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(54) **ALLOY, ALLOY MEMBER AND PRODUCT**

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(57) **ABSTRACT**

An alloy according to the present embodiment contains Fe, Cr and V as a first element group. Said alloy may also contain one or more types of element selected from Mn, Co, Ni, Si, Ge, Ru and Pd as a second element group. When the total is 100 at % (hereinafter, written the same), the first element group each constitutes 10-45 at %, inclusive (at %=element ratio. Hereinafter, written as 10-45 at %). The Mg lattice mismatch is 13% or higher, and the dislocation movement barrier energy is 300 kJ/mol or higher.

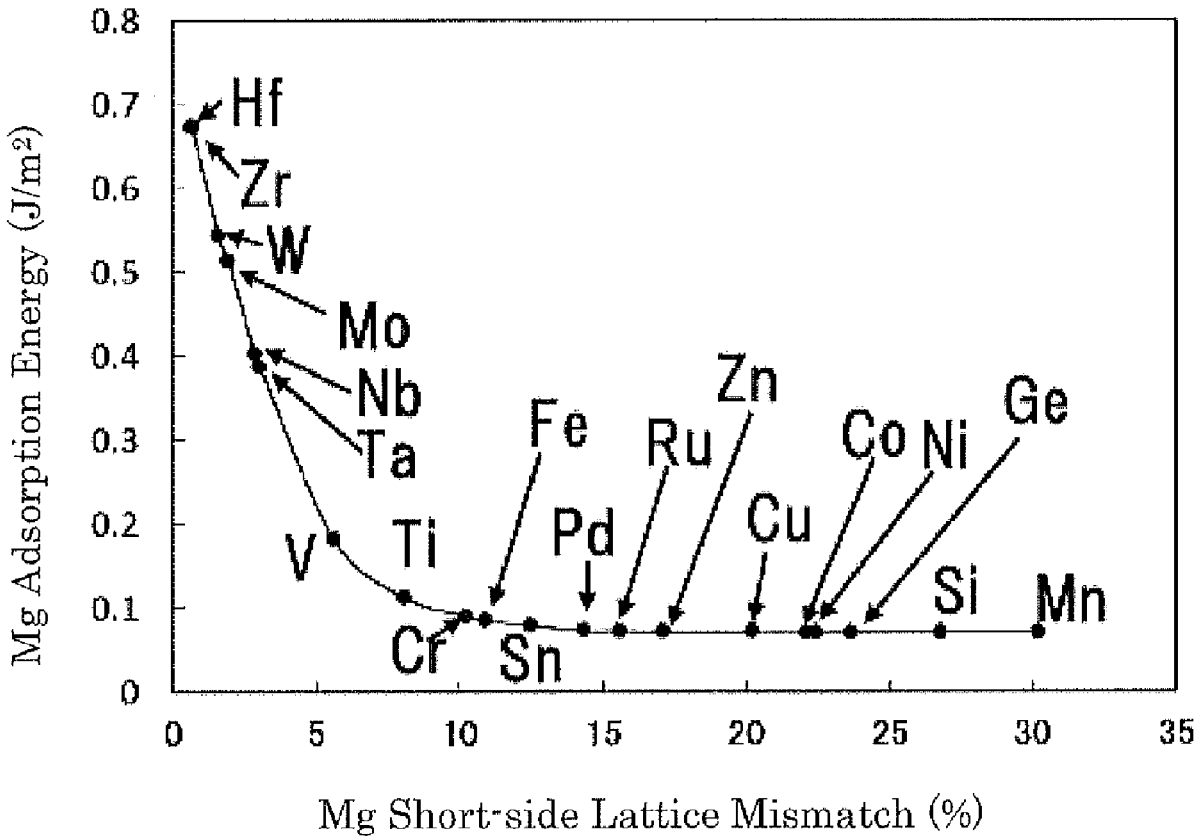


Fig. 1

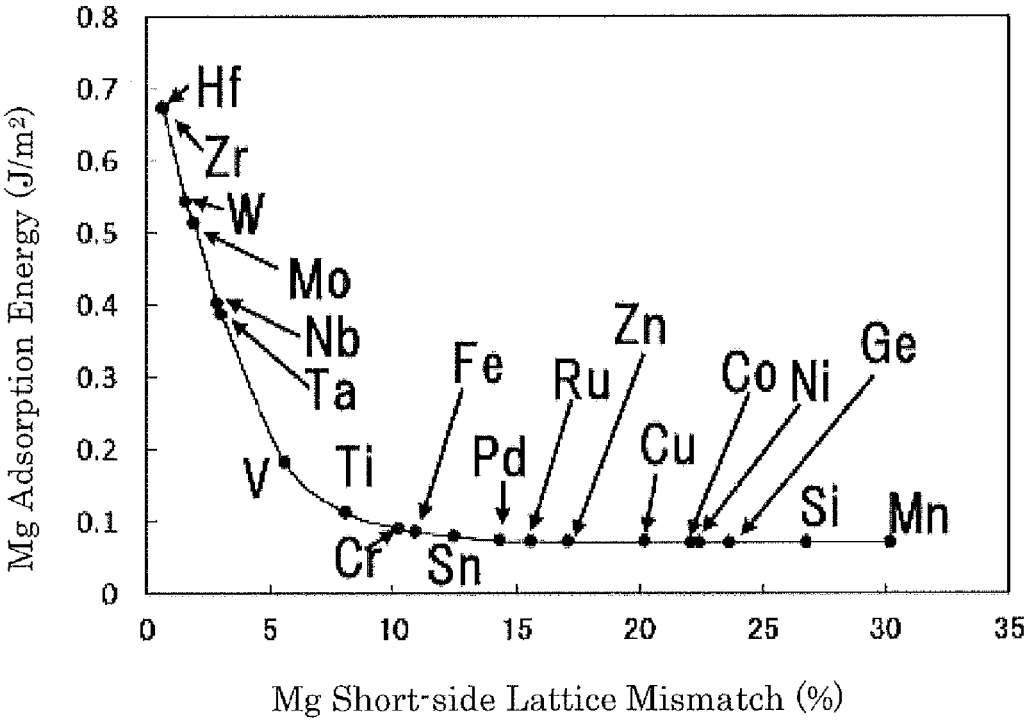

Mg Adsorption Energy (J/m²)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Hf
Zr
W
Mo
Nb
Ta
V
Ti
Cr
Sn
Fe
Pd
Ru
Zn
Cu
Co
Ni
Ge
Si
Mn
0
5
10
15
20
25
30
35
Mg Short-side Lattice Mismatch (%)

