, an aging period of eight hours, using 250° F. and 400° F., yields properties only slightly improved over those obtainable by an aging heat of 400° F. for the entire eight hours, indicating that overaging is a deleterious factor, markedly more so than underaging. It is further ascertained that an increase of the time required for aging to obtain a maximum tensile strength produces a considerably less favorable combination of strength and elongation than does underaging. Furthermore, the complete aging time decreases with increasing temperature but the properties simultaneously decrease.

Application to commercial practice of the stepped aging treatment above-mentioned has given even better results than those obtained by laboratory tests of the improved stepped aging treatment.

A large number of bars of commercial production have been tested over a 4-hour aging period consisting of one hour at 250° F. and three hours at 400° F. This stepped aging treatment produced properties distinctly superior to commercial procedure of sixteen hours at 350° F. The tensile strength was equivalent, and the yield strength and elongation were higher, despite the reduction of 75% in total aging time.

The results indicate that other promising combinations of temperatures for stepped aging are 250° F. and 375° F., 275° F. and 375° F., and 225° F. and 400 F., utilized for a total aging time of about four hours, in which the aging time at the lower temperature does not exceed one-half the total aging time. Results obtained indicate that the best combination of properties is obtained by a total aging time of approximately four hours, one and one-half hours at about 250° F., and two and one-half hours at about 400° F.

My theory of the cause of the improved characteristics obtained by the improved 2-stage aging treatment above-described is as follows:

It is known that, in the cast condition, in a magnesium-base alloy casting containing aluminum and zinc as major alloying elements, an aluminum, magnesium, and zinc compound is concentrated in scattered areas at the grain boundaries, and that, when the casting is given the solution heat treatment, this scattered $Al_xMg_yZn_z$ compound passes into solid solution. When this solution is aged by the known processes above-mentioned, viz., heating at sixteen hours at 350° F., the consequent pearlitic precipitation of the aluminum-magnesium-zinc compound is a coarse formation produced by a comparatively rapid action. During the preliminary aging period, namely, about three (3) hours heating at 250° F.±15°, the aluminum-magnesium-zinc compound comparatively slowly precipitates in a fine pearlitic structure, and during the later treatment for about thirteen (13) hours at

350° F.,+30°,—10°

the precipitation is accelerated but continues on the basis of the fine precipitation which takes place during the earlier aging period at the lower temperature. Thus the characteristics of the final product are bettered to substantially the respective amounts hereinbefore mentioned. The improvements are noted in the other specific procedures described.

A microscopic examination of the test bars has been made. Solution-heat-treated magnesium alloy consists of uniform solid solution crystals with some heterogeneous phases (Mg_2Si.,Mn.), both at the grain boundaries and within the grain. The structure of all commercially usable aged condition metal consists of 75 to 50% of apparently retained solid solution crystals and 25 to 50% precipitated areas, similar in appearance to pearlite in steel. Such grain structure is in agreement with X-ray investigation which indicates that during aging an increasing portion of the solid solution decomposes (almost) to its equilibrium condition while the remainder is subject to a very slow precipitation process. The completely precipitated material apparently has only minor commercial significance because it possesses both lower tensile strength and elongation than the intermediate stages, although possibly associated with a higher yield strength. The microstructure of the partially (and completely) precipitated conditions when aged at the same temperature throughout the entire aging period is distinctly different for different aging temperatures. The lamellae in the precipitated areas are thinner and closer together the lower the aging temperature. And at lower aging temperatures the aging time appears to be of little influence in this regard. At the higher aging temperatures, comparatively long periods of aging time result in some breaking up and coagulation of the lamellae.

The microstructure of the bars subjected to the improved stepped aging also exhibits distinctly finer lamellae than that of metal aged during the entire aging period at the higher of the two temperatures used in the stepped aging. To this distinctly finer lamellar precipitate is attributed the superior physical properties of the product obtained by stepped aging. Stepped aging results in a structure and in properties very similar to those obtained over a considerably longer period by an aging at a single temperature intermediate the two temperatures of the two stages of stepped aging. Hence, a major benefit derived from stepped aging is a reduction in aging time.

What I claim is:

1. The process of improving the ultimate strength, hardness, and elongation characteristics of a magnesium-base alloy, consisting in solution-heat-treating a casting thereof, containing a proportion of aluminum of from about 6% to about 9%, and a proportion of zinc in percentage of from about one-half to about one-fifth the percentage of aluminum, substantially all of the remainder being magnesium, the solution heat treatment including a quenching; then aging the alloy, by heat treatment thereof at 250° F. and continued heat treatment thereof at 350° F.

