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MAGNESIUM BASE FORGING ALLOY

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The present invention relates to improved magnesium base alloys containing aluminum and manganese. One object of our invention is to produce magnesium base alloys which contain both aluminum and manganese that are capable of being readily forged. Other objects and advantages will appear as the description proceeds.

The magnesium base alloys containing from 3 to 15 per cent aluminum and manganese in amount usually from 0.1 to 0.5 per cent have a good degree of resistance to corrosion and are among the strongest of the known alloys possessing the characteristic lightness and other valuable properties of the magnesium alloys, but they are difficult to forge or otherwise plastically work satisfactorily. So far as we are aware no one has investigated the possibility of improving the plastic workability of these alloys otherwise highly satisfactory as among the lightest of the commercial structural metals.

Heretofore when it has been attempted to shape the above-mentioned magnesium alloys containing aluminum and small amounts of manganese by forging, rolling, or by similar methods, particularly hammer forging, flaws tend to develop in the article being forged. These flaws usually appear in the form of cracks which are especially noticeable at the outermost portions of the metal mass, such as the edges, where they may open up making voids of considerable size. The only known procedure employed at present to minimize this flaw formation has been to control the speed of working and the amount of working between heatings. For example, edge cracking is much less pronounced in forgings made by the slow method of pressing the metal between dies than by the more rapid method of hammer forging under similar conditions such as working temperature and amount of reduction in cross sectional area per working operation for a given alloy. In order to obtain a forging free from edge cracking, it has been necessary in the past to use a somewhat larger piece of metal than is required by the size of the forging desired and, after forging to shape, the outer portions which involve cracked or otherwise spoilt metal are removed by machining or otherwise. Even in such cases there is the possibility for the existence of minute cracks in the forging which are not evident by a simple visual inspection. These difficulties are encountered even when particular care is used in most suitably controlling the temperature of the metal and the working rate during the deformation operation.

In the following description we have employed the term "forgeability" to define the capacity of the alloys for plastic deformation by pressure, which may be applied not only by hammering, but also by other means such as slow pressing between dies in an hydraulic press, by the rolls of a rolling mill or by any means in which a change in cross sectional area is brought about by applying pressure.

We have found that the comparative lack of forgeability of the alloys mentioned above is dependent upon the quantity of aluminum present as well as upon that of manganese and that the presence of manganese, while valuable as a means to increase the resistance of the alloys to corrosion and to increase the yield point, has at the same time a disadvantageous tendency to decrease the forgeability, especially at fast working rates, such as the comparatively high rate of working when the forging is carried out by means of hammer blows. We have further discovered that these disadvantages can be overcome by suitably regulating the quantity of aluminum employed to less than 3 per cent if there is added at the same time a small quantity of one of the metals cadmium, silicon, or zinc. In this manner, we are enabled to retain the valuable properties conferred upon the alloys by manganese and aluminum as well as to produce alloys with as good mechanical properties as the corresponding known magnesium-aluminum-manganese alloys, but which possess a combination of mechanical properties, together with a degree of forgeability and resistance to corrosion, hitherto unknown in the art of producing magnesium alloys.

The alloys which form the subject of our invention, then, contain the four metals consisting of magnesium, aluminum, manganese, and one of the metals of the group cadmium, silicon, and zinc. The magnesium content coming within the scope of our invention is in excess of 90 per cent, that of aluminum is between 0.5 and 3.0 per cent, that of manganese is between 0.2 and 1.0 per cent, while the amount of the fourth constituent, e. g. cadmium, silicon, or zinc, may be at least 0.2 per cent, but not more than 6.0 per cent.

The preferred quantity of aluminum to employ will vary with the use to which the alloy is to be put. The higher the aluminum content the less the forgeability, while the tensile strength and other mechanical properties will be increased somewhat, so that the aluminum content within the limits given is to be governed by the choice between maximum forgeability and the highest mechanical properties to suit the particular application of the alloy. Usually about 2 per cent aluminum will meet most requirements.

