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AIR FORCE SYSTEMS COMMAND

RARE-EARTH METALS AND THEIR APPLICATIONS IN AVIATION

by

Zhu Changzhong and Li Zhonghan

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RARE-EARTH METALS AND THEIR APPLICATIONS IN AVIATION

Zhu Changzhong and Li Zhonghan

Abstract

Rare-earth metals have many outstanding properties and special qualities and they have very extensive applications. Since the 1950's with the realization of industrialized production, development has been rapid and various nations have given their serious attention. China has vast rare-earth natural resources and it is known to be the nation with the greatest store of rare-earth natural resources in the world. The applications of rare-earth metals have a bright future in aviation. The full use of these natural resources will accelerate the development of the aviation industry which has great significance for strengthening natural defense construction and catching up with and surpassing the advanced international level.

Although rare-earth metals are not as common as iron and steel which are visible everywhere, yet they are not unfamiliar to us. We often encounter them in everyday life.

When you see an excellent revolutionary film and are educated by it, there is the "credit" of rare-earth metals within it because the arc lamp in the film projector relies on the aid of rare-earth luminescent agent and thus the light rays are able to be so bright and natural.

When you watch color television and see such a brightly colored red flag, the sparkling red star or the flame in front of Tian An Men Square on National Day, you will perhaps not think that the dazzling red light is emitted by the compound of the rare-earth metals of yttrium and europium.

Even more commonly seen is the flint of a lighter. It is an alloy of rare-earth metal and iron. It contains about 30% iron and the remainder is a composite rare-earth alloy primarily of cerium and trace impurities. Flint mainly uses rare-earth metals with low catching fire point properties and the scraped off flying bits are very quickly heat ignited (Fig. 1).

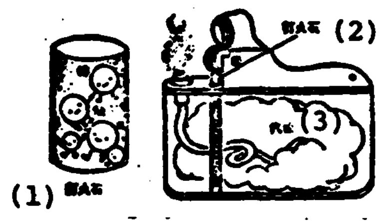

Fig. 1 The flint of a lighter.
Key: (1)-(2) Striking flint; (3) Gasoline.

Rare-earth metals can also be used to manufacture the detonators of bullets and shells as well as the pyrophoric alloys of firing devices. This type of alloy has a 49.5% content of the rare-earth element cerium, 44% lanthanum and neodymium, 4.5% steel, 0.5% aluminum and the remainder is calcium, silicon and carbon. This is because the lanthanium cerium etc. elements have the special feature of "impingement combustibility." Rare-earth metals are very valuable natural materials and in recent years their applications have been extended to various departments of the national economy. Iron and steel workers like them because adding a very small amount of rare-earth element into molten steel is advantageous for deoxidation, desulphurization, eliminating gases, reducing the effects of harmful elements and greatly raising the quality of steel; the strength of rare-earth alloys is high and heat resistance is good. Petroleum workers like them. They use chemical compounds of rare-earth materials to carry out catalytic splitting and the extraction of gasoline from petroleum is one hundred times greater than when using the activation of silicon-aluminum catalysts. Poor and lower-middle peasants like them. In agriculture, it is only necessary to add a very small amount of rare-earth element compound into soil to be able to greatly increase agricultural production. Medical personnel like them as they are very effective for curing various types of tumors, arthritis, cancer etc.

The Seventeen Rare-Earth Metals

When we open up a chemistry book and look at the periodic table of chemical elements already discovered, if we calculate using 105 elements, then rare-earth elements occupy one-sixth of them. Rare-earth elements is a general term for a class of metal elements and are therefore also called rare-earth metals. They include the 15 elements from lanthanum with the atomic number of 57 to lutetium with the atomic number of 71. In chemistry, they are called the fifteen elements of the "lanthanum system." Adding in the elements which have similar chemical properties to lanthanum, scandium with the atomic number of 21 and yttrium with the atomic number of 39, we have a total of 17 elements. Their names are: lanthanum, cerium, praseodynium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium and yttrium.

Based on the properties and atomic structures of these elements as well as their intergrowth distribution in minerals, rare-earth elements are commonly divided into two groups: the first group is called "light rare-earth" and includes cerium, lanthanum, neobium, samarium, praseodymium and europium; the other category is called "heavy rare-earth" and includes gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium as well as scandium and yttrium. Aside from these, promethium is an artifical element, it has radioactivity and is almost non-existent in the earth's crust.