2. The process of improving the ultimate strength, hardness, and elongation characteristics of a magnesium-base alloy, consisting in solution-heat-treating a casting thereof, containing a proportion of aluminum of from about 6% to about 9%, and a proportion of zinc in percentage of from about one-half to about one-fifth the percentage of aluminum, substantially all of the remainder being magnesium, the solution heat treatment including a quenching; then aging the alloy, by heat treatment thereof for approximately three hours at 250° F. and continued heat treatment thereof for approximately thirteen hours at 350° F.

3. An aging treatment to improve the ultimate strength, hardness, and elongation characteristics of a magnesium-base alloy, a casting of which has been solution-heat-treated and air-quenched, said casting having from 6 to 9% aluminum and 2 to 3% zinc, substantially all of the remainder being magnesium, consisting in first heating such alloy at from 235° F. to 265° F., and then continuing the heat treatment at from 340° F. to 380° F.

4. An aging treatment to improve the ultimate strength, hardness, and elongation characteristics of a magnesium-base alloy, a casting of which has been solution-heat-treated and air-quenched, said casting having from 6 to 9% aluminum and 2 to 3% zinc, substantially 0.15% manganese, the remainder being magnesium, consisting in first heating such alloy for approximately three hours at from 235° F. to 265° F., and then continuing the heat treatment for approximately thirteen hours at from 340° F. to 380° F.

5. Improvements in treating a magnesium-base alloy containing from 6 to 9% aluminum, from 2 to 3% zinc, substantially all of the remainder being magnesium, consisting in solution-heat-treating a casting of such alloy, including an air-quench; then aging the alloy by heat treatment thereof for approximately three hours at from 235° F. to 265° F.; continuing the heat treatment for approximately thirteen hours at from 340° F. to 380 F.; and then air-cooling at and to room temperature.

6. Improvements in treating a magnesium-base alloy containing from 6 to 9% aluminum, from 2 to 3% zinc, substantially all of the remainder being magnesium, consisting in solution-heat-treating a casting of such alloy, including quenching thereof; then aging the alloy by heating it at from 235° F. to 265 F. to effect comparatively slow precipitation of an aluminum-magnesium-zinc compound having a fine pearlitic structure, and then continuing the heat treatment at a higher temperature to accelerate precipitation.

7. A magnesium-base alloy produced by a 2-stage aging treatment consisting in first heating a solution-heat-treated and quenched casting containing 6 to 9% aluminum and 2 to 3% zinc, substantially all of the remainder being magnesium, at from 235° F. to 265° F. for a substantial portion of the entire aging period, and then continuing the heat treatment at from 340° F. to 380° F., the alloy being characterized by improved ultimate strength, hardness, and elongation, as compared with alloys aged for substantially the same period of total aging time at the higher temperature of the 2-stage aging.

8. A magnesium-base alloy produced by a 2-stage aging treatment consisting in first heating a solution-heat-treated and quenched casting containing substantially 6% aluminum and substantially 3% zinc, substantially all of the remainder being magnesium, at from 235° F. to 265° F., and then continuing the heat treatment at from 340° F. to 380° F., the alloy being characterized by precipitated aluminum-magnesium-zinc compound having a fine pearlitic structure imparting thereto improved ultimate strength, hardness, and elongation.

9. A magnesium-base alloy produced by a 2-stage aging treatment consisting in first heating a solution-heat-treated and quenched casting containing substantially 9% aluminum and substantially 2% zinc, substantially all of the remainder being magnesium, at from 235° F. to 265° F., and then continuing the heat treatment at from 340° F. to 380° F., the alloy being characterized by precipitated aluminum-magnesium-zinc compound having a fine pearlitic structure imparting thereto improved ultimate strength, hardness, and elongation.

10. A magnesium-base alloy produced by a 2-stage aging treatment consisting in first heating a solution-heat-treated and quenched casting containing substantially 6% aluminum, substantially 3% zinc, and substantially 0.15% manganese, the remainder being magnesium, at from 235° F. to 265° F. for a substantial portion of the entire aging period, and then continuing the heat treatment at from 340° F. to 380° F., the alloy being characterized by improved ultimate strength, hardness, and elongation, as compared with alloys aged for substantially the same period of total againg time at the higher temperature of the 2-stage aging.

11. A magnesium-base alloy produced by a 2-stage aging treatment consisting in first heating a solution-heat-treated and quenched casting containing substantially 9% aluminum, substantially 2% zinc, and substantially 0.15% manganese, the remainder being magnesium, at from 235° F. to 265° F. for a substantial portion of the entire aging period, and then continuing the heat treatment at from 340° F. to 380° F., the alloy being characterized by improved ultimate strength, hardness, and elongation, as compared with alloys aged for substantially the same period of total aging time at the higher temperature of the 2-stage aging.

