Be-Al Alloy

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Be-Al alloy is a type of in situ metal matrix composite composed of a primary Be phase for strength and stiffness and a continuous Al matrix for ductility and toughness. Be-Al alloy has the characteristics of low density (2.1-2.2 g/cm^3), high elastic modulus (＞170 GPa) and specific stiffness (＞88 GPa/(g/cm^3)) as a preferred material for lightweight aerospace products.

Keywords: Be-Al alloy ; high elastic modulus ; adding elements

1. Introduction

Be-Al alloy combining Be with Al takes the advantages of the excellent ductility of the Al phase and the high modulus of Be phase [1][2]. The alloy has the characteristics of lightweight, high specific strength, high specific stiffness, good thermal stability, high toughness, high modulus, and corrosion resistance. As the solid solubility between Be and Al is very low, Be-Al alloys with properties substantially different from those of pure metals should be defined as a composite material when the Be content is below 65 wt.%, in which discontinuous granular Be phase reinforces continuous Al phase as a matrix material [2]. Be-Al alloy has been widely used in missile, airborne and spaceborne platforms in Europe and the United States [3]; moreover, it has been listed as a key material in the development of kinetic energy interceptors by the United States [4]. Be-Al alloy was first developed in the 1960s by the United States. Nowadays, the alloy is becoming the key material for high-end equipment, such as kinetic energy interceptors, airborne situational awareness devices, and directed energy weapons [5][6].

Be-Al alloy is an important feature of military applications, and its research status and development trend are of great concern to everyone.

2. The Characteristics of Investment Be-Al Alloy

Be-Al alloy is a combination of high stiffness and low density of Be element with easy processability characteristics of Al element. The binary alloy phase diagram is illustrated in **Figure 1**a, and the temperature of the eutectic reaction is about 644 °C. The atomic fraction of Be element at the eutectic point is only 2.4 at.%, and there are no intermetallic compounds. Subsequently, the separation of Be and Al elements occurs in the process of solidification. Based on the properties of the Be-Al binary system, the two phases can be separated without nucleation; finally, the special three-dimensional network structure [7] of Be phase (62 wt.% Be) and Al phase (38 wt.% Al) is shown in **Figure 1**b from the X radia Context Micro CT will be formed, in which, Be embedded in the Al matrix in columnar crystal form. The solid solubility of Be in the Al phase is 0.1 wt.%, and the solid solubility of Al in Be phase is only 0.02 wt.% [8]. Therefore, Be-Al alloy should be defined as a composite material when the atomic fraction of Be is in the range of 60–80 at.%. The discontinuous granular Be phase reinforces the matrix of the continuous Al phase shown in **Figure 1**b. In the scanning electron microscopy (SEM) image of the Be-Al alloy, the dark imaging phase in the microstructure is the Be phase (62 wt.% Be), and the grey imaging matrix is the Al phase (38 wt.% Al), as shown in **Figure 2**. The casting difficulty of Be-Al alloy is significantly greater than other common alloys due to the particularity of the solidification process. The growth of pure primary Be dendrites is within the Al matrix during solidification and thus hinders the production of Be-Al alloys with beneficial properties, which are substantially are close to those of pure constituents [9].

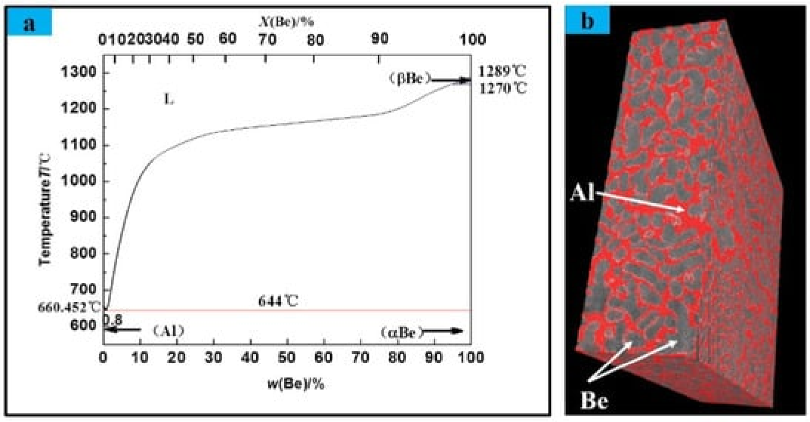

Figure 1. The phase diagram of Be-Al alloy (**a**), three-dimensional microstructure (**b**) [7]. Reprinted/adapted with permission from Ref. [7]. Copyright 1994, Elsevier Ltd.

