Nov. 17, 1953 T. E. LEONTIS ET AL 2,659,131

COMPOSITE ALLOY

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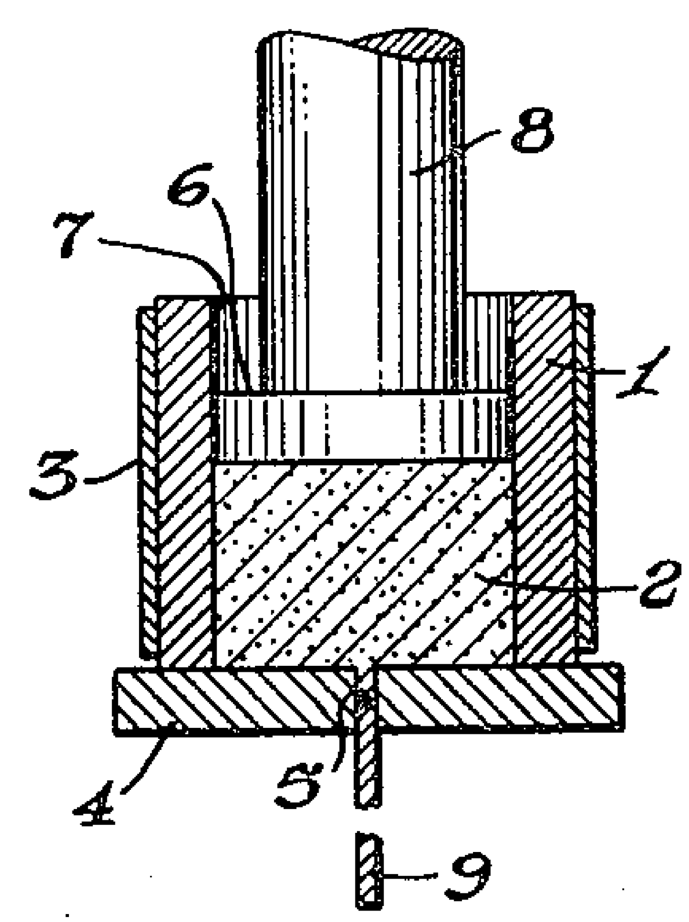