12. Improvements in treating a magnesium-base alloy containing from 6 to 9% aluminum, from 2 to 3% zinc, substantially all of the remainder being magnesium, consisting in solution-heat-treating a casting of such alloy, including quenching thereof; then aging the alloy by heating it at about 250° F. to effect comparatively slow precipitation of an aluminum-magnesium-zinc compound having a pearlitic structure, and then continuing the heat treatment at about 350° F. to accelerate precipitation the heat treatment at about 250° F. being for a substantial portion of the entire heat-treating period.

13. A manganese-base alloy produced by a 2-stage aging treatment consisting in heating a solution-heat-treated and quenched casting containing 6 to 9% aluminum and 2 to 3% zinc, substantially all of the remainder being magnesium, over a total heating period of from four to eight hours, first at from 225° F. to 275° F. for a substantial portion of the entire heating period but not exceeding one-half of the total time, and then continuing the heat treatment for the balance of the heating period at from 340° F. to 400° F., the alloy being characterized by precipitated aluminum-magnesium-zinc compound having a fine pearlitic structure imparting thereto an improved combination of properties over those of similar alloys heated for a substantially longer total heating period at the temperature at which the second of the above-mentioned heat treatments is effected.

14. An aging treatment to improve the ultimate strength, hardness, and elongation characteristics of a magnesium-base alloy, a casting of which has been solution-heat-treated and air-quenched, said casting having from 6 to 9% aluminum and 2 to 3% zinc, substantially 0.15% manganese, the remainder being magnesium, consisting in first heating such alloy for approximately three hours at about 250° F., and then continuing the heat treatment for approximately thirteen hours at about 350° F.

15. An improvement in aging commercial magnesium casting alloys comprised of from 5.3 to 6.7% aluminum, from 2.5 to 3.5% zinc, a minimum of 0.15% manganese, and a maximum of 0.30% silicon, the balance being magnesium, consisting in heating the solution-heat-treated condition thereof from about one to about one and one-half hours at from 225° F. to 275° F., and then stepping-up the heating temperature to from about 375° F. to about 400° F. and continuing the heating at the stepped-up temperature for from about two and one-half hours to about three hours.

16. An improvement in aging commercial magnesium casting alloys comprised of from 5.3 to 6.7% aluminum, from 2.5 to 3.5% zinc, a minimum of 0.15% manganese, and a maximum of 0.30% silicon, the balance being magnesium, consisting in continuously heating the solution-heat-treated condition thereof at two stepped temperatures of about 250° F. and 400° F., respectively, for a total period of about four hours, of which the initial heating at about 250° F. is from about one to about one and one-half hours.

17. An improvement in aging commercial magnesium casting alloys comprised of from 5.3 to 6.7% aluminum, from 2.5 to 3.5% zinc, a minimum of 0.15% manganese, and a maximum of 0.30% silicon, the balance being magnesium, consisting in continuously heating the solution-heat-treated condition thereof at two stepped temperatures of about 250° F. and 400° F., respectively, for a total period of about four hours, of which the initial heating at 250° F. is about one hour.

18. A magnesium-base alloy produced by an aging treatment consisting in continuously heating a solution-heat-treated casting containing from 6 to 9% aluminum, from 2 to 3% zinc, about 0.15% manganese, the balance being magnesium, at two stepped temperatures of about 250° F. and from about 340° F. to about 380° F., respectively, in which the initial lower heating temperature at about 250° F. is utilized over a substantial portion of the entire heating period but not exceeding one-half of the total time, the alloy being characterized by an improved combination of properties over those of similar alloys heated for the whole period at the higher temperature of the stepped temperatures.

19. A magnesium-base alloy produced by an aging treatment consisting in first heating a solution-heat-treated casting containing from 5.3 to 6.7% aluminum, from 2.5 to 3.5% zinc, a minimum of 0.15% manganese, and a maximum of 0.30% silicon, the balance being magnesium, for from one to one and one-half hours at a temperature of from about 225° F. to 275° F. and then stepping-up the heating temperature to from 375° F. to 400° F. and continuing the heating at the stepped-up temperature for from two and one-half to three hours, the alloy being characterized by a structure and combination of properties comparable to those of similar alloys aged by standard commercial practice, viz., for periods materially longer than four hours and at a single temperature intermediate 225° F. and 400° F.