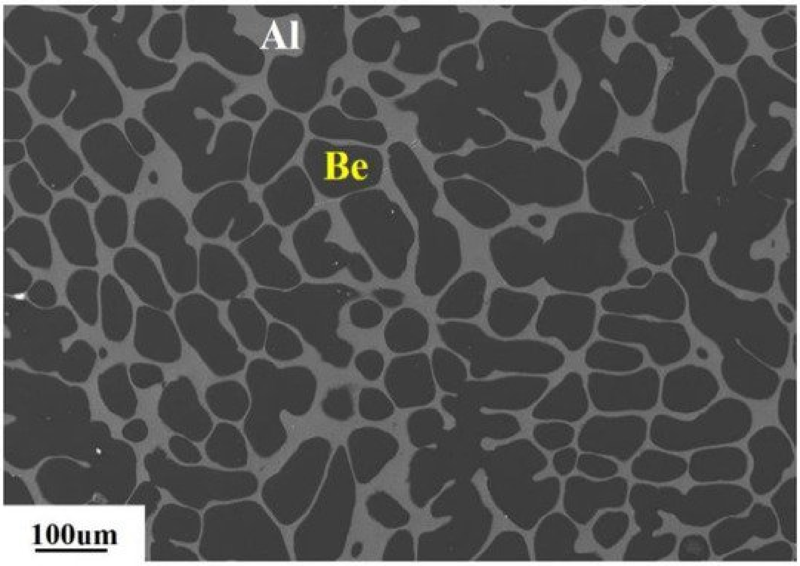

Figure 2. The SEM image of Be-Al alloy.

3. The Heat Treatment of Casting Be-Al Alloy

The strength of Be-Al alloy casting can be improved by heat treatment. Both the homogenization and aging treatment are the main heat treatment processes of Be-Al alloy as listed in **Table 1**.

Because the solution of adding elements in the Be phase is very small and the diffusion rate is low at a certain temperature, the heat treatment process generally refers to the corresponding heat treatment of Al alloy [10][11]. A series of Be-Al alloys(65Be-31Al-2Si-2Ag-0.04Sr) were solution heat treated (HT) for 2 h at 550 °C, and water quenched, then aged for 16 h at 190 °C and air cooled. The mechanical properties are shown in **Table 2**. Heat treatment caused grain growth and the insoluble phases Si aggregated and coarsened, resulting in an enhancement of tensile strength, similar to Al-Si alloy [12]. The melting temperature of the eutectic Al phase in Al-Si alloy [13] is lower. The process is to enhance the Al phase by Si [14][15] and Ag, mainly.

The temperatures of solution treatment are 475 °C (4.5 h), 505 °C (2.5 h) and 545 °C (4.5 h), separately. Subsequently, the temperatures of artificial ageing are 280 °C (6 h), 165 °C (4 h) and165 °C (6 h), respectively [16].

Table 1. The heat treatment of casting Be-Al alloy.

Heat Treatment	Composition	Advantages Due to the Heat Treatment	Reference
Solution and aging treatment.	**65Be-31Al-2Si-2Ag-0.04 Sr(0.25Cu, Ni and Co)**	**Strength improved**	[17]
Homogenizing and aging treatment.	**62Be-37.6Al-0.4Sc**	**Hardness improved** **Electrical conductivity improved**	[18][19]

Table 2. The mechanical properties of Be-Al alloys (as-cast and heat treated) [17].

Composition	Conditions	Tensile Strength MPa	Yield Strength MPa	Elongation(%)
60Be-40Al	as-cast	110.5	91.7	1.0
65Be-31Al-2Si-2Ag-0.04Sr	as-cast heat treated	190.3 217.9	138.6 158.6	2.3 2.5

The mechanical properties of 62Be-37.6Al-0.4Sc can also be improved by heat treatment when Al_3Sc phases in the as-cast state dissolved completely in the matrices. According to a previous study, there are numerous primary Al_3Sc particles with an average particle size of ~80 nm in the Al matrix of an as-cast Be-Al-0.4Sc alloy [18]. During the homogenizing process at 620 °C [18], these primary Al_3Sc phases in the as-cast state dissolved completely in the matrices after 2 h, resulting in an initial decrease in electrical conductivity and an increase in hardness, which was ascribed to the solid-solution strengthening [19] before this duration. The density of dislocations, which acted as heterogeneous nucleation sites for the Al_3Sc precipitates as the homogenizing time increased [20].

The mechanical property of Be-Al alloy can also be improved by hot isostatic pressing; it was found that the density of Be-Al alloy increased from 2.05 g/cm^3 to 2.14 g/cm^3, close to the theoretical density of alloy 2.17 g/cm^3 after hot isostatic pressing by Northwest Rare Metal Materials Research Institute Ningxia Co., Ltd. The temperature is selected as 550–580 °C in order to prevent Al from melting out, and the pressure is 60–80 MPa for 2 h.