Fig. 2

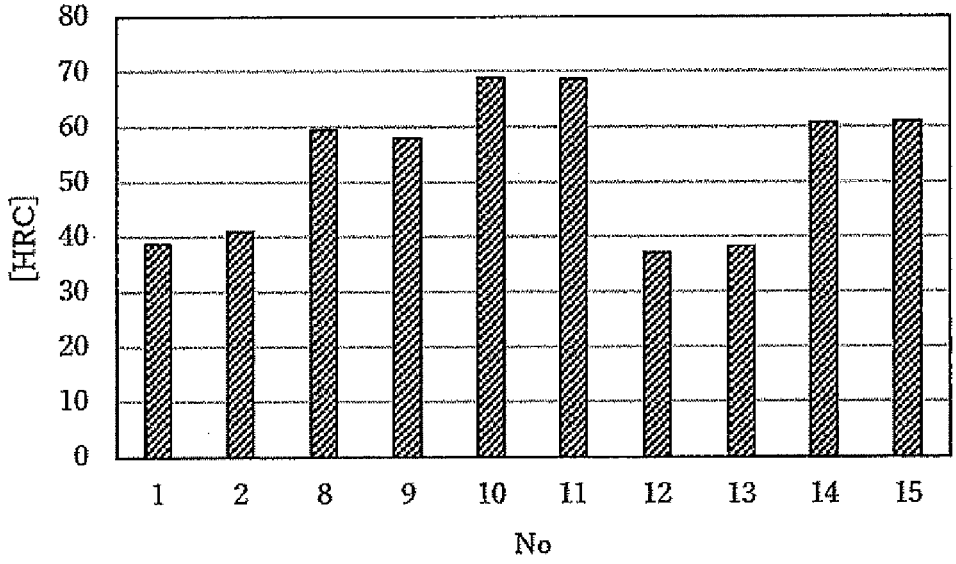

[HRC]
80
70
60
50
40
30
20
10
0
1
2
8
9
10
11
12
13
14
15
No

Fig. 3

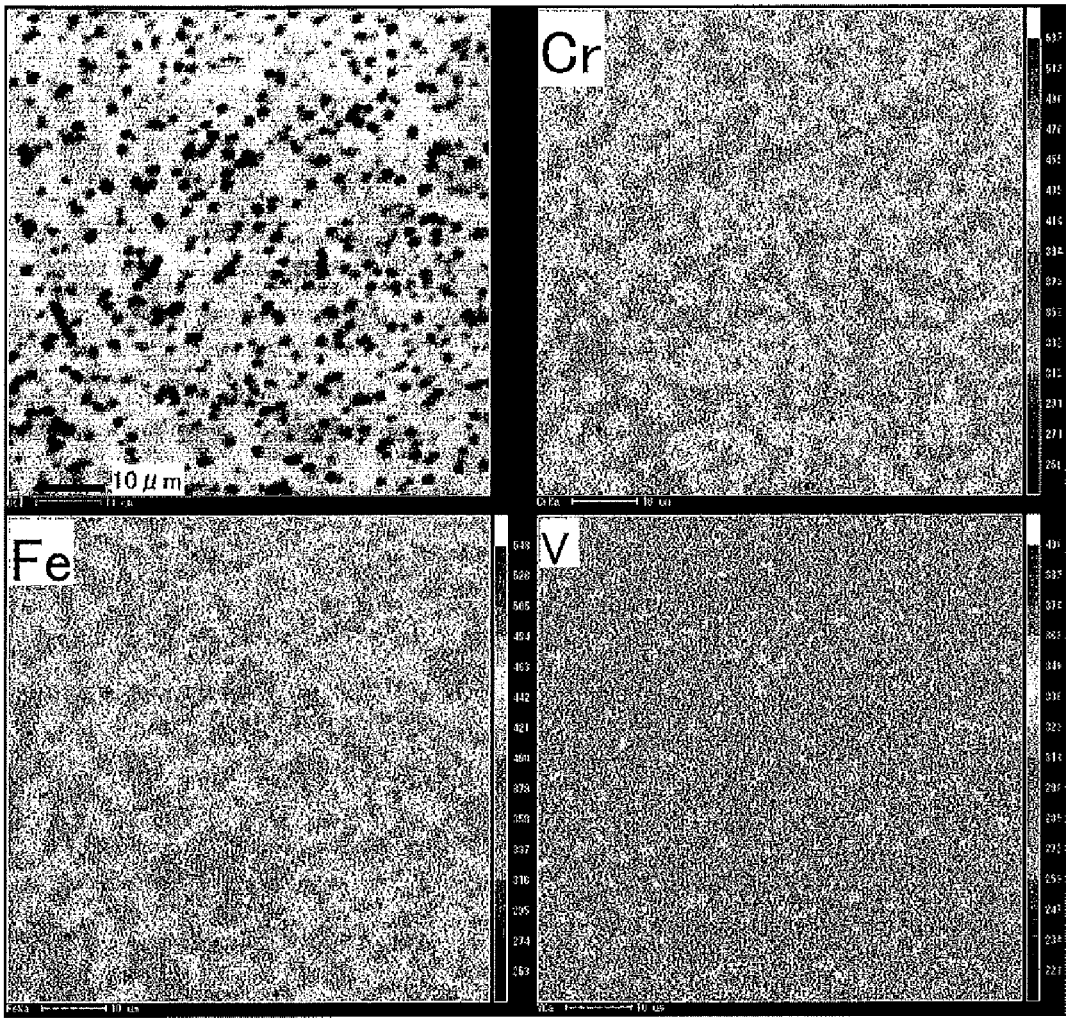
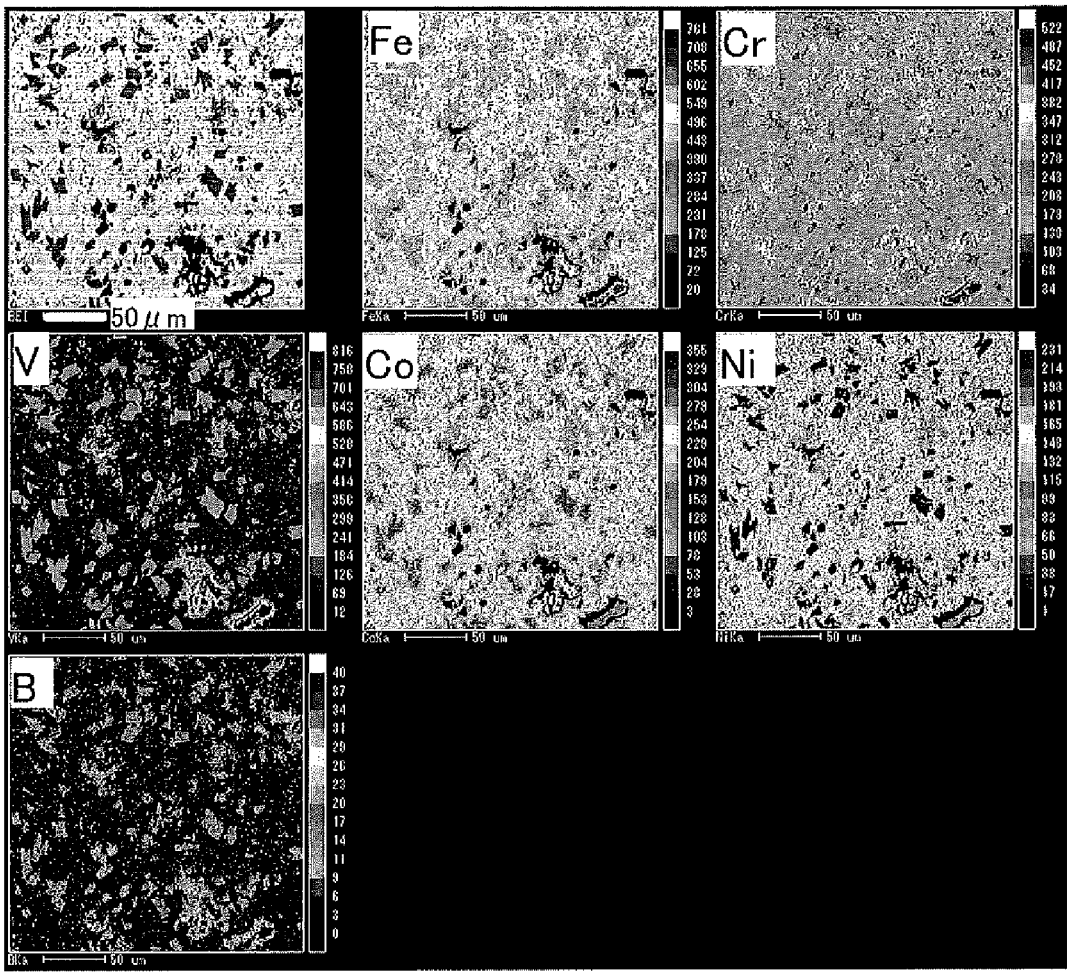