The manganese content effective to modify the properties of these alloys is limited by the amount thereof which can exist in the alloys in solid solution, and approximately the maximum quantity of manganese which can be dissolved in the alloys is preferably used. This saturating quantity of manganese decreases with increase in the aluminum content, since the latter reduces the solu-

bility of manganese in the alloys. The active quantity of manganese varies from about 0.5 to 1.0 per cent as the aluminum content varies from 3 to 0.5 per cent, respectively, these amounts being in accordance with the solubility of the same in magnesium alloys containing aluminum. Silicon also reduces the solubility of manganese in magnesium and therefore somewhat less manganese can be retained in solid solution as the silicon content is increased.

The cadmium, zinc, and silicon content of the present alloys greatly improves the forgeability and mechanical properties thereof. The preferred quantities to employ between the limits stated above are from 0.5 to 2.0 per cent of cadmium or about 0.5 to 1.0 per cent of zinc or of silicon, in order to secure maximum forgeability.

The improved forgeability of our new alloys may be shown by comparing their forgeability with that of the known magnesium-aluminum-manganese alloys. In order to set forth the comparative forgeability we employ a simple system of visual inspection in which numerical values are assigned to the forged alloy samples, such numbers being based upon the relative amount of cracking which occurs during the forging operation or upon the entire absence of any cracking. Forgings showing entire absence of cracking are rated 100; those showing very slight cracking, either on being press forged or hammer forged with heavy blows, are rated 80; slight, but readily noticeable cracking by press forging or by heavy blows from the hammer, are rated 60; slight cracking by medium hammer blows are rated 40; bad cracking with medium blows or pressing are rated 20; while bad cracking with the press or light blows from the hammer are rated 0. A number of samples of each of the alloys were forged and in each case a forgeability number was assigned and an average value of the several determinations for each alloy composition was obtained, representing its forgeability.

In the examples given below showing the comparative forgeability, all the forgings were made from the same size of extruded stock under approximately the same conditions of temperature, and the reduction in area by forging was the same in every case. The hammer forging was started with light blows from a steam hammer and continued with heavier blows. The starting blows were delivered at the rate of about 90 per minutes and the rest of the blows at about 150 per minute. The forging was completed in about 22 seconds. The press forging was carried out by pressing the sample between dies brought together in an hydraulic press at such a rate that the forging was completed in about 30 seconds.

Examples showing forgeability and properties of binary magnesium-aluminum alloys are given in Table I below wherein the forgeability is rated according to the system just described.

Table I

Composition percent Al in alloy (balance Mg)	Forgeability of the binary Mg—Al alloys		
	Tensile strength lbs./sq. in.	Yield point lbs./sq. in.	Forgeability number
3	35,000	16,000	100
4	36,000	18,000	80

Thus it is seen that a small percentage of aluminum in magnesium produces a readily forgeable alloy but the forgeability tends to decrease as the aluminum content increases. If to these alloys manganese is now added to form the magnesium-aluminum-manganese ternary alloys having low percentages of aluminum and manganese, the forgeability is materially decreased in spite of the valuable increase in yield point and corrosion resistance imparted by the manganese. This increased yield point and decreased forgeability is shown by the examples in the following Table II:—

Table II

Composition 95.5-97.5 Mg, about 0.5 Mn, and Al as below	Forgeability of the ternary Mg—Al—Mn alloys		
	Tensile strength lbs./sq. in.	Yield point lbs./sq. in.	Forgeability number
Percent			
Al 2.0	36,000	21,000	70
Al 3.0	37,000	24,000	60
Al 4.0	38,000	25,000	30

Examples of the forgeability and properties of our improved quaternary magnesium alloys are given in the following Table III:—

