|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical compostion（at.%） | Preparation method | Critical  Diameter/thickness(mm) | Tg  (K) | Tx  (K) | Tl  (K) | σy(MPa) | Modulus (GPa) | Ε(%) | Reference |
| Zr52.5Al10Ti5Cu17.9Ni14.6 | Arc-melting/copper mold casting | 7 | 665±5 | 723 | 1090 | 1654 | 83.4 | 0.06 | [1] |
| Zr61Cu17.5Ni10Al7.5Si4 | Melt spinning | - | - | - | - | ~1800 |  |  | [2] |
| Zr57Nb5Cu15.4Ni12.6Al10 | Arc-melting/copper mold casting | 5 | 682 |  | 1115 | 1600 | 86.7 | 0.08 | [3, 4] |
| Zr57Cu18.67Ni8Al16.33 | Arc-melting/copper mold casting | 3 | 707 | 777 | - | 1326 |  | 1.1 | [5] |
| Zr56.36Cu20.53Ni7.6Al15.51 | Arc-melting/copper mold casting | 3 | 708 | 779 | - | 1396 | - | 1.5 | [5] |
| Zr55.7Cu22.4Ni7.2Al14.7 | Arc-melting/copper mold casting | 3 | 696 | 778 | - | 1609 | - | 5.5 | [5] |
| Zr54.4Cu26.13Ni6.4Al13.07 | Arc-melting/copper mold casting | 3 | 707 | 774 | - | 1329 | - | 1.8 | [5] |
| Zr50.46Cu35.19Ni2.65Ag2.15Al9.55 | Arc-melting/copper mold casting | 12 | 641.6 | 731.9 | 1168.9 | 1872 | - | 0.1 | [6] |
| Zr50.12Cu35.22Ni2.69Ag2.69Al9.28 | Arc-melting/copper mold casting | 12 | 700.4 | 786.0 | 1140.8 | 1854 | - | 0.1 | [6] |
| Zr49.80Cu35.20Ni2.73Ag3.24Al9.03 | Arc-melting/copper mold casting | 12 | 699.6 | 782.0 | 1138.1 | 1924 | - | 0.1 | [6] |
| Zr49.52Cu35.12Ni2.76Ag3.80Al8.80 | Arc-melting/copper mold casting | 12 | 700.3 | 781.5 | 1134.1 | 1850 | - | 0.4 | [6] |
| Zr49.24Cu35.01Ni2.79Ag4.38Al8.58 | Arc-melting/copper mold casting | 12 | 696.8 | 778.6 | 1128.2 | 1846 | - | 0.3 | [6] |
| Zr48.99Cu34.85Ni2.82Ag4.96Al8.38 | Arc-melting/copper mold casting | 12 | 698.3 | 779.2 | 1139.0 | 1874 | - | 0 | [6] |
| Zr60Cu25Al10Fe5 | Arc-melting/copper mold casting | 8 | 668.2 | 750.7 | 1179.9 | 1772 | - | 0.4 | [7] |
| Zr60Cu25Al10Fe4Ag1 | Arc-melting/copper mold casting | 8 | 668.3 | 753 | 1180.4 | 1739 | - | 1.3 | [7] |
| Zr60Cu25Al10Fe3Ag2 | Arc-melting/copper mold casting | 8 | 667.3 | 754.6 | 1182 | 1798 | - | 1.4 | [7] |
| Zr60Cu25Al10Fe3Ag3 | Arc-melting/copper mold casting | 8 | 665.5 | 748.9 | 1201.6 | 1762 | - | 1.5 | [7] |
| Zr60Cu25Al10Fe1Ag4 | Arc-melting/copper mold casting | 8 | 664.7 | 741.5 | 1207.9 | 1721 | - | 3.7 | [7] |
| Zr60Cu25Al10Ag5 | Arc-melting/copper mold casting | 8 | 660 | 729.8 | 1209 | 1747 | - | 1.5 | [7] |
| Zr55Ti3Cu32Al10 | Arc-melting/copper mold casting | 8 | 668 | 723 | 1188 | - | 85 | 0 | [8] |
| Zr55Ti3Hf1Cu31Al10 | Arc-melting/copper mold casting | 8 | 670 | 728 | 1179 | - | 82 | 0 | [8] |
| Zr55Ti3Hf2Cu30Al10 | Arc-melting/copper mold casting | 8 | 676 | 746 | 1127 | 1745 | 76 | 0.25 | [8] |
| Zr55Ti3Hf3Cu29Al10 | Arc-melting/copper mold casting | 8 | 677 | 746 | 1124 | 1800 | 74 | 2.6 | [8] |
| Zr55Ti3Hf4Cu28Al10 | Arc-melting/copper mold casting | 8 | 694 | 751 | 1163 | 1771 | 73 | 1.64 | [8] |
| Zr55Ti3Hf5Cu27Al10 | Arc-melting/copper mold casting | 8 | 697 | 756 | 1180 | 1765 | 74 | 1.63 | [8] |
| Zr56Cu24Al9Ni7Ti4 | Arc-melting/copper mold casting | 2 | 678 | 710 | 1161 | 1677 | - | 7.5 | [9] |