Fig. 4



ALLOY, ALLOY MEMBER AND PRODUCT

TECHNICAL FIELD

[0001] The present invention relates to an alloy that is either in a molten state or in a plastic state, more particularly to an alloy that is resistant to magnesium alloys, and to an alloy member and a product using the same.

BACKGROUND OF THE INVENTION

[0002] For molds to be used for die-casting etc. of magnesium alloys, JIS SKD61 has been used, for example. If the same mold is repeatedly used for casting, the mold may get damaged. One of the main causes of the damage is erosion. Erosion is said to occur when a part of the mold being in contact with molten magnesium alloy turns into an alloy, thereby having a lower melting point.

[0003] If erosion is severe, the eroded part is to be repaired by overlaying by welding. As a repairing material, an erosion-resistant alloy having a high melting point with an excellent creep-resistance at high temperatures is preferable. One example of such the alloy is disclosed in Patent Document 1.

[0004] While there is a demand for high strength and high corrosion-resistance, high entropy alloys (HEA) have been attracting attention. For example, Patent Document 2 discloses an HEA formed of multiple components including, in addition to titanium, zirconium, niobium, and tantalum, at least one selected from a group consisting of molybdenum, hafnium, tungsten, vanadium, and chromium. The HEA disclosed in Patent Document 2 is to be used as a metal material for organisms.

RELATED APPLICATIONS

Patent Documents

[0005] [Patent Document 1] Published Japanese Translation of PCT International Publication for Patent Application No. H01-502680 (JP-T-H01-502680)

[0006] [Patent Document 2] Japanese Unexamined Patent Application Publication No. 2018-70949 (JP-A-2018-70949)

Non-Patent Documents

[0007] [Non-Patent Document 1] R. Car, M. Parrinello (1985). Unified Approach for Molecular Dynamics and Density-Functional Theory. PHYSICAL REVIEW LETTERS. VOLUME 55, NUMBER 22, 2471-2474

[0008] [Non-Patent Document 2] S. J. Plimpton, E. D. Wolf (1990). Effect of interatomic potential on simulated grain-boundary and bulk diffusion: A molecular-dynamics study. Physical Review B. VOLUME 41, NUMBER 5, 2712-2721

[0009] [Non-Patent Document 3] T. Iwasaki, H. Miura (2001). Molecular dynamics analysis of adhesion strength of interfaces between thin films. Materials Research Society. VOLUME 16, NUMBER 6, 1789-1794

[0010] [Non-Patent Document 4] T. Tsuru, D. C. Chrzan (2015). Effect of solute atoms on dislocation motion in Mg: An electronic structure perspective. Scientific Reports. VOLUME 5:8793 | DOI: 10.1038/srep08793, 1-8

[0011] [Non-Patent Document 5] T. Iwasaki (2000). Molecular dynamics study of adhesion strength and diffusion at interfaces between interconnect materials and underlay materials. Springer-Verlag. Computational Mechanics. VOLUME 25 (2000), 78-86

[0012] [Non-Patent Document 6] Tomio IWASAKI (2018). Efficient Optimum Design of Metal with Strong Adhesion to Ceramics with a Combination of Orghogonal Array and Response-Surface Method. Journal of the Society of Materials Science, Japan. VOLUME 67, NUMBER 8, 803-810

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

[0013] Unfortunately, with the alloy disclosed in Patent Document 2, erosion resistance against molten metal, such as magnesium alloys, and machine strength are insufficient. Thus, a purpose of the present invention is to provide a multicomponent alloy, and an alloy member and a product using the alloy member, in which the alloy is resistant to magnesium, especially having resistance to erosion and mechanical strength, during a process of casting or the like of magnesium alloys.