The term "rate-earth" has been used for the last 150 years since the discovery of rare-earth elements of the end of the eighteenth century. Actually, they are not "rare" and do not resemble "earth." Rare-earth elements often coexist in minerals in small quantities in the natural world. Because the chemical properties and atomic structures of rare-earth elements (e.g. the lanthanum system) are somestimes very similar, this determined the very diffcult separation between these substances. Sweden, in Northern Europe, was the place where the earliest rare-earth elements were discovered. In 1794, "yttrium-earth" was discovered in a silicon-beryllium-yttrium ore in Sweden. This "yttrium -earth" was actually not a single substance but a mixture of many rare-earth oxides. The technical level at that time was unable to further separate them and what was obtained was only a type of oxide which did not dissolve in water. At that time, this type of oxide was customarily called "earth" and it was the same as aluminum oxide which was called "aluminum earth" and calcium oxide which was called "alkaline-earth." This type of oxide which is difficult to extract and which externally resembles alkaline-earth metals was called "rare-earth." It has now been ascertained that there are over 250 types of minerals in the natural world which contain rare-earth elements and among these there are 60 to 65 types of minerals (about 5% to 8%) which contain large quantities of them. The average abundance in the earth's crust is 0.016 which is several times and even several ten and several hundred times that of commonly seen copper, tin, lead, zinc, silver, mercury, molybdenum and tungsten. We therefore say that "rare-earth" is not rare.

"The history of mankind is one of continuous development from the realm of necessity to the realm of freedom." Following advancements in science and technology, a method to separate rare-earth elements was finally found. Since the 1950's, the use of the ion exchange method and solution extraction method for separation and purification have been successful in obtaining highly pure single rare-earth elements, realizing industrialized production and thus greatly decreasing the cost for manufacturing and extracting rare-earth metals and their compounds and for expanding research work. At present, the various manufactured single rare-earth metals in no way resemble "earth." They are the same as typical metals as they possess the luster of metals and have excellent malleability and electroconductivity. However, because this name has been used for so long throughout history, they are still customarily called "rare-earth elements," "rare-earth metals" or abbreviated are "rare-earth." China has vast territory and abundant resources and its underground mineral store is extensive. Since liberation, under the guidance of the revolutionary line of Chairman Mao, China's broad working class and scientific and technical personnel have been self-reliant, have worked hard for the prosperity of the country and exerted themselves in tapping underground precious mineral deposits. It has been established that China's rare-earth resources are widely distributed, there are vast numbers of mineral types which contain rare-earth and at present it is known that China has the largest rare-earth reserves in the world. China's rare-earth industry emerged during the Great Leap Forward in 1958 and grew to maturity during the Cultural Revolution of the Proletariat. At present, aside from being used in the metallurgy industry, the various rare-earth products produced by China itself have been widely used for glass polishing materials, laser materials, luminescent materials, electronic materials, electric light source-materials, rare-earth permanent magnetic materials as well as for the manufacture of rare-earth glass with special optical properties.

The Properties of Rare-Earth Metals

Rare-earth metals are all typical metals. Their external appearance is a silver gray metallic luster while its internal structure is a metal lattice. The electroconductivity of pure rare-earth metals is strong and the electroconductivity decreases with the decreases of the metal's purity. Under ultra-low temperatures (-268.78°C), they have ultra-conductivity. Under normal atmospheric temperature, rare-earth metals and their compounds have paramagnetism, the magnetic susceptibility is very high and samarium, gadolinium and dysprosium have ferromagnetism. Their malleability (i.e. plasticity) is very good and the plasticity of ytterbium and europium are best. At room temperature, pure rare-earth metals can be forged, rolled and carry out cold machining and hot machining. Their melting points follow the law of rising with the increases of the atomic number, the melting point of cerium is lowest being 800°C and the melting point of lutetium is highest being 1700°C.

The chemical properties of rare-earth metals are very similar. This is because their atomic structures are very similar. Their chemical properties are very reactive and can chemically combine with oxygen, sulphur, halogen etc. and therefore very easily oxidize in air. That is, under relatively low temperatures, they can produce chemical reactions with hydrogen, carbon, nitrogen and phosphorus.

The Vitamins of Aviation Metals

Although the amount of vitamins used by people is small, yet they play a major role in people's lives. We can use rare-earth" to draw an analogy to the vitamins in metals. Although their added quantities are not great, the effects are very noticeable and they can be used as the additives, reducing agents, desulphurization agents, denaturization agents and regulating agents etc. of metals.

Rare-earth metals seem to have excellent effects on nonferrous metal alloys and they can improve the physical and mechanical properties of alloys. Their increased content range is very wide, from 0.003-0.5% to 8-10%, and when the increase is suitable we can obtain light weight and high strength alloys. This is especially important for aviation materials.

Rare-earth magnesium alloys. The adding of rare-earth metals into magnesium alloys can cause alloy purification, improve alloy structure, raise the heat resistance of alloys and their mechanical properties at room temperature. They can increase the fluidity and reduce the microporosity in cast alloys. This cannot only raise the casting quality but is very advantageous for production. When most magnesium alloys exceed temperatures of 150°C, its strength drastically decreases but if we add rare-earth metals, the working temperature can reach to about 250°C. For example, at less than 204°C, magnesium alloys containing 2.5% composite rare-earth, 2.5% zinc and 0.6% zirconium have excellent tensile strength and anti-creeping properties. They can be used for many parts of jet engines. Figure 2 is a rare-earth magnesium alloy casting used to make an engine casing. The normal temperature strength of another rare-earth magnesium alloy with dysprosium (1.2-3.0% dysprosium, 2-3% silver and 0.7% zirconium) is not inferior to that of the above mentioned magnesium-zinc system alloys. Its heat resistance properties are even better, its casting properties are good, it does not produce casting defects and it is suitable for making high grade aviation castings and its application is daily increasing in aircraft, rockets, missiles and artificial satellites. At present, there is a new type of rare-earth cast magnesium alloy. The castings do not have microporosity, they possess high fatigue strength, the working temperature can reach 166°C and they can be used for helicopter structural materials, transmission castings and engine wheels and gear boxes etc.