20. A magnesium-base alloy produced by an

aging treatment consisting in continuously heating a solution-heat-treated casting containing from 5.3 to 6.7% aluminum, from 2.5 to 3.5% zinc, a minimum of 0.15% manganese, and a maximum of 0.30% silicon, the balance being magnesium, for about four hours total time at two stepped temperatures of about 250° F. and 400° F., respectively, in which the lower heating temperature is utilized over a period of about one and one-half hours, the alloy being characterized by markedly increased elongation, as compared with that of a similar alloy aged by a single conventional temperature heating at about 350° F. over a period of sixteen hours.

21. A process of aging commercial magnesium casting alloys consisting in heating the solution-heat-treated condition of a casting thereof containing a proportion of aluminum of from about 6% to about 9%, and a proportion of zinc of from about 3% to 2%, substantially all of the remainder being magnesium, at stepped-up temperatures, viz., first of from about 235° F. to about 265° F., and then of from about 340° F. to about 380° F., the first-mentioned heating in the temperature range of from about 235° F. to about 265° F. being utilized over a substantial proportion of the entire heating period but not exceeding one-half the total aging time, the aged alloys being characterized by an improved combination of properties over those of similar alloys heated for the whole period at a single temperature within the range of from about 235° F. to about 380° F.

22. A process of aging commercial magnesium casting alloys consisting in heating the solution-heat-treated condition of a casting thereof containing a proportion of aluminum of from about 6% to about 9%, and a proportion of zinc of from about 3% to 2%, substantially all of the remainder being magnesium, at stepped-up temperatures, viz., first of about 250° F., and then of from about 350° F. to about 400° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being from about 25% to about 37½% of the total aging time.

23. A process of aging commercial magnesium casting alloys consisting in heating the solution-heat-treated condition of a casting thereof containing from 5.3% to 6.7% aluminum, from 2.5% to 3.5% zinc, a minimum of .15% manganese, and a maximum of 0.30% silicon, substantially all of the remainder being magnesium, at stepped-up temperatures, viz., first of about 250° F., and then of from about 350° F. to about 400° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being from about 25% to about 37½% of the total aging time.

24. A process of aging commercial magnesium casting alloys consisting in heating the solution-heat-treated condition of a casting thereof containing a proportion of aluminum of from about 6% to about 9%, and a proportion of zinc of from about 3% to 2%, substantially all of the remainder being magnesium, at stepped-up temperatures, viz., first of about 250° F., and then of about 375° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being not to exceed two hours.

25. A magnesium-base alloy containing from about 6% to about 9% aluminum, and from about 3% to 2% zinc, substantially all of the remainder being magnesium, produced by an aging treatment consisting in heating a solution-heat-treated casting thereof for from about four hours to about eight hours total time at stepped-up temperatures, viz., first of from about 225° F. to about 275° F., and then of from about 350° F. to about 400° F., in which the first-mentioned heating in the temperature range of from about 225° F. to about 275° F. is utilized over a period not exceeding one-half of the total aging time, the alloy being characterized by an improved combination of properties over those of similar alloys heated for the whole period at a single temperature within the range of from about 225° F. to about 400° F.

26. A magnesium-base alloy containing from about 6% to about 9% aluminum, and from about 3% to 2% zinc, substantially all of the remainder being magnesium, produced by an aging treatment consisting in heating a solution-heat-treated casting thereof at stepped-up temperatures, viz., first of about 250° F., and then of from about 350° F. to about 400° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being from about 25% to about 37½% of the total aging time.

27. A magnesium-base alloy containing from 5.3% to 6.7% aluminum, from 2.5% to 3.5% zinc, a minimum of .15% manganese, and a maximum of 0.30% silicon, substantially all of the remainder being magnesium, produced by an aging treatment consisting in heating a solution-heat-treated casting thereof at stepped-up temperatures, viz., first of about 250° F., and then of about 375° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being for about one hour.

28. A magnesium-base alloy containing from 5.3% to 6.7% aluminum, from 2.5% to 3.5% zinc, a minimum of .15% manganese, and a maximum of 0.30% silicon, substantially all of the remainder being magnesium, produced by an aging treatment consisting in heating a solution-heat-treated casting thereof, at stepped-up temperatures, viz., first of about 250° F., and then of about 400° F., the total aging time being about four hours, and the first-mentioned heating of about 250° F. being for about one hour, the alloy being characterized by increased yield strength and elongation with no substantial loss in tensile strength as compared with similar alloys aged at a single temperature of about 350° F. for about sixteen hours.

EDWARD J. VARGO.

No references cited.

Certificate of Correction

Patent No. 2,477,503 July 26, 1949

EDWARD J. VARGO

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 5, line 13, for the syllables and hyphen "specifica-" read *specification*; column 9, line 25, for "againg" read *aging*; line 54, for the words "manganese-base" read *magnesium-base*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 20th day of December, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.