[0014] Non-Patent Documents 1 to 6 disclose technical documents that are necessary to provide supplementary descriptions of embodiments of the present invention. For example, Non-Patent Document 1 describes a method for simulating a process of atomic movements based on a basic equation of quantum mechanics, i.e. the calculation principle of the first principle molecular dynamics method. Since electrons and nuclei forming atoms of a material follow the rules of quantum mechanics, such the simulation can evaluate properties of the material. Non-Patent Document 2 mentions a method for calculating a diffusion coefficient by molecular dynamics simulation. Also, Non-Patent Document 3 mentions a method for calculating adsorption energy by molecular dynamics simulation. Remaining Non-Patent Documents 4 to 6 will be mentioned below in sections describing the embodiments of the present invention.

Means for Solving Problems

[0015] To achieve the above object, a first aspect of the present invention is an alloy including, as a first element group, 10 at % or more and 45 at % or less each of Fe, Cr, and V, in which a Mg lattice mismatch is 13% or more and dislocation movement barrier energy is 300 kJ/mol or more.

[0016] The alloy may further include, as a second element group, 10 at % or more and 25 at % or less each of one or more types of element selected from a group consisting of Mn, Co, Ni, Si, Ge, Ru, and Pd.

[0017] Also, it is preferable that Mg adsorption energy is 0.2 J/m^2 or less.

[0018] According to the first aspect of the present invention, the lattice mismatch with magnesium is large, and thus the alloy has an excellent erosion resistance to magnesium. In addition, since the dislocation movement barrier energy is higher than a prescribed value, the alloy having sufficient rigidity can be obtained.

[0019] By further adding the second element group, higher Mg erosion resistance and mechanical properties can be obtained.

[0020] Such effects can be obtained with more certainty when the magnesium adsorption energy is 0.2 J/m^2 or less.

[0021] A second aspect of the present invention is an alloy member including at least partly an alloy including, as a first element group, 10 at % or more and 45 at % or less each of Fe, Cr, and V with remainder made up of unavoidable impurities, in which a Mg lattice mismatch is 13% or more and dislocation movement barrier energy is 300 kJ/mol or more.

[0022] The alloy may further include, as a second element group, 10 at % or more and 25 at % or less each of one or more types of element selected from a group consisting of Mn, Co, Ni, Si, Ge, Ru and Pd.

[0023] Also, it is preferable that Mg adsorption energy of the alloy is 0.2 J/m^2 or less.

[0024] According to the second aspect of the present invention, the lattice mismatch with magnesium is large, and thus the alloy member has an excellent erosion resistance to magnesium. In addition, since the dislocation movement barrier energy is higher than a prescribed value, the alloy member having sufficient rigidity can be obtained.

[0025] Also, by adding the second element group, higher Mg erosion resistance and mechanical properties can be obtained.

[0026] Also, the above effects can be obtained with more certainty when the magnesium adsorption energy is 0.2 J/m^2 or less.

[0027] A third aspect of the present invention is a product including at least partly the alloy member according to the second aspect of the present invention.

[0028] Also, it is preferable that the product is a metal mold for processing magnesium.

[0029] According to the third aspect of the present invention, the product having an excellent erosion resistance to magnesium and sufficient rigidity can be obtained. More particularly, a metal mold for processing magnesium in which erosion can be prevented in magnesium casting etc. can be obtained.

Effects of the Invention

[0030] The present invention can provide a multicomponent alloy, and an alloy member and a product using the alloy member, in which the alloy is resistant to magnesium, especially having resistance to erosion and mechanical strength, during processes such as casting of magnesium alloys.

BRIEF DESCRIPTION OF DRAWINGS

[0031] FIG. **1** is a profile of adsorption energy versus a short-side lattice mismatch with Mg.

[0032] FIG. **2** is a graph showing Rockwell hardness (HRC) of samples.

[0033] FIG. **3** shows a structural photograph and element mappings of Sample No. 2.

[0034] FIG. **4** shows a structural photograph and element mappings of Sample No. 13.

DETAILED DESCRIPTION

[0035] Hereinafter, an embodiment of the present invention will be described with reference to the accompanying drawings. To obtain resistance to molten magnesium alloys (hereafter, simply referred to as 'magnesium resistance'), the embodiment is to hardly react with magnesium alloys in a molten state, for example. Thus, for the non-reactiveness to molten magnesium alloys, which is regarded highly in the present invention, it is important to make sure that magnesium adsorption is difficult (magnesium can hardly approach) and magnesium intrusion is difficult (magnesium can hardly spread from surfaces).

[0036] Difficulty of magnesium adsorption is expressed as how low adsorption energy (may also be referred to as detachment energy), such as the one disclosed in Non-Patent Document 5, is: the lower the adsorption energy is, the harder the adsorption becomes. The adsorption energy is found by calculation, and a method for the calculation will be described below.

[0037] Dominant factors of the adsorption energy are lattice constants and a lattice mismatch, which is a relative difference between the lattice constants, as shown in Non-Patent Document 6, for example. That is, the lattice constants and the lattice mismatch, which is the relative difference between the lattice constants, are more dominant factors than other factors such as surface energy, cohesive energy, and electronegativity. Thus, the inventor of the present invention has paid attention to the lattice mismatch, which is the relative difference between the lattice constants, and then has found out that, by using a material having the large lattice mismatch with magnesium, it is possible to obtain magnesium resistance, especially an excellent erosion resistant property. The lattice mismatch is sometimes referred to as lattice inconsistency and can be found by calculation. A method of the calculation will be described below.