| Zr56Cu24Al9Ni6Ti4Fe1 | Arc-melting/copper mold casting | 2 | 680 | 708 | 1081 | 1702 | - | 6.36 | [9] |
| Zr56Cu24Al9Ni4Ti4Fe3 | Arc-melting/copper mold casting | 2 | 678 | 706 | 1089 | 1709 | - | 10.55 | [9] |
| Zr57Cu20Al10Ni8Ti5 | Arc-melting/copper mold casting | 8 | 660.6 | 715.2 | 1153.7 | 1469 | 257.5 | 0.11 | [10] |
| Zr57Cu20Al10Ni8Ti4Ag1 | Arc-melting/copper mold casting | 8 | 663.2 | 725.9 | 1149.3 | 1366 | 279.2 | 0.87 | [10] |
| Zr57Cu20Al10Ni8Ti3Ag2 | Arc-melting/copper mold casting | 8 | 662.3 | 738.4 | 1153.5 | 1579 | 242.9 | 0.75 | [10] |
| Zr57Cu20Al10Ni8Ti2Ag3 | Arc-melting/copper mold casting | 8 | 663.5 | 759.7 | 1124.4 | 1511 | 218.9 | 0.52 | [10] |
| Zr60Cu19Al10Ni10Nb1 | Arc-melting/copper mold casting | 3 | 409 | 490 | - | 1305 | - | 0.329 | [11] |
| Zr60Cu17Al10Ni10Nb3 | Arc-melting/copper mold casting | 3 | 405 | 492 | - | 1491 | - | 0.117 | [11] |
| Zr60Cu15Al10Ni10Nb5 | Arc-melting/copper mold casting | 3 | 404 | 467 | - | 1538 | - | 0.152 | [11] |
| Ti32.8Zr30.2Cu9Ni5.3Be22.7 | Arc-melting/copper mold casting | 5 | 598 | 651 | 942 | - | - | - | [12] |
| (Cu50Zr43Al7)98Y2 | Arc-melting/copper mold casting | 15 | 696 | 770 | 1165 | 2006 | 103 | - | [13, 14] |
| (Cu50Zr43Al7)96Y4 | Arc-melting/copper mold casting | 12 | 679 | 715 | 1150 | 1787 | 101 | - | [13, 14] |
| (Cu50Zr43Al7)94Y6 | Arc-melting/copper mold casting | 8 | 665 | 703 | 1145 | - | - | - | [13] |
| Zr35Hf13Al11Ag8Ni8Cu25 | Arc-melting/copper mold casting | 15 | 723 | 802 | 1112 | - | - | - | [15] |
| Zr30Hf25Al20Co10Ni10Cu5 | Arc-melting/copper mold casting | 12 | 775 |  | 1337 |  |  |  | [16] |
| Zr35Hf17.5Ti5.5Al12.5Co7.5Ni12Cu10 | Arc-melting/copper mold casting | 18 | 725 |  | 1206 |  |  |  | [16] |
| Zr60Ti2Nb2Al7.5Ni10Cu18.5 | Arc-melting/copper mold casting | 10 | 378 | 446 | 870 | 1500 | 80 | 1.1 | [17] |
| Ti29.44Cu46.72Ni7.88Zr7.6Hf8.4 | Arc-melting/copper mold casting | 3 | 684 | 729 | 1195 | 2050 | - | - | [18] |
| Ti30.42Cu45.26Ni8.32Zr7.6Hf8.4 | Arc-melting/copper mold casting | 4 | 680 | 729 | 1189 | 2115 | - | - | [18] |
| Ti31.4Cu43.8Ni8.8Zr7.6Hf8.4 | Arc-melting/copper mold casting | 4 | 683 | 726 | 1185 | 2021 | - | - | [18] |
| Ti32.38Cu42.34Ni9.28Zr7.6Hf8.4 | Arc-melting/copper mold casting | 4 | 682 | 722 | 1168 | 2072 | - | - | [18] |
| Ti33.36Cu40.88Ni9.76Zr7.6Hf8.4 | Arc-melting/copper mold casting | 3 | 679 | 716 | 1188 | - | - | - | [18] |
| Zr57Cu  20Ni8Al10Ti5 | Arc-melting/copper mold casting | 2 | 655 | 711 | 1095 | 1907 |  | 1.8 | [19] |
| Zr56Cu  20Ni8Al10Ti5Sc1 | Arc-melting/copper mold casting | 2 | 655 | 711 | 1094 | 1857 |  | 5.4 | [19] |
| Zr55Cu  20Ni8Al10Ti5Sc2 | Arc-melting/copper mold casting | 2 | 652 | 710 | 1087 | 1815 |  | 9.1 | [19] |
| Zr54Cu  20Ni8Al10Ti5Sc3 | Arc-melting/copper mold casting | 2 | 649 | 705 | 1083 | 1770 |  | 3.0 | [19] |
| Zr53Cu  20Ni8Al10Ti5Sc4 | Arc-melting/copper mold casting | 2 | 645 | 700 | 1080 | 1750 |  | 1.9 | [19] |