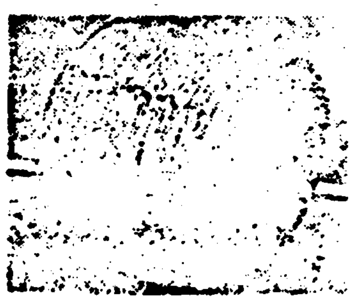

Fig. 2 Large-scale magnesium alloy casting with rare-earth (engine casing).

Rare-earth aluminum alloys. Because the atomic radii of rare-earth metals are much larger than that of aluminum and can form a compound with a high melting point and great hardness with aluminum, it is therefore an excellent alloying element of aluminum. Use of rare-earth metals can refine the structure of the aluminum alloy, raise the fluidity of the liquid state metal, reduce the gas hole looseness and improve the heat resistance and mechanical properties. For example, the addition of aluminum alloy with 2% rare-earth metal can cause the hardness to be nearly double that of pure aluminum; in aluminum alloy with 5% yttrium and cerium, the hardness can be raised two fold. This type of aluminum alloy can be used to make jet engine, rocket, missile etc. parts.

Rare-earth heat-resisting alloys. Rare-earth metals can not only raise the creep rupture strength and elongation of heat-resisting alloys but are also effective for improving the high temperature anti-oxidation properties. Adding small quantities of yttrium, tantalum and hafnium into steel-cadmium-nickel superalloy raises the alloy's high temperature anti-oxidation properties to 1260°C. The addition of 0.1% to 0.2% yttrium in cobalt base alloys and the addition of lanthanum or cerium in nickel-base alloys can raise the corrosion resistance of turbines used for boats ten times.

Titanium alloys. The addition of lanthanum can raise the tensile strength 50%.

Rare-earth structural steel. The addition of cerium-iron nickel-chromium-molybdenum and the chromium-nickel-vanadium structural steel can lower the sulphur content from 0.02% to 9.05% and noticeably raise the low temperature brittleness of steel plates. Moreover, the addition of rare-earth into nickel-chromium-molybdenum steel can prevent white spot defects from easily appearing in large-scale products and thus raise the quality of the steel plates.

The Applications of Rare-Earth Metal Compounds In Aviation

Glass with rare-earth compounds added in makes a special type of glass which can pass through infrared rays, absorb ultraviolet rays and resist x-ray and gamma-ray radiation.

Solid solutions composed of 90% Y_2O_3 and 10% ThO_2 make glass ceramic with special transparency which can be used at temperatures above 1900°C for the window glass of ultraviolet ray reflectors and high temperature combustion chambers.

Rare-earth sulfides (e.g. Ce_2S_2), lanthanum system borides (e.g. LaB_8) etc. high melting point substances can be used to make jet aircraft and rocket part materials.

LaH_3 is a thermosensitive material which can emit or absorb hydrogen gas. Its hydrogen content is large and it is made into thyratrons which are used in radar, accelerators and aviation modulators.

The rare-earth-cobalt compound particles are a new type of permanent magnet and among them the samarium-cobalt alloy ($SmCo_5$) has superior magnetic properties and is used to make missile detection accelerators and praseodymium-cobalt alloys are used to outfit satellites, missiles and radar.

Aside from this, rare-earth compounds have gained a great deal of attention in modern aviation technology as garnet materials. For example, yttrium-iron garnets are used in the microwave electronically controlled instruments of unmanned aircraft, the microwave modulators on insulators of radar and other communication systems, satellite communications, amplification circulators, wave filters, microwave integrated circuits and ultra-small wide band oscillators etc. (Fig. 3).

Fig. 3 The applications of rare-earth compounds in aviation.

In recent years, rare-earth products have attained to wide utilization in various areas of China's national economy and the achievements have been inspiring. However, "everything divides into two." Rare-earth has the above mentioned series of outstanding properties, yet if we want their full role to have extensive effects it is necessary to grasp their laws and aside from using suitable added quantities, it is also necessary to carry out deeper and more meticulous technological research. As regards rare-earth alloys, if the technology is inappropriate, the rare-earth can be distributed within the alloy in the form of inclusions and give rise to property lowering effects. Under the guidance of Chairman Mao's revolutionary line of the proletariat, the rare-earth industry of China has developed from nothing and from something small into something great. We believe that in the not to distant future, the scientific research, production and applications of rare-earth in China will necessarily reach a new level and make an even greater contribution to socialist revolution and construction as well as strengthening national defense.