[0038] As an example in which the lattice mismatch is paid attention to in the conventional field of metal materials, Non-Patent Document 5 describes bonding strength such as interface strength between a wiring film and a barrier film of an electron component, in which an attempt to reduce the lattice mismatch as much as possible, ideally to zero, has been made. Contrary to the above, the present invention aims to obtain magnesium resistance, i.e. non-reactiveness to molten magnesium, by increasing the lattice mismatch, which is an idea opposite to the conventional one.

[0039] It is also important, to enhance the resistance, that the molten magnesium does not intrude from surfaces and react with the alloy. Difficulty of magnesium intrusion is evaluated by a diffusion coefficient from the surface to the inside. Results of a study on relationships between the lattice mismatch and the magnesium diffusion coefficients of some alloys show that the larger the lattice mismatch is, the more the adsorption energy and the magnesium diffusion coefficients (hereafter, may be simply referred to as diffusion coefficients) can be suppressed. The magnesium diffusion coefficient can be found by calculation, and a method for the calculation will be described below.

[0040] Also, preferably, the alloy hardly deforms and thus the alloy hardly fractures. For example, when a cycle time is shortened to increase productivity in die-casting, a mold is repeatedly exposed to high and low temperatures many times and thus heat stress may be concentrated. Thus, as a material, mechanical strength is preferably high. In general, deformation of a metal such as an alloy is expressed by dislocation movement; and how hard it is to deform, i.e. the mechanical strength of the metal, is expressed by how hard the dislocation movement is. That is, as shown in Non-Patent Document 4, for example, the mechanical strength of a metal is represented by dislocation movement barrier energy, and the higher the dislocation movement barrier energy required for dislocation movement is, the more

difficult the deformation is and the higher the mechanical strength is. Thus, in the present invention, the dislocation movement barrier energy has also been paid attention to. Details of a method of calculation of the dislocation movement barrier energy etc. will be described below.

[0041] Next, an alloy according to the embodiment of the present invention will be described in detail. FIG. **1** is a profile showing a relation between a lattice mismatch with magnesium (hereafter, simply referred to as the lattice mismatch) and magnesium adsorption energy (hereafter, simply referred to as adsorption energy) of several different metal elements. FIG. **1** shows that if the lattice mismatch increases, the adsorption energy decreases. In particular, if the lattice mismatch is 13% or more, the adsorption energy is sufficiently low without much further decline. Thus, the lattice mismatch is preferably 13% or more.

[0042] On the other hand, with only an element system having the lattice mismatch of 13% or more, it is hard to obtain sufficient hardness (mechanical properties). Thus, to obtain sufficient hardness with certainty, studies have been made on a multiple element system to build a bec structure with sufficient hardness by using inner distortion effects. As a result, it has been found out that a multiple element alloy including Fe, Cr, and V as main constituents (Fe, Cr, and V alone occupy 50 at % or more) with the relatively large lattice mismatches have excellent properties. Table 1 shows each composition range of the alloy according to the present embodiment.

TABLE 1

	Fe	Cr	V	B	Mn	Co	Ni	Si	Ge	Ru	(at %) Pd
1	25-45	25-45	25-45								
2	10-25	10-25	10-25		10-25	10-25					
3	10-25	10-25	10-25		10-25		10-25				
4	10-25	10-25	10-25		10-25			10-25			
5	10-25	10-25	10-25			10-25	10-25				
6	10-45	10-45	10-45	1-60							
7	10-25	10-25	10-25	1-60	10-25	10-25					
8	10-25	10-25	10-25	1-60	10-25		10-25				
9	10-25	10-25	10-25	1-60	10-25			10-25			
10	10-25	10-25	10-25	1-60		10-25	10-25				
11	10-25	10-25	10-25		10-25				10-25		
12	10-45	10-45	10-45					10-25		10-25	
13	10-25	10-25	10-25					10-25			10-25
14	10-25	10-25	10-25	1-60	10-25				10-25		
15	10-25	10-25	10-25	1-60				10-25		10-25	
16	10-25	10-25	10-25	1-60				10-25			10-25

[0043] The alloy according to the present embodiment includes, as a first element group, Fe, Cr, and V. Also, as a second element group, the alloy may further include one or more types selected from a group consisting of Mn, Co, Ni, Si, Ge, Ru, and Pd. When a total is 100 at % (the same applies hereafter), an amount of each of the elements included in the first element group is 10 at % or more and 45 at % or less (at %:element ratio; hereafter, written as 10-45 at %). Also, if the second element group is included, an amount of each element included in the second element group is 10-25 at %. Furthermore, if the alloy is to be used as a mold, thermal conductivity of the alloy is preferably high to obtain a sufficient cooling speed with certainty. For this reason, B may be added such that an element ratio thereof is 1-60 at %, preferably 10-45 at %, or more preferably 14-40 at %. Also, it is preferable that B is included 1.5 times, or more preferably 2 times or more, an amount of each element of the first element group or the first and second element groups.

[0044] The ranges of the element ratios of the first and second element groups are acknowledged as content amounts of elements constituting a high entropy alloy. If the second element group is not included, it is more preferable that each element of the first element group is included at 25-45 at %. Also, the element ratios of all the elements constituting the alloy may be equal. The alloy according to the present embodiment may include, other than the first and second element groups, unavoidable impurities as remainder. For example, 500 ppm or less each of unavoidable impurity elements such as C, N, and O may be included. The high entropy alloy in the present description is meant to have a maximum of 45 at % or less, or more preferably a maximum of 34 at % or less, of each element.

[0045] Next, each items to be evaluated for the alloy according to the present embodiment will be described in detail.

(Lattice Mismatch)

[0046] As mentioned above, it is preferable that the alloy according to the present embodiment has the small adsorption energy and the small diffusion coefficient to prevent reacting with magnesium approaching surfaces thereof or even intruding therein. For this reason, the lattice mismatch with Mg is to be 13% or more.