Fig. 1

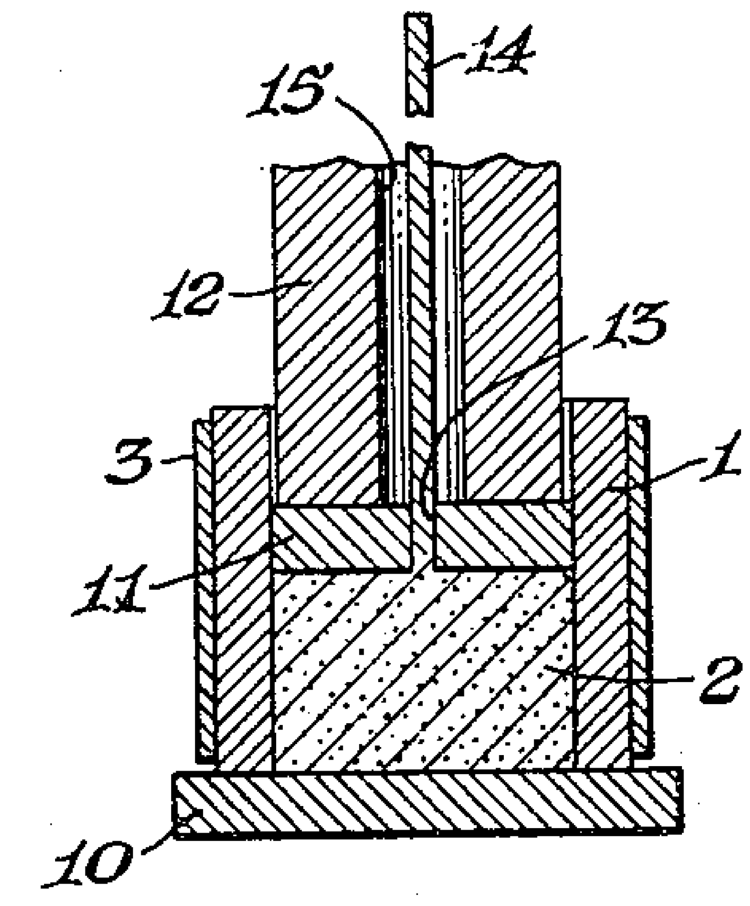

Fig. 2

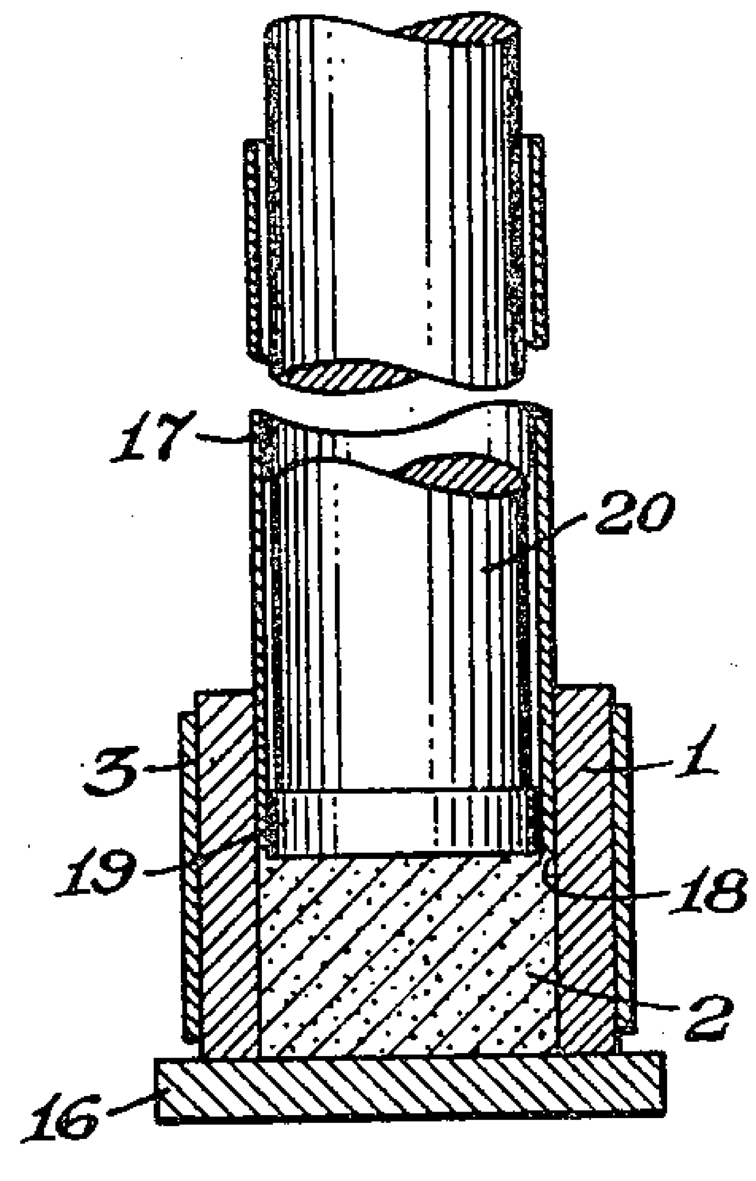

Fig. 3

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COMPOSITE ALLOY

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The invention relates to a composite metal body of which magnesium is the predominant constituent. It more particularly concerns an improved composite magnesium-base alloy body comprising magnesium alloyed with zirconium.

Zirconium alloys with magnesium, under conventional alloying conditions, to a maximum extent of about 0.8 per cent. Among the advantages of alloying zirconium with magnesium are that a strong fine grained alloy is obtained. It is also possible to improve the binary magnesium-base zirconium alloy by alloying various magnesium-soluble metals therewith, such as calcium, cerium (mischmetal), silver and zinc. In contrast, attempts to alloy the magnesium-soluble metal aluminum with the zirconium-containing magnesium-base alloys have not been successful because the aluminum and the zirconium react together to form an insoluble compound which settles out of the alloy. Insofar as we are aware, it is not possible with existing alloying methods to form magnesium-base alloys containing significant amounts of both aluminum and zirconium. The term "magnesium-base alloy" used herein means a magnesium alloy containing at least 80 per cent magnesium by weight.

We have now discovered that the foregoing difficulties of forming magnesium-base alloys containing both aluminum and zirconium in substantial amount are overcome by extruding at elevated temperature a zirconium-containing magnesium-base alloy in particulate form in admixture with the aluminum-containing metal constituent in particulate form. The resulting extrusion is a composite alloy body having enhanced tensile strength and other desirable properties. In addition, other metallic constituents capable of modifying the properties of the composite alloy may be included in its composition.

The invention then consists of the improved magnesium-base aluminum and zirconium-containing composite alloy, and method of making the same, hereinafter fully described and particularly pointed out in the claims, the following description setting forth several modes of practicing the invention.

In carrying out the invention, various zirconium-containing magnesium-base alloys in par-

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ticulate form may be used having an alloyed zirconium content of 0.1 to 0.8 per cent. A preferable proportion of zirconium is between about 0.2 and 0.6 per cent, 0.3 per cent being generally satisfactory. Although the binary magnesium-base alloy of magnesium and zirconium may be used as the zirconium-containing magnesium-base alloy in the mixture of particulate metals to be extruded, generally higher strengths are obtained by including at least another metal, which is soluble in magnesium in the presence of zirconium, as an alloyed constituent of the magnesium-base zirconium-containing alloy, as for example, cerium (e. g. mischmetal) in amount up to about 2 per cent, zinc up to about 8 per cent, silver up to about 6 per cent, or calcium up to 1 per cent. Combinations of two or more of these metals may be used in the alloy.

The zirconium-containing magnesium-base alloy may be reduced to particulate form for use in the invention in any convenient manner as by grinding or atomizing. The atomized form is preferred and may be produced by forming a melt of the alloy and atomizing it by impinging a jet of a cool gas, e. g. natural gas, against a thin falling stream of the molten alloy. The atomized alloy consists of a mixture of various sized fine spherical rapidly solidified particles of the alloy, the particles having a very fine structure. It is desirable to screen out particles coarser than those passing about a 10 to 20 mesh standard sieve.

The aluminum constituent of the mixture of the particulate metals to be extruded, according to the invention, may be either elementary aluminum or aluminum alloyed with a magnesium-alloyable metal. It is preferable to employ the aluminum as an alloy with magnesium, as in magnesium-base alloys containing aluminum. For example, the binary magnesium-base alloy of magnesium and aluminum, and the ternary magnesium-base alloys of magnesium, aluminum, and zinc, such as the conventional magnesium-base aluminum- and zinc-containing structural alloys, which may also contain a small amount of manganese, may be used in particulate form to supply the aluminum constituent of the mixture of the particulated metals to be extruded.

