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SPECIAL ALLOYS BASED ON BERYLLIUM FOR MACHINE-BUILDING PARTS

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Abstract
In the nomenclature of structural materials for machinery construction there are a lot of nonferrous metals and alloys which possess special properties: heat resisting, antifriction materials, those for aviation and rocket engineering, etc. The necessity to develop special property alloys is conditioned by the development and improvement of technology: increase of working loads and speeds, expansion of working temperature and pressure range, the necessity to increase the specific strength of traditional engineering materials. Heat resisting materials and titanium-, tantalum-, niobium- and tungsten-based alloys are of a particular interest. The interest of

industrial manufacturers to materials with high specific strength properties has traditionally been high.

Keywords: Beryllium, beryllium-based alloys; half-finished products; high-temperature processing; mechanical properties; heat conduction; alloying beryllium; beryllium-based materials.

1. Introduction

Magnesium- and beryllium-based alloys in a number of cases are an adequate substitution for steels. Antifriction tin-, lead- and zinc-based alloys have been among the most widely used special nonferrous alloys till lately. But due to high cost and insufficient heat resistance of such alloys as well as depletion of resources their share in general consumption of special alloys is decreasing. Modern methods of powder metallurgy, electro-arc and zone melting, etc. are used for production and processing of metals and alloys with special properties.

Beryllium is a steel-grey metal belonging to the second group of Mendeleev's periodic system with melting temperature of 1284°C. There are two polymorphous modifications of beryllium: low-temperature (below 250°C with close-packed hexagonal lattice) and high-temperature (with bbc lattice). Density of beryllium is 1.845 g/cm^3.

Beryllium belongs to rare metals. Its content in Earth crust is about $5\cdot10^{-4}$%. Beryllium metal is obtained by reduction of beryllium fluoride with magnesium at the temperature of 900-1300°C or by electrolysis of beryllium chloride in mixture with sodium chloride. Beryllium is refined to 99.98% by vacuum remelting.

Beryllium atom size is very small (atomic diameter is 0.226 nm) that is why even a small amount of impurities embrittles it considerably. Ductile beryllium with impurity content not exceeding 10^{-4}% is obtained by electrolysis of its chloride melts with following zone melting.

2. Methods

Compact half-finished products are produced using powder metallurgy methods. The smaller the powder grain size is the higher strength and plastic properties of half-finished products are. Beryllium and its compounds in the form of power, dust and vapour are highly toxic; they affect respiratory organs and skin. Finished products containing beryllium are quite safe.

The technology of high-temperature processing of beryllium has its specific features as beryllium is oxidized a lot in the air. When processed by pressure, beryllium half-finished products are placed in steel coatings heating up to 800–1100°C and then processing by pressure. Sheet beryllium which is the main half-finished product for rocket engineering is produced by rolling.

Beryllium is badly processed by cutting and thus requires using special carbide-tipped tooling. Permanent joining of beryllium parts are produced by soldering and arc welding in protective medium.

Mechanical properties of beryllium depend on its purity, production technology and grain size.

Beryllium possesses both the unique combination of physical and mechanical properties and higher specific strength as compared with other lightweight metals (Table 1).

Table 1. Comparative characteristics of nonferrous alloys

Material	σ_B, MPa	γ, g/sm^3	$\sigma_B/(\gamma g)$, km	$E/(\gamma g)\cdot 10^{-3}$, km
Magnesium alloy – MA10	430	1,8	24	2,3
Aluminium alloy – B95	700	2,9	21	2,4
Titanium-based alloy BT6	1500	4,5	22	2,6
Steel – O3H18K9M5T	1750	7,8	23	2,6
Beryllium	680	1,8	38	16,1

3. Results and Discussion

Beryllium has high electrical and heat conduction close to aluminium heat conduction; it exceeds all other metals by specific heat [≈ 2500 J/(kg·K)].

Beryllium is resistant to various types of corrosion. Interacting with air, an oxide film protecting the metal from oxygen effect is formed on the surface of beryllium samples. When the temperature exceeds 700°C, visible signs of gas corrosion can be observed; at 1200°C beryllium metal turns into white oxide powder.

Disadvantages of beryllium are extremely high cost and low cold resistance.

Difficulties in alloying beryllium are caused by small sizes of its atoms. That is why the majority of alloying elements deforms significantly the lattice of beryllium thus increasing its brittleness. It is reasonable to alloy beryllium only with those elements with which it forms mechanical mixtures with minimal mutual solubility.

Alloying beryllium with aluminium increases cold resistance of the former.

In eutectic Al-Be alloys solid particles of beryllium are evenly distributed in ductile aluminium matrix.

The Be-Al alloys have the structure consisting of soft ductile eutectic and solid brittle beryllium inclusions. These alloys combine high rigidity, strength and low density typical for beryllium.

In order to increase their strength, Be-Al alloys are additionally alloyed with magnesium and silver - the elements that are solved in aluminium.

As a result, beryllium matrix acquires higher strength and viscosity rate.

The unique combination of the valuable performance characteristics such as low density, high specific strength and rigidity which remain up to 500-600°C, high heat capacity and heat conduction conditions the predominant usage of beryllium and beryllium-based alloys in aviation and space-rocket hardware.

4. Conclusion

Using beryllium in constructions it is necessary to take into account its brittleness and notch sensitivity at tensile stress influence. That is why beryllium alloys are used in constructions that predominantly work at compression. In rockets and air planes the mass of such parts can make up from 30 to 80 %.

The usage of beryllium ensures three-fold gain in mass compared with aluminium and magnesium alloys, fourfold gain compared with titanium and fivefold one compared with steels. With the temperature rise, the efficiency of beryllium alloys increases. Due to its unique thermal characteristics, beryllium is used in heat-shielding structures of rockets and spaceships. Beryllium and beryllium-based materials are used in production of rocket engine parts including combustion chambers and nozzles which have working temperatures up to 3000°C.

Beryllium-aluminium alloys are used in sheathing of controllable projectile.

Beryllium is used for production of spaceship and satellite antennas, control surfaces of spacecrafts, mirrors of optical telescopes, etc.

Brake disks of airplanes should combine high tribotechnical properties with good thermophysical properties.

Due to high heat capacity and heat conduction beryllium discs of airplanes at slowing-down are heated only to 240°C while steel disks are heated up to 670°C.

High cost and toxicity prevent wide usage of beryllium and berillium-based alloys in mechanical engineering and other branches of industry.

But the unique properties of beryllium will definitely contribute to the expansion of its fields of application.

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