(Dislocation Movement Barrier Energy)

[0047] In general, deformation of a metal is represented by dislocation movement: how hard it is to be deformed, i.e., mechanical strength of the metal, is represented by how hard the dislocation movement is. Thus, as shown in Non-Patent Document 4, for example, mechanical strength of a metal is represented by dislocation movement barrier energy. If the dislocation movement barrier energy is large, hardness, which will be described below, increases. For the alloy according to the present embodiment, the dislocation movement barrier energy (dislocation movement barrier energy at 800° C., for example) is preferably 300 kJ/mol or higher.

The dislocation movement barrier energy is one of indicators that show the mechanical strength of the alloy according to the present embodiment.

(Magnesium Adsorption Energy)

[0048] To enhance resistance to molten magnesium, or in other words, to be non-reactive to magnesium when in contact with magnesium in a molten state, it is important to have a state in which it is hard for magnesium to approach and adsorp. How easy it is for magnesium to adsorp can be evaluated by the above-mentioned adsorption energy: the smaller the adsorption energy is, the more difficult it is to adsorp. Details will be described along with simulations described below.

[0049] The adsorption energy (adsorption energy at 800° C., for example) of the alloy according to the present embodiment is 0.2 J/m^2 or less. The adsorption energy can be considered as one of indicators that show magnesium resistance. Thus, in the present embodiment, the adsorption energy is preferably 0.2 J/m^2 or less. The adsorption energy in the present embodiment is more preferably 0.15 J/m^2 or less, further preferably 0.1 J/m^2 or less, or furthermore preferably 0.08 J/m^2 or less.

(Magnesium Diffusion Coefficient)

[0050] To improve the resistance of the alloy, it is important that molten magnesium does not intrude from the surface and react with the alloy. How easy it is for magnesium to intrude can be evaluated by a coefficient of diffusion from the surface to the inside. The diffusion coefficient can be considered as one of indicators that show magnesium resistance. Details of the diffusion coefficient will be described below.

(Hardness)

[0051] Hardness of the alloy according to the present embodiment at a normal temperature is preferably 430 or higher in terms of Vickers hardness (HV). Hardness is one of indicators that show the mechanical strength of the alloy according to the present embodiment.

(Crystal Structure)

[0052] Crystal structures of the alloy according to the present embodiment are all in body-centered cubic structures (BCC). The crystal structures can be observed under an X-ray diffraction (XRD). The alloy may have a single type of the BCC structure or multiple types of the BCC structures. Also, it is most preferable that an entire system of the alloy according to the present embodiment includes the body-centered cubic structures.

[0053] However, the system of the alloy may include, as a volume ratio (content ratio), 60% or more, or more preferably 80% or more, of the body-centered cubic structures.

[0054] Next, the calculation method for each item in the present embodiment will be described. Each item can be calculated by using molecular dynamics simulation as disclosed in Non-Patent Document 1, etc.

(Calculation Method for Lattice Mismatch)

[0055] Lattice constants for calculating the lattice mismatch are defined as follows based on Non-Patent Document 5. That is, mismatches of a short side lattice constant 'a' and a long side lattice constant 'b' of a face-centered rectangular lattice, which represents a plane with the highest atomic density, i.e., the closest-packed crystal plane described below, are expressed in percentages, and the short side lattice mismatch is represented by Δ a and the long side lattice is represented by Δ b. Since Δ a having a shorter interatomic distance is more important, Δ a is considered as the lattice mismatch in the present embodiment, unless otherwise specified.

[0056] However, in cases of SKD61 and nitrides thereof mentioned below as comparison examples, while the short side magnesium lattice mismatch Δ a is as small as approximately 2% or less, the long side lattice mismatch Δ b is as large as 16% or more, and thus an arithmetic mean value between Δ a and Δ b are taken as the lattice mismatch. In a case of a body-centered cubic structure, the closest-packed crystal plane is (110) plane, and a ratio of the short side a to the long side b is approximately $1:\sqrt{2}$. On the other hand, magnesium as a counter material has a stable crystal structure of a hexagonal closest-packed structure (hcp) at a normal temperature and at a normal pressure, and the body-centered cubic structure becomes stable at higher temperatures. For example, the closest-packed crystal plane of the hexagonal closest-packed structure is (0001) plane, and the ratio of the short side 'a' to the long side 'b' is approximately $1:\sqrt{3}$. Note that it is known from Non-Patent Document 5 etc. that crystal planes other than the closest-packed crystal plane defined here contribute less to the adsorption energy and have fewer effects. Thus, the closest-packed crystal plane is taken as a basis for the decision.

[0057] To calculate the lattice mismatch defined above, the above-mentioned 'a' and 'b' can be calculated by performing relaxation calculations and finding a stable crystal structure using a molecular dynamics simulation such as the one described in Non-Patent Document 5, and the lattice mismatch can be calculated based thereon. The lattice constant and the lattice mismatch are calculated using self-made molecular dynamics software, and in parallel, calculations are performed using Dmol3 and Forcite of Dassault Systemes' Materials Studio, and it was confirmed that both the results are consistent with each other.

(Calculation Method for Dislocation Movement Barrier Energy)

[0058] As shown in Non-Patent Document 4, for example, mechanical strength of a metal can be represented by dislocation movement barrier energy. The dislocation movement barrier energy is a barrier energy to be overcome while changing from a state before the dislocation movement to a state after the dislocation movement, and can be calculated by a molecular dynamics simulation, similarly as a method shown in Non-Patent Document 4, for example. The barrier energy is calculated using self-made molecular dynamics software, and in parallel, calculations are performed using Dmol3 and Forcite of Dassault Systemes' Materials Studio, and it was confirmed that both the results are consistent with each other.

(Calculation Method for Adsorption Energy)

[0059] Adsorption energy represents energy required to change an adsorption state into a detached state, and the adsorption energy can be obtained by, as shown as an

equation (3) in Non-Patent Document 3, subtracting energy of the adsorption state from energy of the detached state. The adsorption energy is calculated using self-made molecular dynamics software, and in parallel, calculations are performed using Dmol3 and Forcite of Dassault Systemes' Materials Studio, and it was confirmed that both the results are consistent with each other. The higher the adsorption energy is, the easier the adsorption is.