The aluminum-containing constituent of the mixture of particulate metals to be extruded is reduced to particulate form in any suitable way, such as any of those mentioned in connection with the magnesium-base magnesium-zirconium alloy. In the instances in which the aluminum constituent is alloyed with magnesium, as aforementioned, it is preferable to reduce the alloy to particulate form by atomization as already described. The particle size of the bulk of the aluminum-containing constituent is made preferably smaller than that of the bulk of the zirconium-containing constituent in order to obtain good distribution of the aluminum-containing constituent throughout the extrusion charge. Other metallic constituents, if any, in the extrusion charge may be reduced to particulate form in any appropriate manner.

Before extrusion, the metals in the particulate form described are mixed together to form a uniform mixture of the metal particles comprising the extrusion charge. Substantially all the particles should be capable of passing about a 10 to 20 mesh standard sieve. The relative amounts of the particulated zirconium-containing magnesium-base alloy and the particulated aluminum constituent are adjusted so that there is a minimum content of about 0.5 per cent to a maximum of about 6 per cent of the aluminum constituent (either alloyed with magnesium or as elementary aluminum) in the mixture, and a zirconium content in the mixture of at least about 0.095 per cent. The major portion by weight of the mixture of particulated metals to be extruded is the magnesium of the alloyed magnesium therein. The minor portion comprises the non-magnesium metals, viz. the constituents: aluminum and zirconium as well as any additional magnesium-soluble metals which may be used in the charge, e. g. cerium, silver, zinc, calcium, cadmium, lead, tin and manganese. Of these additional metals, the Ce, Ag, Zn and Ca may be introduced into the mixture as alloyed constituents of the particulated magnesium-base zirconium alloy, as aforesaid. The manganese may be introduced into the charge as particulated elementary manganese or it may be alloyed with the magnesium with which the aluminum constituent may be alloyed, or it may be introduced as an alloyed constituent of an additional particulated magnesium-base alloy not containing either aluminum or zirconium (this alloy may also contain Ca or Zn). The zinc and calcium may be used as just indicated or as particulated unalloyed metal introduced optionally into the extrusion charge. Cadmium, lead, and tin likewise may be used in particulated unalloyed form to modify the character of the composite alloy formed. The metals: Mn, Cd, Pb, Sn, and Zn when used in unalloyed form may be added in total amount up to about 2 per cent of the weight of the charge. The amount of magnesium in the charge is thus dependent upon the amount of the non-magnesium constituents introduced into the charge, and, exclusive of the zirconium and aluminum, which together constitute at most about 6.1 per cent of the charge, the aforementioned non-magnesium constituents (both alloyed and unalloyed) may amount to as much as about 18 per cent of the weight of the charge. The magnesium content, determined by difference, may range from a minimum of about 82 per cent to a maximum of about 99.4 per cent. The following chart summarizes the foregoing and shows the sources of the zirconium, aluminum, and other magnesium-soluble metal, if any, in the extrusion charge, or mixture of particulate metal, to be extruded to form the composite alloy.

Chart of extrusion charge components of particulated metals

Sources of zirconium in charge—Zirconium-containing magnesium-base alloy (Zr content 0.1 to 0.8%).	Sources of aluminum in charge—Aluminum-containing metal	Sources of optional modifying components in charge	
		Unalloyed metal	Alloyed metal
(1) Magnesium-base binary magnesium-zirconium alloy. (2) Magnesium-base magnesium-zirconium alloy containing up to 2% of Ce, up to 6% of Ag, up to 8% of Zn, up to 1% of Ca. Amount used being sufficient to introduce at least 0.095% of Zr by weight into the charge.	(1) Unalloyed aluminum. (2) Binary magnesium-aluminum alloys. (3) Magnesium-base alloys containing up to 12% of aluminum and up to 5% of zinc. (4) Magnesium-base alloys containing up to 12% of aluminum and up to 2% of manganese. (5) Magnesium-base alloys containing up to 12% of aluminum, up to 5% of zinc and up up to 2% of manganese. Amount used being sufficient to introduce at least 0.5 to 6% by weight of aluminum into the charge.	(1) Manganese. (2) Cadmium. (3) Lead. (4) Tin. (5) Zinc. One or more of above, if used, in total amount up to 2% of charge.	(1) Mn as magnesium-base magnesium-manganese alloy containing 0.1 to 2.5% of Mn. (2) Ditto and containing up to 0.5% of Ca and up to 3% of Zn. Amount used, if any, being sufficient to introduce up to 1% of manganese by weight into the charge.

The mixture of the particulated metals is charged into the heated container of a ram extruder, having a suitable size container and die opening, and subjected to extrusion pressure to cause the particulate metals to be heated and extruded together through the die-opening.

As to the extrusion conditions, the temperature of the particulated metal mixture in the container may be the same as that conventionally employed for extruding solid ingots of the known magnesium-base aluminum-containing alloys, e. g. from about 500° to 900° F., the usual temperature being about 650° to 850° F. The ratio of the cross-sectional area of the extrusion container to that of the die-opening has a material effect on the mechanical properties of the extrusion product obtained. A desirable ratio is at least about 30 to 1, although ratios as high as 150 to 1 or more may be used. The speed of extrusion may be varied over a wide range and depends to some extent upon the size and shape of the die-opening. In any case, the speed is to be held down to that at which the extrusion produced is free from hot shortness. A safe extrusion speed may be ascertained by visual examination of the product as it extrudes, the hot shortness being evident as cracks in the extruded product and sharply reduced strength.