[1] Ren Z Q, Churakova A A, Wang X, et al. Enhanced tensile strength and ductility of bulk metallic glasses Zr52.5Cu17.9Al10Ni14.6Ti5 via high-pressure torsion[J]. Materials Science and Engineering: A, 2021, 803140485.

[2] Lin C H, Huang C H, Chuang J F, et al. Simulated body-fluid tests and electrochemical investigations on biocompatibility of metallic glasses[J]. Materials Science and Engineering: C, 2012, 32(8):2578-2582.

[3] Li H, Subhash G, Kecskes L J, et al. Mechanical behavior of tungsten preform reinforced bulk metallic glass composites[J]. Materials Science and Engineering: A, 2005, 403(1):134-143.

[4] Mukherjee S, Schroers J, Zhou Z, et al. Viscosity and specific volume of bulk metallic glass-forming alloys and their correlation with glass forming ability[J]. Acta Materialia, 2004, 52(12):3689-3695.

[5] 朱坤森, 陶平均, 张超汉, et al. Zr基块体非晶合金的成分设计及其性能研究[J]. 材料导报, 2021, 35(24):24113-24116.

[6] 于德川. Zr基块体非晶合金的形成能力与性能 [D]; 东北大学, 2016.

[7] Li B, Sun W C, Qi H N, et al. Effects of Ag substitution for Fe on glass-forming ability, crystallization kinetics, and mechanical properties of Ni-free Zr–Cu–Al–Fe bulk metallic glasses[J]. Journal of Alloys and Compounds, 2020, 827154385.

[8] Jin Z S, Yang Y J, Zhang Z P, et al. Effect of Hf substitution Cu on glass-forming ability, mechanical properties and corrosion resistance of Ni-free Zr–Ti–Cu–Al bulk metallic glasses[J]. Journal of Alloys and Compounds, 2019, 806668-675.

[9] Shi H, Zhou H, Zhou Z, et al. Improved mechanical properties and corrosion resistance of Zr-Cu-Al-Ni-Ti bulk metallic glass by Fe substitution for Ni[J]. Journal of Non-Crystalline Solids, 2022, 576121246.