(Calculation Method for Diffusion Coefficient)

[0060] The diffusion coefficient can be found, as shown as an equation (2) in Non-Patent Document 2, from the following Einstein relation: Equations 1 (a equation (A) and a equation (B)).

(Equations 1)

$$D = \lim_{t\to\infty} D(t) \quad \text{(A)}$$

$$D(t) = \langle [r_i(t + t_0) - r_i(t_0)]2\rangle / 6t \quad \text{(B)}$$

[0061] In the equation (B), a mean-square displacement from a time t_0, which is a reference time set after sufficient relaxation, to a time $t+t_0$ is divided by 6t, converging in limited time steps in reality. Thus, the diffusion coefficient can be calculated without calculating up to infinity. Note that $r_i(t+t_0)-r_i(t_0)$ can be calculated from a motion equation. When calculating the diffusion coefficient for intrusion in a direction perpendicular to an interface, the diffusion coefficient can be calculated from the mean square displacement of the displacement in that direction. The larger the diffusion coefficient is, the easier the intrusion is. This means that molten magnesium easily intrudes from the surface and reacts, or in other words, erosion can easily occur.

(Results of Calculation)

[0062] Next, each alloy according the present embodiment will be described. Table 2 shows results of the calculation of the lattice mismatch with Mg, the dislocation movement barrier energy, and Mg adsorption energy of nine types of alloys according to the present embodiment. Each alloy consists of components of all equal element ratios. For example, if the alloy consists of three elements, each composition element is included at an element ratio of 33.3 at %; if the alloy consists of five elements, each composition element is included at an element ratio of 20 at %; and if the alloy consists of six elements, each composition element is included at an element ratio of 16.6 at %. Also, as comparison examples, the same calculations are performed on SKD61 (JIS G 4404), which is an alloy tool steel for hot-working molds, SKD61 of which surface is nitride treated, and a PdRuZn alloy (equal element ratios). The calculation results of the diffusion coefficient, hardness, thermal conductivity, etc. of Mg in the alloys are omitted.

TABLE 2

	Alloy *	Mg Lattice Mismatch (%)	Dislocation Movement Barrier Energy (kJ/mol)	Mg Adsorption Energy (J/m^2)
Working Examples	VCrFeMnCoNi	13.2	323	0.0762
	VCrFeCoNi	13.5	343	0.0745
	VCrFeMnCo	13.1	316	0.0769
	VCrFeMnNi	13.3	314	0.0755
	VCrFeMnSi	13.4	319	0.0751
	VCrFeMnGe	13.6	304	0.0741
	VCrFeSiRu	13.2	362	0.0763
	VCrFeSiPd	13.3	356	0.0754
	VCrFe	13.1	311	0.0767
Comparison Examples	SKD61	11.53	346	0.273
	SKD61(nitrization)	11.24	354	0.236
	PdRuZn	16.8	137	0.0726

* If the alloy consists of three elements, each composition element is included at an element ratio of 33.3 at %; if the alloy consists of five elements, each composition element is included at an element ratio of 20 at %; and if the alloy consists of six elements, each composition element is included at an element ratio of 16.6 at %.

[0063] Also, instead of a magnesium element, the same calculations are performed on KUMADAI magnesium alloy (Mg—Al—Ca) ("KUMADAI magnesium alloy" is a registered trademark). The results are shown in Table 3.

TABLE 3

	Alloy *	Mg Alloy Lattice Mismatch (%)	Dislocation Movement Barrier Energy (kJ/mol)	Mg Adsorption Energy (J/m^2)
Working Examples	VCrFeMnCoNi	14.3	323	0.0757
	VCrFeCoNi	14.6	343	0.0738
	VCrFeMnCo	14.2	316	0.0762
	VCrFeMnNi	14.4	314	0.0748
	VCrFeMnSi	14.5	319	0.0744
	VCrFeMnGe	14.7	304	0.0733
	VCrFeSiRu	14.3	362	0.0756
	VCrFeSiPd	14.4	356	0.0747
	VCrFe	13.2	311	0.0761
Comparison Examples	SKD61	12.5	346	0.271
	SKD61 (nitrization)	12.2	354	0.234
	PdRuZn	18.3	137	0.0719

* If the alloy consists of three elements, each composition element is included at an element ratio of 33.3 at %; if the alloy consists of five elements, each composition element is included at an element ratio of 20 at %; and if the alloy consists of six elements, each composition element is included at an element ratio of 16.6 at %.

[0064] In all calculations, the results show that all the alloys according to working examples have sufficient properties in that the lattice mismatch with Mg is 13% or more, the dislocation movement barrier energy is 300 kJ/mol or more, and the Mg adsorption energy is 0.2 J/m^2 or less (0.08 J/m^2 or less). On the other hand, the conventional SKD61 alloy has a small Mg lattice mismatch of less than 13%, and the Mg adsorption energy of more than 0.2 J/m^2, regardless of the nitride treatment. Also, for the PdRuZn alloy that does not include the first element group but includes mainly the second element group, although the lattice mismatch with Mg of 13% or more and the Mg adsorption energy of 0.2 J/m^2 or less (0.08 J/m^2 or less) are satisfied, the dislocation movement barrier energy is less than 300 kJ/mol and sufficient strength cannot be obtained.

[0065] Next, some of the alloys are used for additive manufacturing in practice, and structures etc. thereof are observed.

[0066] As shown in Table 4, powdered bodies with alloy compositions of No. 1-No. 13 are prepared and additively manufactured by a directed energy deposition (DED) method. The manufactured products are shown in Table 4. Regarding the compositions of the products shown in Table 4, No. 1 and No. 2 include 33.3 at % each of Fe, Cr, and V as the first element group. Also, No. 3 to No. 7, No. 14, and No. 15 include 20 at % each of Fe, Cr, and V as the first element group and 20 at % each of two types selected from Mn, Co, Ni, and Si as the second element group. Also, No. 8 and No. 9 further include 40 at % of B in addition to 20 at % each of Fe, Cr, and V. Also, No. 10 to No. 13 include 14.3 at % each of Fe, Cr, and V as the first element group and 14.3 at % each of two types selected from Mn, Co, Ni, and Si as the second element group, and further include 28.6 at % of B.