The extruded product obtained is a composite metal body or alloy having the same compactness and integrity as the usual magnesium-base alloy extrusions made from a solid mass, such as an ingot of a magnesium-base alloy, but uniquely differs from it in metallographic structure. The structure is essentially multimetallic, being composed of the innumerable particles of each of the particulated forms of the metals in the extrusion charge, the particles having become elongated with the long axis parallel to that of the extrusion. The elongated particles are welded one to the other without voids. There is diffusion of some of the aluminum constituent of the aluminum-containing particles into the particles of the zirconium-containing magnesium-base alloy and precipitation thereby of zirconium therein; and there is some diffusion of magnesium from the zirconium-containing magnesium-base alloy particles into the aluminum or other magnesium-soluble metal constituent, if present, forming composite alloy. The composite alloy extrusion obtained may be subjected to the same types of metal working operations as employed with conventional magnesium-base alloys, e. g. rolling, welding, forging, chemical finishing, electroplating, etc. The mechanical properties of the composite alloy generally surpass those of the conventional magnesium-base zirconium-containing alloys and the amount of zirconium may be at least as much as may be alloyed with magnesium alone in spite of the inclusion of aluminum or other magnesium-soluble metal.

The invention may be further illustrated and explained in connection with the accompanying drawing in which:

Fig. 1 shows a schematic sectional elevation of an extrusion apparatus suitable for use in practicing the invention;

Fig. 2 is a similar view to Fig. 1 showing a modification of the apparatus; and

Fig. 3 is a similar view to Fig. 1 showing another modification of the apparatus.

As shown, the apparatus comprises, in its three forms, an extrusion container 1 adapted to confine a charge 2 of the mixture of metal particles to be formed into the composite alloy. The container is provided with a heating element 3. In Fig. 1, one end of the container 1 is closed by the die plate 4 in which is provided the die-opening 5. In this form of the apparatus, the charge 2 is caused to be compacted in the container and extruded through the die-opening 5 by application of pressure by means of the dummy block 6 forced into the bore 7 of the container by the ram 8 to form the extrusion 9 of composite alloy.

In the form of the apparatus shown in Fig. 2, the container 1 is closed at one end by the plate 10. The other end of the container receives the die block 11 carried by the hollow ram 12 which forces the die block into the container causing the charge 2 to be compacted and to extrude through die opening 13 to form the composite alloy extrusion 14 which extends into bore 15 of the hollow ram 12.

In the modification of Fig. 3, the container is closed at one end with a plate 16. The charge 2 is extruded as a tubular composite alloy extrusion 17 through the annulus 18 around the die block 19 while it is forced into the container by the ram 20.

The forms of the apparatus shown are conventional.

By putting a charge of the mixture of the metals involved according to the invention under pressure while at heat, as with the apparatus shown, the mixture of metal particles is compacted but not subjected to further mixing before extrusion. The metals originally in the charge as individual metal particles become welded together without voids into an integral compacted mass of elongated particles substantially without mixing. The particles in the compacted mass do not lose their original distinctive composition except at the surfaces of the union of the different kinds of particles which become extended and lengthened during extrusion, giving the particles their elongated form. At these surfaces during extrusion, some diffusion takes place of metal of one kind of particle to an adjacent particle of different metal, as already mentioned, forming composite alloy.

Examples, set forth in Table I, are illustrative of the invention as embodied in the coextrusion of a particulated binary magnesium-base zirconium alloy and particulated elementary aluminum mixed together to form the extrusion charge.

Table I

Example No.—Blank No.	Composition of extrusion charge of particulated A mixed with particulated aluminum			Mechanical properties of extrusion in 1,000's p. s. i.							
				As extruded		Aged		H. T.		H. T.+Aged	
	Weight percent A	Analysis of A	Weight percent Al	TYS	TS	TYS	TS	TYS	TS	TYS	TS
1	99.9	0.36% Zr, bal. Mg	0.1	28	38	35	43	31	40	36	42
2	99.5	do	0.5	33	40	39	44	41	45	42	45
3	94.0	do	6.0	40	42	41	41	49	52	49	51
Blank 1	100.0	do	None	26	36	29	37	28	37	28	36
Blank 2	99.5	100% Mg	0.5	26	36	32	37	25	32	25	33
Blank 3	94.0	do	6.0	24	33	24	34	29	39	25	34
Blank 4	100.0	do	None	27	36	27	36	20	39	22	30

"Aged"=heated 16 hours at 350° F.
H. T.=heated 1 hour at 750° F.
H. T.+Aged=heated 1 hour at 750° F. followed by heating for 16 hours at 350° F.
TYS=tensile yield strength, the stress at which the stress strain curve deviates 0.2 per cent from the modulus line.
TS=tensile strength.

Referring to Table I, the various compositions shown of the particulated metal or metals were extruded in the form of wire 0.086 inch in diameter from a heated extrusion container 0.5 inch in diameter at the rate of about 1 to 2 feet per minute using an apparatus similar to that of Fig. 1. The reduction in area was 34 to 1. The alloyed with magnesium in the proportions corresponding to the eutectic compositions, in the binary magnesium-aluminum alloy system, viz. 31.6 per cent Al, balance Mg, and 66.5 per cent Al, balance Mg. In making these extrusions, the same apparatus was used as for the extrusions of Table I, the reduction in area being 34:1.