[10] Cui X, Zu F-Q, Jiang W-X, et al. Achieving superior glass forming ability of Zr–Cu–Al–Ni–Ti/Ag bulk metallic glasses by element substitution[J]. Journal of Non-Crystalline Solids, 2013, 37583-87.

[11] Long Z, Tao P, Wang G, et al. Effect of Nb and Ta addition on mechanical properties of Zr-based bulk metallic glasses and composites[J]. Journal of Alloys and Compounds, 2022, 912165071.

[12] Wang Y, Zhu Z, Wang A, et al. Ultrastrong behaviors of a non-equiatomic Ti-Zr-Ni-Cu-Be high entropy metallic glass with ultrahigh glass forming ability[J]. Journal of Non-Crystalline Solids, 2022, 577121323.

[13] Malekan M, Rashidi R, Shabestari S G, et al. Thermodynamic and kinetic interpretation of the glass-forming ability of Y-containing Cu-Zr-Al bulk metallic glasses[J]. Journal of Non-Crystalline Solids, 2022, 576121266.

[14] Malekan M, Rashidi R, Bozorg M, et al. Tailoring the glass forming ability, mechanical properties and corrosion resistance of Cu–Zr–Al bulk metallic glasses by yttrium addition[J]. Intermetallics, 2023, 158107906.

[15] Ohashi Y, Wada T, Kato H. High-entropy design and its influence on glass-forming ability in Zr–Cu-based metallic glass[J]. Journal of Alloys and Compounds, 2022, 915165366.

[16] Wada T, Jiang J, Yubuta K, et al. Septenary Zr–Hf–Ti–Al–Co–Ni–Cu high-entropy bulk metallic glasses with centimeter-scale glass-forming ability[J]. Materialia, 2019, 7100372.

[17] Murphy A G, Meagher P, Norman A, et al. Mechanical and thermal stability of Bulk Metallic Glass alloys identified as candidates for space mechanism applications[J]. Materials & Design, 2022, 224111350.

[18] Li P, Wang G, Ding D, et al. Glass forming ability, thermodynamics and mechanical properties of novel Ti–Cu–Ni–Zr–Hf bulk metallic glasses[J]. Materials & Design, 2014, 53145-151.

[19] Zhu J, Gao W, Cheng S, et al. Improving the glass forming ability and plasticity of ZrCuNiAlTi metallic glass by substituting Zr with Sc[J]. Journal of Alloys and Compounds, 2022, 909164679.

[20] Lou H B, Wang X D, Xu F, et al. 73 mm-diameter bulk metallic glass rod by copper mould casting[J]. Applied Physics Letters, 2011, 99(5):051910.

[21] Peker A, Johnson W L. A highly processable metallic glass: Zr41.2Ti13.8Cu12.5Ni10.0Be22.5[J]. Applied Physics Letters, 1993, 63(17):2342-2344.

[22] Scudino S, Surreddi K B, Wang G, et al. Effect of stress concentration on plastic deformation of Zr41.2Ti13.8Cu12.5Ni10Be22.5 bulk metallic glass under compressive loading[J]. Materials Letters, 2016, 179202-205.

[23] Jana P P, Das J. Accurate measurement of glass transition temperature of Cu47.5Zr47.5Al5 and Zr41.2Ti13.8Cu12.5Ni10Be22.5 using step-scan modulated differential scanning calorimeter[J]. Journal of Alloys and Compounds, 2019, 800314-319.

[24] Inoue A, Zhang T, Nishiyama N, et al. Preparation of 16 mm Diameter Rod of Amorphous Zr<SUB>65</SUB>Al<SUB>7.5</SUB>Ni<SUB>10</SUB>Cu<SUB>17.5</SUB> Alloy[J]. Materials Transactions, JIM, 1993, 34(12):1234-1237.

[25] Zhang Q S, Zhang W, Wang X M, et al. Structure, Thermal Stability and Mechanical Properties of Zr<SUB>65</SUB>Al<SUB>7.5</SUB>Ni<SUB>10</SUB>Cu<SUB>17.5</SUB> Glassy Alloy Rod with a Diameter of 16 mm Produced by Tilt Casting[J]. MATERIALS TRANSACTIONS, 2008, 49(9):2141-2146.