TABLE 4

No.	Product Composition *	Laser Output (W)	Scanning Speed (mm/min)
1	VCrFe	2000	800
2		2400	800
3	FeCrVMnSi	2400	800
4		1700	400
5	FeCrVMnCo	1500	400
6	FeCrVMnNi	1500	400
7	FeCrVMnSi	1500	400
8	$FeCrVB_2$	2000	400
9		2400	400
10	$FeCrVB_2MnSi$	1500	400
11		2400	400
12	$FeCrVB_2CoNi$	2200	400
13		1800	400
14	VCrFeCoNi	2200	400
15		1800	400

* No. 1, 2: 33.3 at % each

No. 3-7, 14, 15: 20 at % each

No. 8, 9: 20 at % each, except for 40 at % of B

No. 10-12: 14.3 at % each, except for 28.6 at % of B

[0067] With the above conditions, sound products without cavities can be obtained for No. 1, 2, 8, 12, and 13.

[0068] FIG. **2** shows Rockwell hardness (HRC) of some of the samples. Although there are differences due to alloy compositions, hardness of at least 37 or more of Rockwell hardness (HRC=37 or higher) can be obtained.

[0069] Also, as an example, FIG. **3** shows a structure image and element mappings of No. 2, and FIG. **4** shows a structure image and element mappings of No. 13. As shown in FIG. **3**, in the product having FeCrV composition, although there is some segregation shown, all the elements are melted and turned into an alloy. On the other hand, as shown in FIG. **4**, in the product having $FeCrVB_2CoNi$ composition, VB_2 added as powder did not melt and are dispersed as particles. Also, an overlap between the mappings of VB_2 and Cr is shown.

[0070] Next, erosion test pieces are produced from the products having alloy compositions of No. 2 and No. 8, and the test pieces are tested for erosion to Mg. Each of the erosion test pieces is in a cylindrical shape having an outer diameter of 13, an inner diameter of 5.5 and a height of 3.5. As a comparison, the same erosion test is performed on a erosion test piece (No. 0) made from SKD61 with a nitride treated surface, which is a hot-working tool steel used generally as Mg die-casting molds. SKD61 has Rockwell hardness of 45 HRC and the surface thereof is nitride treated of a thickness of 50 μm.

[0071] The produced erosion test pieces are mounted and immersed in Mg alloy of 99% purity, which has been melted in a fusion furnace. The erosion test pieces are immersed for an hour while stirring the Mg alloy with a stirring rod rotating at a speed of 116 rotations/min. A temperature of the molten metal is set between 936K and 961K. The erosion test evaluates an erosion rate. The erosion rate is calculated by: erosion rate (%)=(mass before the test-mass after the test)/mass before the test×100. The results are shown in Table 5.

TABLE 5

								Mass [g]		Erosion
	Sample	Composition [at %]						Before	After	Rate
No.	Names	Fe	Cr	V	Co	Ni	B	Test	Test	[%]
0	SKD61 with nitrization	Compositions and methods for manufacturing conform to JISG4404						2.4049	2.3982	0.2778
2	FeCrV	Bal.	33.3	33.3				2.2409	2.2409	0.0393
8	$FeCrVB_2$	Bal.	20	20			40	2.0585	2.0558	0.1287

[0072] The results of the Mg erosion tests are shown in Table 5. As shown in Table 5, the erosion rates are 0.0393% for No. 2, 0.1287% for No. 8, and 0.2778% for No. 0, which is the comparison example of SKD61 with surface nitride treatment. Also from the results of the erosion tests, it is confirmed that, compared to No. 0 that is supposed as a conventional material, alloys such as No. 2 including 10-45 at % each of Fe, Cr, and V as the first element group, and No. 8 including 10-45 at % each of Fe, Cr, and V as the first element group and 0.5-60 at % of B have excellent Mg erosion resistance.

[0073] As above, the alloy according to the present embodiment can be applied to an alloy member that at least partly includes the alloy (e.g., as a surface of a base material), and to a product that at least partly includes the alloy member. More specifically, it is preferable that the alloy is applied to a metal mold used for processing magnesium. For example, for a magnesium die-casting mold that can be manufactured by emitting an electron beam or a laser beam onto alloy powder having a desired element ratio to be melted and solidified, the alloy according to the present embodiment may be formed at least on a surface of the mold so that it is possible to obtain a magnesium die-casting mold in which erosion etc. with magnesium can be prevented.

[0074] Although the embodiments of the present invention have been described referring to the attached drawings, the technical scope of the present invention is not limited to the embodiments described above. It is obvious that persons skilled in the art can think out various examples of changes or modifications within the scope of the technical idea disclosed in the claims, and it will be understood that they naturally belong to the technical scope of the present invention.

1. An alloy comprising:
10 at % or more and 45 at % or less each of Fe, Cr, and V as a first element group, wherein
a lattice mismatch with Mg is 13% or more; and
dislocation movement barrier energy is 300 kJ/mol or more.

2. The alloy according to claim **1**, further comprising:
10 at % or more and 25 at % or less each of one or more types of element selected from a group consisting of Mn, Co, Ni, Si, Ge, Ru, and Pd, as a second element group.

3. The alloy according to claim **1**, further comprising:
0.5 at % or more and 60 at % or less of B.

4. The alloy according to claim **1**, wherein Mg adsorption energy is 0.2 J/m2 or less.

5. An alloy member comprising:
at least partly an alloy comprising:
10 at % or more and 45 at % or less each of Fe, Cr, and V as a first element group, wherein
a lattice mismatch with Mg is 13% or more; and
dislocation movement barrier energy is 300 kJ/mol or more.

6. The alloy member according to claim **5**, wherein
the alloy further comprising:
10 at % or more and 25 at % or less each of one or more types of element selected from a group consisting of Mn, Co, Ni, Si, Ge, Ru and Pd as a second element group.

7. The alloy member according to claim **5**, wherein Mg adsorption energy of the alloy is 0.2 J/m2 or less.

8. A product comprising:
at least partly the alloy member according to claim **5**.

9. The product according to claim **8**, wherein the product is a metal mold for processing magnesium.

10. The alloy according to claim **2**, further comprising:
0.5 at % or more and 60 at % or less of B.

* * * * *