Table II

Example No. — Blank No.	Composition of extrusion charge of particulated A mixed with particulated B (Mg-Al eutectic)			Extrusion temp., °F.	Mechanical properties [1] in 1000's p. s. i.							
	Weight percent A	Analysis of A	Weight percent B		As extruded		Aged		H. T.		H. T. + Aged	
					TYS	TS	TYS	TS	TYS	TS	TYS	TS
4	97	0.54% Zr, bal. Mg	[2] 3	800	38	40	37	41	39	43	40	43
5	94	do	[2] 6	800	37	41	39	44	38	46	37	46
6	91	do	[2] 9	800	36	43	39	45	40	47	42	47
7	88	do	[2] 12	800	41	42	44	46	46	47	43	48
8	82	do	[2] 18	800	40	47	41	44	43	50	43	47
Blank 5	100	do	None	800	28	36	33	41	28	38	28	37
9	91	0.33% Zr, bal. Mg	[3] 9	750	39	43	45	48	46	48	45	48
Blank 6	100	do	None	670	24	35	25	35	25	36	27	34

[1] See footnotes of Table I.
[2] Analysis 31.63% Al, balance Mg.
[3] Analysis 66.5% Al, balance Mg.

container temperature was about 800° F. and the die about 710° F. The particles of the magnesium-base magnesium-zirconium alloy were of atomized form passing a 20 mesh sieve and remaining on a 200 mesh sieve. The particulated aluminum was finer in particle size than the particulated magnesium-base alloys, about 82 per cent passing through 100 mesh sieve and about 58 per cent passing through a 200 mesh sieve. The particulated elementary magnesium included in blanks 2 to 5 for comparison was in the atomized form and similar in sieve analysis to that of the binary magnesium-zirconium alloy used.

The extrusion of Examples 1, 2 and 3 contain both aluminum and zirconium in amounts far beyond those alloyable with magnesium in conventional manner. Metallographic examination shows that each extrusion is essentially a unique multimetallic body of elongated particles of the binary magnesium-base magnesium-zirconium alloy and elongated aluminum particles, the two kinds of particles being interspersed and welded together into a composite alloy without voids. The elongated particles in the extrusion are oriented with their long axes parallel to the axis of the extrusion. In addition, some diffusion occurs of aluminum into the surface of the elongated magnesium-zirconium alloy particles and of the magnesium into the surface of the elongated aluminum particles; and there is the formation and precipitation of some zirconium-aluminum compound in the binary magnesium-zirconium alloy particles near the boundaries demarking the two kinds of metal particles of the composite alloy.

Examples, set forth in Table II, are illustrative of the invention as embodied in the coextrusion of a particulated binary magnesium-zirconium alloy and a particulated alloyed form of aluminum. In these examples, the aluminum is

By employing the aluminum constituent of the extrusion charge alloyed with a considerable proportion of magnesium, as in the foregoing examples (4 to 9, inclusive), a better distribution is had of the aluminum constituent throughout the mixture of particulate metal to be extruded, and the surface of the composite alloy extrusion is generally smoother than similar composite alloys made with unalloyed aluminum. The proportion of aluminum in the extrusion charges of Examples 4 to 8, inclusive, is approximately 1, 2, 3, 4, and 6 per cent, respectively, the zirconium content is approximately 0.52%, 0.51%, 0.49%, 0.47%, and 0.44%, respectively, and the balance is magnesium. The proportion of aluminum in the extrusion charge of Example 9 is about 6 per cent and that of the zirconium about 0.3 per cent, the balance is magnesium. The metallographic structure of the extrusions of Examples 4 to 9 is generally similar to that of the extrusions of Examples 1, 2 and 3.

The inclusion of one or more magnesium-soluble metals, e. g. cerium (mischmetal), zinc, calcium, silver as an alloyed constituent of the zirconium - containing magnesium - base alloy member of the extrusion charge, as aforementioned, is generally advantageous. Examples are set forth in Tables III and IV which are illustrative of the use of cerium in this embodiment of the invention, additional examples also appear in Table VII below (in the examples of Table IV, the aluminum constituent in the extrusion charge is the alloyed aluminum constituent of a conventional magnesium-base alloy containing aluminum, zinc, and manganese); the examples in Table V are illustrative of the use of zinc, in this embodiment of the invention; the examples in Table VI are illustrative of the use of two magnesium-soluble metals, calcium and zinc, in this embodiment of the invention (further examples of this use of calcium and zinc also appear in Table VII below); and the examples in Table VIII are illustrative of the use of silver in this embodiment of the invention.