[26] Shi B, Xu Y, Ma W, et al. Effect of Ti addition on the glass forming ability, crystallization, and plasticity of (Zr64.13Cu15.75Ni10.12Al10)100−xTix bulk metallic glasses[J]. Materials Science and Engineering: A, 2015, 639345-349.

[27] Bian X L, Wang G, Yi J, et al. Atomic origin for rejuvenation of a Zr-based metallic glass at cryogenic temperature[J]. Journal of Alloys and Compounds, 2017, 718254-259.

[28] Sun Y J, Qu D D, Huang Y J, et al. Zr–Cu–Ni–Al bulk metallic glasses with superhigh glass-forming ability[J]. Acta Materialia, 2009, 57(4):1290-1299.

[29] Qu D D, Liss K D, Sun Y J, et al. Structural origins for the high plasticity of a Zr–Cu–Ni–Al bulk metallic glass[J]. Acta Materialia, 2013, 61(1):321-330.

[30] Qiao J C, Pelletier J M. Influence of thermal treatments and plastic deformation on the atomic mobility in Zr50.7Cu28Ni9Al12.3 bulk metallic glass[J]. Journal of Alloys and Compounds, 2014, 615S85-S89.

[31] Inoue A, Zhang T, Nishiyama N, et al. Preparation of 16 mm Diameter Rod of Amorphous Zr65Al7.5Ni10Cu17.5 Alloy[J]. Materials Transactions, JIM, 1993, 34(12):1234-1237.

[32] Khademian N, Gholamipour R, Shahri F, et al. Effect of vanadium substitution for zirconium on the glass forming ability and mechanical properties of a Zr65Cu17.5Ni10Al7.5 bulk metallic glass[J]. Journal of Alloys and Compounds, 2013, 54641-47.

[33] Inoue A, Zhang T. Fabrication of Bulk Glassy Zr55Al10Ni5Cu30 Alloy of 30 mm in Diameter by a Suction Casting Method[J]. Materials Transactions, JIM, 1996, 37(2):185-187.

[34] Jana P P, Gunti A, Das J. Improvement of intrinsic plasticity and strength of Zr55Cu30Ni5Al10 metallic glass by tuning the glass transition temperature[J]. Materials Science and Engineering: A, 2019, 762138102.

[35] Chen J, Lu X-Y. Numerical investigation of the non-Newtonian blood flow in a bifurcation model with a non-planar branch[J]. Journal of Biomechanics, 2004, 37(12):1899-1911.

[36] Li X P, Roberts M P, O'keeffe S, et al. Selective laser melting of Zr-based bulk metallic glasses: Processing, microstructure and mechanical properties[J]. Materials & Design, 2016, 112217-226.

[37] Perez-Bergquist A G, Bei H, Leonard K J, et al. Effects of ion irradiation on Zr52.5Cu17.9Ni14.6Al10Ti5 (BAM-11) bulk metallic glass[J]. Intermetallics, 2014, 5362-66.

[38] Ouyang D, Li N, Xing W, et al. 3D printing of crack-free high strength Zr-based bulk metallic glass composite by selective laser melting[J]. Intermetallics, 2017, 90128-134.

[39] Sergiienko R A, Shcheretskyi O A, Zadorozhnyy V Y, et al. Investigation of Zr55Cu30Al10Ni5 bulk amorphous alloy crystallization[J]. Journal of Alloys and Compounds, 2019, 791477-482.

[40] Bordeenithikasem P, Shen Y, Tsai H-L, et al. Enhanced mechanical properties of additively manufactured bulk metallic glasses produced through laser foil printing from continuous sheetmetal feedstock[J]. Additive Manufacturing, 2018, 1995-103.

[41] Gibson M A, Mykulowycz N M, Shim J, et al. 3D printing metals like thermoplastics: Fused filament fabrication of metallic glasses[J]. Materials Today, 2018, 21(7):697-702.