Table III

Approximate composition (balance Mg)	Forgeability of the quaternary Mg alloys		
	Tensile strength lbs./sq. in.	Yield point lbs./sq. in.	Forgeability number
Percent			
Al 2.0 Mn 0.5 Cd from 0.5 to 2.0	35,000	21,000	100
Al 2.5 Mn 0.5 Si 0.5	38,000	25,000	80
Al 2.0 Mn 0.5 Zn 0.5	36,000	22,000	100

Thus it is evident that in spite of the presence of manganese the foregability has been increased by the addition of cadmium, silicon, or zinc to the magnesium-aluminum-manganese alloys in accordance with our invention and at the same time the increased yield point and resistance to corrosion due to manganese has been retained.

These alloys may be mechanically deformed in any of the usual ways, such as by hammer or press forging, rolling, extruding, etc., without cracking or otherwise fracturing the metal at temperatures from 750° to 900° F., or even at slightly higher or lower temperatures. When it is desired to secure a maximum improvement in tensile strength and other properties, the temperature range for working should be controlled within narrower limits and adapted to the quantity of the alloying metals present. For example, alloys containing approximately 2 per cent aluminum and 0.5 per cent manganese with either approximately 2 per cent of cadmium or 0.5 per cent zinc and the balance magnesium, are best forged or otherwise plastically worked at a temperature near 800° F. Similar working temperatures are suitable for the alloys with about 0.5 to 1.0 per cent of silicon or preferably about 0.6 per cent, together with approximately 2.5 per cent aluminum and 0.2 per cent manganese with the balance magnesium.

The development of the maximum values for the mechanical properties by plastic deformation

varies also with the amount of reduction in cross sectional area of the metal. Usually a reduction in area of about 90 per cent of the original area considered brings about as great an improvement in properties as it is possible to attain, other factors being equal.

Heat treatment according to the methods known to those skilled in the art of treating magnesium alloys may be practiced with these improved alloys but it is not necessary to apply the heat treatment before the forging operations. Following plastic deformation, the cooling of the worked article may be artificially retarded or otherwise maintained at a suitable temperature to give a precipitation heat treatment to the alloys containing alloying metal in greater amount than corresponds to saturation at lower temperatures, or to redissolve metal not in solid solution in the alloy as forged.

These alloys may be prepared in any convenient manner by employing any of the well known metallurgical methods of melting and alloying magnesium and following this they may be cast, extruded, or otherwise brought into suitable forms for plastic working.

Other modes of applying the principle of our invention may be employed instead of the one explained, change being made as regards the proportions of the ingredients employed within the limits specified, provided the ingredients stated by any of the following claims or the equivalent of such stated ingredients be employed.

We therefore particularly point out and distinctly claim as our invention:—

1. A magnesium base alloy consisting of magnesium in amount from 90 to 99 per cent, aluminum from 0.5 to 3.0 per cent, manganese from 1.0 to 0.2 per cent, and from 0.2 to 6.0 per cent of at least one of the metals cadmium, silicon.

2. A magnesium base alloy consisting of magnesium in amount from 90 to 98.5 per cent, aluminum from 0.5 to 3.0 per cent, manganese from 1.0 to 0.5 per cent, and from 0.5 to 6.0 per cent of cadmium.

3. A magnesium base alloy consisting of from 0.5 to 3.0 per cent of aluminum, from 0.5 to 1.0 per cent of manganese, and from 0.5 to 2.0 per cent of silicon, the balance being magnesium.

4. A magnesium base alloy consisting of approximately 95.5 per cent of magnesium, 2 per cent aluminum, 0.5 per cent manganese and 2.0 per cent cadmium.

5. A magnesium base alloy consisting of approximately 96.8 per cent magnesium, 2.5 per cent aluminum, 0.2 per cent manganese, and from 0.5 to 1.0 per cent silicon.

6. An alloy consisting of aluminum 3 per cent, manganese 0.5 per cent, silicon 0.5 per cent to 1 per cent, and the balance magnesium.

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