Table III

Example No.—Blank No.	Composition of extrusion charge of particulated A mixed with particulated B				Mechanical properties of extrusion in 1000's p. s. i.										
	Weight percent A	Analysis of A	Weight percent B	Analysis of B	As extruded		Aged		H. T.		H. T. Aged		Extrusion condition		
					TYS	TS	TYS	TS	TYS	TS	TYS	TS	Dia., inches	Red.	Temp. ° F.
10	99.9	0.51% Zr, 0.99% Ce, bal. Mg.	0.1	100% Al	49	49	-----	52	47	47	49	49	0.088	33:1	700
11	99.5	do	0.5	do	50	51	52	53	48	49	48	49	0.088	33:1	700
12	99.0	do	1.0	do	50	50	53	53	49	50	50	51	0.088	33:1	700
13	97.0	do	3.0	do	50	50	50	50	50	51	50	52	0.088	33:1	700
14	94.0	do	6.0	do	50	51	50	50	52	53	50	50	0.088	33:1	700
Blank 7	100	do	none		48	48	51	51	43	43	43	43	0.088	33:1	700
15	99.9	0.44% Zr, 1.92% Ce, bal. Mg.	0.1	100% Al	53	53	51	51	47	47	48	49	0.088	33:1	700
16	99.5	do	0.5	do	51	51	51	52	48	48	49	49	0.088	33:1	700
17	99.0	do	1.0	do	52	52	52	52	47	50	47	49	0.088	33:1	700
18	99.0	do	3.0	do	51	51	50	50	45	49	51	54	0.088	33:1	700
19	94.0	do	6.0	do	51	52	-----	47	51	51	53	54	0.008	33:1	700
Blank 8	100	do	none		50	50	50	50	45	45	45	46	0.088	33:1	700
20	97.0	0.51% Zr, 0.99% Ce, bal. Mg.	3.0	31.6% Al, bal Mg	51	52	52	52	47	48	46	47	0.088	33:1	700
21	94.0	do	6.0	do	-----	53	50	51	47	49	49	50	0.088	33:1	700
22	91.0	do	9.0	do	49	50	53	53	48	49	49	49	0.088	33:1	700
23	88.0	do	12.0	do	51	51	52	52	51	53	51	53	0.088	33:1	700
24	82.0	do	18.0	do	52	53	-----	52	53	55	54	56	0.088	33:1	700
25	97.0	0.44% Zr, 1.92% Ce, bal. Mg.	3.0	do	50	50	49	50	48	49	46	47	0.088	33:1	700
26	94.0	do	6.0	do	50	50	52	52	43	45	46	48	0.088	33:1	700
27	91.0	do	9.0	do	49	50	53	53	46	48	48	50	0.088	33:1	700
28	82.0	do	18.0	do	54	54	54	55	50	53	49	50	0.088	33:1	700
29	75.0	0.30% Zr, 0.2% Ce, bal. Mg.	25.0	5.6% Al, bal. Mg.	32	38	41	44	40	43	39	44	0.086	34:1	700
30	50.0	do	50.0	do	36	42	38	42	36	43	35	43	0.086	34:1	700
31	25.0	do	75.0	do	32	43	35	43	31	40	32	41	0.086	34:1	700
Blank 9	100	do	none		37	42	38	42	33	38	34	40	0.086	34:1	700
Blank 10		do	100	5.6 Al, bal. Mg	31	44	29	43	26	41	26	39	0.086	34:1	700

Table IV

Example No.—Blank No.	Composition of extrusion charge of particulated A mixed with particulated B				Extrusion[1] tensile strength in 1000 p. s. i.	Extrusion conditions		
	Weight percent A	Analysis of A	Weight percent B	Analysis of B		Extrusion diameter, inches	Reduction in area	Temp., ° F.
32	75	0.46% Zr, 0.40% Ce, bal. Mg	25	2.8% Al, 1.0% Zn, 0.42% Mn, bal. Mg	43	0.092	30:1	750
33	50	do	50	do	42	0.092	30:1	750
34	25	do	75	do	37	0.092	30:1	750
Blank 11	100	do	None	do	42	0.092	30:1	750
Blank 12	None	do	100	do	33	0.092	30:1	750
35	75	0.37% Zr, 0.49% Ce, bal. Mg	25	6.3% Al, 0.71% Zn, 0.23% Mn, bal. Mg	40	0.092	30:1	750
36	50	do	50	do	40	0.092	30:1	750
37	25	do	50	do	34	0.092	30:1	750
Blank 13	100	do	None	do	39	0.092	30:1	750
Blank 14	None	do	100	do	28	0.092	30:1	750
38	75	do	25	5.64% Al, 3.08% Zn, 0.26% Mn, bal. Mg	43	0.092	30:1	750
39	50	do	50	do	39	0.092	30:1	750
40	25	do	75	do	33	0.092	30:1	750
Blank 15	None	do	100	do	27	0.092	30:1	750
41	75	do	25	8.5% Al, 0.45% Zn, 0.24% Mn, bal. Mg	42	0.092	30:1	750
42	50	do	50	do	40	0.092	30:1	750
43	25	do	75	do	35	0.092	30:1	750
Blank 16	None	do	100	do	33	0.092	30:1	750
44	75	0.30% Zr, 0.2% Ce, bal. Mg	25	9.0% Al, 1.85% Zn, 0.2% Mn, bal. Mg	37	0.086	34:1	700
45	50	do	50	do	36	0.086	34:1	700
Blank 17	None	do	100	do	27	0.086	34:1	700

[1] Extrusion heated 1 hour at 750° F.

Table V

Example No.—Blank No.	Composition of extrusion charge of particulated A mixed with particulated B				Extrusion[1] tensile yield strength in 1000 p. s. i.	Extrusion conditions		
	Weight percent A	Analysis of A	Weight percent B	Analysis of B		Extrusion diameter, inches	Reduction in area	Temp., ° F.
46	99.9	0.28% Zr, 1.14% Zn, bal. Mg	0.1	100% Al	44	0.097	27:1	700
47	99.5	do	0.5	do	45	0.097	27:1	700
48	99.0	do	1.0	do	46	0.097	27:1	700
49	97.0	do	3.0	do	46	0.097	27:1	700
50	94.0	do	6.0	do	48	0.097	27:1	700
Blank 18	100	do	None		42	0.097	27:1	700
51	88.0	do	12.0	31.6% Al, bal. Mg	48	0.097	27:1	700
52	99.0	0.46% Zr, 7.67% Zn, bal. Mg	1.0	100% Al	39	0.097	27:1	700
Blank 19	100	do	None		22	0.097	27:1	630
53	88.0	do	12.0	31.6% Al, bal. Mg	38	0.097	27:1	630
54	99.0	0.57% Zr, 2.12% Zn, bal. Mg	1.0	100% Al	46	0.092	30:1	700
55	97.0	do	3.0	do	50	0.092	30:1	700
56	94.0	do	6.0	do	51	0.092	30:1	700
Blank 20	100	do	None		40	0.092	30:1	700

[1] Extrusion heat treated 1 hour at 750° F.