[42] Zhou W, Li H, Li Z, et al. Bonding of Zr44Ti11Cu10Ni10Be25 bulk metallic glass and AZ31B magnesium alloy by hot staking extrusion[J]. Vacuum, 2019, 166240-247.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical compostion（at.%） | Preparation method | Critical  Diameter/thickness(mm) | Tg  (K) | Tx  (K) | Tl  (K) | σy(MPa) | Modulus (GPa) | ε(%) | Reference |
| Zr46Cu30.14Ag8.36Al8Be7.5 | Arc-melting/copper mold casting | 73 | 705 | 811 | 1103 |  | 96.3 |  | [20] |
| Zr41.2Ti13.8Cu12.5Ni10Be22.5 | Arc-melting/copper mold casting | 12.6 | 611 | 688 |  | 1670 |  | 3.5 | [21-23] |
| Zr65Al7.5Ni10Cu17.5 | Arc-melting/copper mold casting | 16 | 643 | 745 | 1174 | 1540 | 88GPa |  | [24, 25] |
| (Zr64.13Cu15.75Ni10.12Al10)100 | Arc-melting/copper mold casting | 4 | 641 | 744 | 1164 | 1518 |  |  | [26, 27] |
| (Zr64.13Cu15.75Ni10.12Al10)99Ti1 | Arc-melting/copper mold casting | 4 | 644 | 739 | 1161 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)98Ti2 | Arc-melting/copper mold casting | 4 | 643 | 717 | 1157 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)97Ti3 | Arc-melting/copper mold casting | 4 | 639 | 705 | 1149 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)96Ti4 | Arc-melting/copper mold casting | 4 | 637 | 697 | 1148 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)95Ti5 | Arc-melting/copper mold casting | 4 | 642 | 693 | 1142 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)94Ti6 | Arc-melting/copper mold casting | 4 | 636 | 685 | 1138 |  |  |  | [26] |
| (Zr64.13Cu15.75Ni10.12Al10)93Ti7 | Arc-melting/copper mold casting | 4 | 635 | 684 | 1135 |  |  |  | [26] |
| Zr53Cu18.7Ni12Al16.3 | Arc-melting/copper mold casting | 6 | 709 | 815 | 1141 | 1880 |  | 14.5 | [28, 29] |
| Zr51.9Cu23.3Ni10.5Al14.3 | Arc-melting/copper mold casting | 10 | 710 | 804 | 1129 |  |  |  | [28] |
| Zr50.7Cu28Ni9Al12.3 | Arc-melting/copper mold casting | 14 | 719 | 799 | 1142 |  | 112 |  | [28, 30] |
| Zr65Cu17.5Ni10Al7.5 | Arc-melting/copper mold casting | ＜6 | 657 | 736 | 1168 | 1400 |  | 0 | [31, 32] |
| Zr55Cu30Ni5Al10 | Arc-melting/copper mold casting | ＜10 | 682 | 745 | 1104 | 1450 |  | 0 | [33, 34] |
| Zr57.5Cu27.3Ni6.5Al8.7 | Arc-melting/copper mold casting | ＜14 | 651 | 755 | 1124 |  |  |  | [34] |
| Zr51Ti5Cu25Ni10Al9 | Arc-melting/copper mold casting | 14 | 680 | 724 | 1002 |  |  |  | [35] |
| Zr41.2Ti13.8Cu12.5Ni10Be22.5 | Arc-melting/copper mold casting | ＞18 | 623 | 672 | 996 | 1670 |  | 3.5 | [21, 22] |
| Zr52.5Cu17.9Ni14.6Al10Ti5 | SLM | 3 | 653 | 723 |  | 1500 | 102.2 | 0 | [36, 37] |
| Zr55Cu30Al10Ni5 | SLM | 3 | 678 | 744 |  | 1504 |  | 2.2 | [38, 39] |
| Zr65Cu17.5Ni10Al7.5 | LFP | 4 | 657 | 736 | 1168 | 2200(bending) |  | 2.5 | [40] |
| Zr44Ti11Cu10Ni10Be25 | FFF | 2 | 629 | 736 |  | 1200 |  | 0 | [41, 42] |
|  |  |  |  |  |  |  |  |  |  |