References

1. Nikitin, S.N.; Tarasov, B.A.; Shornikov, D.P. Interaction between U-Mo alloys and alloys Al-Be. Phys. Procedia 2015, 72, 370–373.
2. Xu, Q.D.; Yang, L.; He, S.X.; Liu, X.D.; Shi, T.; Zhang, P.C. Three-dimensional microstructure and solidification behavior in laser remelting of beryllium-aluminum alloy. Mater. Lett. 2020, 274, 127963.
3. William, S. Application of aluminum-beryllium composite for structural aerospace component. Eng. Fail. Anal. 2004, 11, 895.
4. Parsonage, T. Beryllium metal matrix composites for aerospace and commercial applications. Mater. Sci. Technol. 2010, 16, 732–738.
5. Anon, S. Be-Al alloy show promise for spacecraft component. J. Fail. Anal. Prev. 2004, 4, 31.
6. US Air Force Research Laboratory, Wright-Patterson Air Force Base. Beryllium-aluminum alloys reduce weight in spacecraft. Adv. Mater. Processes. 2004, 162, 12.
7. Elmer, J.W.; Aziz, M.J.; Tanner, L.E.; Smith, P.M.; Wall, M.A. Formation of bands of ultrafine beryllium particles during rapid solidification of Al-Be alloys: Modeling and direct observations. Acta Metall. Mater. 1994, 42, 1065.
8. Zhang, X.D.; Grensing, F.C.; Meisenkothen, F.; Meyrick, G.; Fraser, H.; Wiezorek, J. Microstructural characterization of novel in-situ Al-Be composites. Metall. Mater. Trans. A 2000, 31, 2963–2971.
9. Nardone, V.C.; Garosshen, T.J. Evaluation of the tensile and fatigue behaviour of ingot metallurgy beryllium/aluminium alloys. J. Mater. Sci. 1997, 32, 3975–3985.
10. Milewski, J.O. Ultra-Narrow Gap Laser Welding of Be-Al Alloys Final Report; Los Alamos National Laboratory: Los Alamos, NM, USA, 1998.
11. Poloczek, Ł.; Kiełbus, A. Influence of technological factors on the quality of aluminum alloys castings. Enterp. Manag. 2016, 19, 14–19.
12. Szymczak, T.; Gumienny, G.; Klimek, L.; Goły, M.; Szymszal, J.; Pacyniak, T. Characteristics of Al-Si Alloys with high melting point elements for high pressure die casting. Materials 2020, 13, 4861.
13. Chen, J.X.; Lu, M.J.; Wu, S.S.; Lü, S.L. Study on eutectic microstructure and modification mechanism of Al-Si alloys. Mater. Sci. Forum 2016, 877, 97–103.
14. Wei, L.; Shuai, L.; Jie, L.; Ang, Z.; Yan, Z.; Qingsong, W.; Chunze, Y.; Yusheng, S. Effect of heat treatment on AlSi10Mg alloy fabricated by selective laser melting: Microstructure evolution, mechanical properties and fracture mechanism. Mater. Sci. Eng. A 2016, 663, 116–125.

15. Wang, G.Q.; Liu, Y.; Ren, G.C.; Zhao, Z.K. Analyzing Si Precipitation on Age Hardening of an Al-Si-Mg Cast Alloy. Adv. Mater. Res. 2010, 146, 1685–1689.
16. Jarco, A.; Pezda, J. Effect of heat treatment process and optimization of its parameters on mechanical properties and microstructure of the AlSi11 (Fe) alloy. Materials 2021, 14, 2391.
17. William, T.N.; Nancy, F.L.; Kevin, R.R. Light Weight, High Strength Beryllium-Aluminum Alloy. U.S. Patent 5,603,780, 18 February 1997.
18. Yu, L.B.; Wang, W.; Li, B.Q.; He, L.F.; Wang, Q.G.; Zhao, F.Z.; Wang, J. Determination of homogenizing conditions and aging behaviors of cast 62Be-37.6 Al-0.4 Sc alloy. J. Alloys Compd. 2019, 808, 151742.
19. Vo, N.Q.; Dunand, D.C.; Seidman, D.N. Improving aging and creep resistance in a dilute Al-Sc alloy by microalloying with Si, Zr and Er. Acta Mater. 2014, 63, 73–85.
20. Gabriel, M.N.; Alan, J.A. Precipitation of Al3Sc in binary Al-Sc alloys. Mater. Sci. Eng. A 2001, 318, 144–154.