Table VI

Example No.—Blank No.	Composition of extrusion charge of particulated A mixed with particulated B				Extrusion [1] tensile yield strength 1000's p. s. i.
	Weight percent A	Analysis of A	Weight percent B	Analysis of B	
57	99.5	0.44% Zr, 1.80% Zn, 0.43% Ca, bal. Mg	0.5	100% Al	39
58	99.0	do	1.0	do	44
59	97.0	do	3.0	do	44
60	94.0	do	6.0	do	46
Blank 21	100.0	do	None		35
61	94.0	do	6.0	31.6% Al, bal. Mg	39
62	91.0	do	9.0	do	44
63	88.0	do	12.0	do	46
64	82.0	do	18.0	do	48
65	99.0	0.61% Zr, 3.81% Zn, 0.28% Ca, bal. Mg	1.0	100% Al	41
66	97.0	do	3.0	do	41
Blank 22	100.0	do	None		35
67	94.0	do	6.0	31.6% Al, bal. Mg	40
68	91.0	do	9.0	do	43
69	88.0	do	12.0	do	46
70	82.0	do	18.0	do	45
71	99.5	0.47% Zr, 5.45% Zn, 0.26% Ca, bal. Mg	0.5	100% Al	34
72	99.0	do	1.0	do	34
73	97.0	do	3.0	do	38
Blank 23	100.0	do	None		24
74	94.0	do	6.0	31.6% Al, bal. Mg	35
75	91.0	do	9.0	do	37
76	82.0	do	18.0	do	40

[1] Extrusion heat treated 1 hour at 750° F.; extrusion conditions: Extrusion temperature 700° F.; extrusion diameter 0.091 inch; reduction in area 30:1.

If desired, there may be included in the mixture of the particulated zirconium-containing magnesium-base alloy and the particulated aluminum-containing constituent to be extruded, another particulated magnesium-base alloy. In such combinations of particulated metal of the extrusion charge, it is advantageous to employ as the particulated magnesium-base alloy, one containing manganese, examples of which appear herein. The use of alloyed manganese in this embodiment of the invention is illustrated in the examples of Table VII.

Table VII

Example No.	Composition of extrusion charge of particulated metals A, B, and C						Extrusion tensile yield strength [1] 1000's p. s. i.	Reduction in area	Extrusion dimensions, inches
	Weight percent A	Analysis of A	Weight percent B	Analysis of B	Weight percent C	Analysis of C			
77	48.5	0.51% Zr, 2.12% Zn, bal. Mg.	3	100% Al	48.5	1.76% Mn, bal. Mg	47	30:1	0.094 wire.
78	47.0	0.45% Zr, 0.22% Ce, bal. Mg.	6	do	47.0	1.37% Mn, bal. Mg	47	31:1	0.090 wire.
79	41.0	do	18	31.6% Al, bal. Mg.	41.0	do	46	31:1	0.091 wire.
80	47.0	0.28% Zr, 1.14% Zn, bal. Mg.	6	100% Al	47.0	do	47	27:1	0.097 wire.
81	41.0	do	18	31.6% Al, bal. Mg.	41.0	do	45	27:1	Do.
82	47.0	0.57% Zr, 2.12% Zn, bal. Mg.	6	100% Al	47.0	1.76% Mn, bal. Mg	49	27:1	Do.
83	47.0	0.47% Zr, 7.67% Zn, bal. Mg.	6	do	47.0	1.37% Mn, bal. Mg	37	27:1	Do.
84	44.0	do	12	31.6% Al, bal. Mg.	44.0	do	42	27:1	Do.
85	47.0	0.44% Zr, 1.80% Zn, 0.43% Ca, bal. Mg.	6	100% Al	47.0	do	49	30:1	0.092 wire.
86	47.0	0.61% Zr, 3.81% Zn, 0.28% Ca, bal. Mg.	6	do	47.0	1.37% Mn	45	30:1	Do.
87	47.0	0.47% Zr, 5.41% Zn, 0.26% Ca, bal. Mg.	6	do	47.0	1.37% Mn, bal. Mg	45	30:1	Do.
88	44.0	0.26% Zr, bal. Mg	12	31.6% Al, bal. Mg.	44.0	1.78% Mn, bal. Mg	39	64:1	0.375 [2] Rod.
89	44.0	0.48% Zr, 0.17% Ce, bal. Mg.	12	do	44.0	1.81% Mn, 0.17% Ca, bal. Mg.	38	150:1	¾ x ⅛ strip. [3]
90	48.5	0.28% Zr, 0.13% Ce, bal. Mg.	3	100% Al	48.5	1.81% Mn, 0.06% Ca, bal. Mg.	39	150:1	Do. [3]
91	48.5	0.4% Zr, 2.53% Zn, bal. Mg.	3	do	48.5	1.78% Mn, bal. Mg	43	150:1	Do. [3]
92	44.0	0.66% Zr, 5.47% Zn, bal. Mg.	12	31.6% Al, bal. Mg.	44.0	1.71% Mn, bal. Mg	40	150:1	Do. [3]
93	44.0	0.44% Zr, 7.67% Zn, bal. Mg.	12	do	44.0	1.81% Mn, 0.06% Ca, bal. Mg.	35	150:1	Do. [3]
94	48.5	0.54% Zr, 3.85% Zn, 0.29% Ca, bal. Mg.	3	100% Al	48.5	do	43	150:1	Do. [3]
95	44.0	do	12	31.6% Al, bal. Mg.	44.0	do	42	150:1	Do. [3]
96	44.0	0.69% Zr, 5.41% Zn, 0.44% Ca, bal. Mg.	12	do	44.0	do	44	150:1	Do. [3]
97	68.25	0.57% Zr, bal. Mg	9	do	22.75	1.82% Mn, bal. Mg	39	150:1	Do. [3]

[1] Heat treated 1 hour at 750° F.
[2] Extruded at 600° F.
[3] Extruded at 650° F.
Wire extruded at 700° F.

In Examples 77 to 88, inclusive, and 91, 92, 97 of Table VII the manganese-containing magnesium-base alloy ingredient of the mixture of particulated metals constituting the extrusion charge are conventional binary magnesium-base magnesium-manganese alloys. In Examples 89, 90, 93, 94, 95, and 96 of the table, a small amount of calcium is included in the binary magnesium-manganese alloys. A particular advantage of including in the extrusion charge the manganese-containing binary magnesium-base alloy, with or without calcium is a reduction in sensitivity of the composite alloy to stress corrosion.

Table VIII

Example No. — Blank No.	Composition of extrusion charge of particulated metals A and B			Mechanical properties in 1000's p. s. i.[1]								
	Weight percent A	Analysis of A	Weight percent B	ASX			H. T. 1 hr. 750° F.			H. T. 16 hrs. 750° F.		
				TYS	CYS	TS	TYS	CYS	TS	TYS	CYS	TS
98	97	0.48% Zr, 2.75% Ag, bal. Mg	3	36	35	43	43	37	49	44	36	49
99	94	do	6	39	33	45	45	36	52	45	36	52
Blank 24	100	do	None	34	26	41	26	15	32	25	11	30
100	97	0.47% Zr, 5.5% Ag, bal. Mg	3	37	36	47	44	40	52	45	38	52
101	94	do	6	37	37	48	46	40	53	47	40	53
Blank 25	100	do	None	33	29	43	28	21	36	26	17	36

Extrusion temp. 650° F. Reduction in area 64:1. Speed 2 feet/min. Size extrusion 1/8" x 7/8" section.
Analysis of B=31.6% Al, Bal. Mg.
[1] ASX=as extruded; H. T.=heat treated; TYS=tensile yield strength; CYS=compression yield strength; TS=tensile strength.

the zirconium-containing magnesium-base alloy also contains zinc.

7. The method according to claim 1 in which the zirconium-containing magnesium-base alloy also contains calcium.

8. The method according to claim 1 in which the zirconium-containing magnesium-base alloy also contains silver.

9. The method of making a solid composite article comprising a magnesium-base magnesium-zirconium alloy which comprises forming a mixture of a particulated zirconium-containing magnesium-base alloy, a particulated aluminum-containing magnesium-base alloy, and a particulated unalloyed magnesium-soluble metal selected from the group consisting of manganese, cadmium, lead, tin, zinc, said mixture comprising at least 0.5 per cent of aluminum, at least 0.095 per cent of zirconium, the amount of the aluminum plus the zirconium not exceeding 6.1 per cent, and up to 18 per cent of the said magnesium-soluble metal, the balance of the mixture being magnesium, and die-expressing the mixture in solid condition at a temperature of at least 500° F.

10. A composite metal body comprising at least two particulated metals, one of the metals consisting of a magnesium-base magnesium-zirconium alloy, the other comprising aluminum, the particles of each of the said two metals being elongated, oriented in the same direction, and welded together into an integral solid, said solid comprising by weight at least 0.5 per cent of aluminum, at least 0.095 per cent of zirconium, the amount of the aluminum plus the zirconium not exceeding 6.1 per cent, and up to 18 per cent of non-magnesium metal, exclusive of the aluminum and zirconium, the balance being magnesium.

The extrusions set forth in the Tables II to VIII, inclusive, were made with apparatus similar to that of Fig. 1 and the composite alloys obtained had a metallographic structure similar to that of other examples.

In addition to the advantages already mentioned, it is manifest that the composite alloy of the invention may be held at elevated temperatures without loss of strength, thereby permitting hot working without loss of tensile strength.

We claim:

1. The method of making a solid composite article comprising a magnesium-base magnesium-zirconium alloy which comprises forming a mixture of a zirconium-containing magnesium-base alloy in particulate form and an aluminum-containing metal in particulate form, said mixture comprising at least 0.5 per cent of aluminum, at least 0.095 per cent of zirconium, the amount of the aluminum plus the zirconium not exceeding 6.1 per cent, and up to 18 per cent of non-magnesium metal exclusive of the said aluminum and zirconium, the balance of the mixture being magnesium, and die-expressing the mixture in solid condition at a temperature of at least 500° F.

2. The method according to claim 1 in which the aluminum-containing metal is a magnesium alloy containing at least 0.5 per cent of aluminum.

3. The method according to claim 1 in which the aluminum-containing metal is a magnesium-base alloy containing at least 0.5 per cent of aluminum and zinc.

4. The method according to claim 1 in which the aluminum-containing metal is a magnesium-base alloy containing zinc, at least 0.5 per cent of aluminum, and manganese.

5. The method according to claim 1 in which the zirconium-containing magnesium-base alloy also contains cerium.

6. The method according to claim 1 in which

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