**Phase prediction based on artificial neural network and mechanical properties of novle Ti**–**Cu**–**Ni**–**Ta multi-principal element alloys**

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Table 1 The phase composition of 220 alloys reported and the values of four characteristic parameters.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Alloys | *δ* | Δ*χ* | Δ*H*m | *S*id | Phases |
| Cu0.5NiAlCoCrFeSi[1]  Zr17Ta16Ti19Nb22Si26[2]  Cu50Zr50[3]  Ni50Nb50[4]  PdPtCuNiP[5]  SrCaYbMgZn[6]  SrCaYbMgZnCu[7]  SrCaYb(Li0.55Mg0.45)Zn[7]  ErTbDyNiAl[7]  AlCrTaTiZr[8]  CuNbNiTiZr[9]  Pd75Si25[10]  Mg50Cu50[11]  Zr50Ni50[12]  Mg50Ni50[13]  ZrHfTiCuNi[14]  ZrHfTiCuFe[14]  ZrHfTiCuCo[14]  Cu0.5NiAlCoCrFeTi[15]  Cu0.5NiAlCoCrFe[16]  AlCrMoSiTi[17]  AlCrMoTaTiZr[18]  AlMoNbSiTaTiVZr[19]  Zr41.2Ti13.8Cu12.5Ni10Be22.5[10]  Pd40Cu30Ni10P20[20]  Fe41Co7Cr15Mo14C15B6Y2[20]  Mg54Cu26.5Ag8.5Gd11[20]  Cu46Zr42Al7Y5[20]  Y36Sc20Al24Co20[20]  Co48Cr15Mo14C15B6Er2[20]  Ti40Zr25Cu12Ni3Be20[22]  Pt42.5Cu27Ni9.5P21[20]  Ca65Mg15Zn20[20]  Ca40Mg30Cu30[23]  Ca45Cu36Mg19[23]  Ca47Cu27Mg19Zn7[24]  Ca50Cu25Mg15Zn10[24]  Ca50Cu25Zn15Mg10[24]  Ca50Cu30Mg20[23]  Ca50Mg25Zn15Cu10[24]  Ca53Cu24Mg23[23]  Ca55Cu25Mg20[23]  Ca55Cu35Mg10[23]  Ca55Mg25Zn20[24]  Ca55Zn27Mg18[24]  Ca58Cu24Mg18[23]  Ca60Mg20Cu20[23]  Ca60Mg25Cu15[23]  Ca60Zn22.5Mg17.5[24]  Ca60Zn30Mg10[24]  Ca63Al32Cu5[24]  Ca65Cu25Mg10[23]  Ca65Mg20Cu15[23]  Ca65Mg25Cu10[23]  Mg65Cu25Dy10[24]  Mg65Cu25Gd10[24]  Mg65Cu25Ho10[24]  Mg65Cu25Pr10[24]  Mg68Ni15Gd10Ag7[25]  Mg69Ni15Gd10Ag6[25]  Mg70La17Ni13[25]  Mg70Ni15Nd15[23]  Mg71Ni18La11[25]  Mg73Ni15Gd10Ag2[25]  Mg75Ni15Gd10[25]  Mg80Ni10Nd10[19]  Ni42Zr25Ti20Al8Cu5[24]  Ni59Zr20Ti16Si5[24]  Ni60Nb25Zr15[24]  Ni60Nb30Zr10[24]  Ni60Zr20Ti5Nb10Al5[26]  Ni61Zr22Nb7Al4Ta6[26]  Pd77Si17Cu6[27]  Pr68Cu25Al7[27]  Pd40Ni40P20[23]  Ti40Cu32Pd18Zr10[23]  Ti40Cu36Pd14Zr10[23]  Ti40Cu40Pd10Zr10[23]  Ti50Be18Zr15Cu9Ni8[28]  Ti50Cu32Ni30Sn3[28]  Ti50Ni24Cu20Sn3Si2B1[24]  Zr42Cu36Al8Ag8Au6[25]  Zr42Cu36Al8Ag8Hf6[25]  Zr42Cu36Al8Ag8Ni6[25]  Zr42Cu36Al8Ag8Ti6[25]  Zr44Cu36Al8Ag8Fe4[25]  Zr44Cu36Al8Ag8Nb4[25]  Zr44Cu36Al8Ag8Pd4[25]  Zr44Cu40Ag8Al8[25]  La55Al25Cu15Ag5[26]  La55Al25Ni10Cu10[26]  La55Al25Ni5Cu10Co5[25]  La62Al14Cu12Ni12[24]  La62Cu17Al14Ag7[24]  La62Cu19Al14Ag5[24]  La62Cu22Al14Ag2[24]  Fe66B22W6Y6[25]  Fe67B22Y6Mo5[29]  Fe67B22Y6W5[25]  Fe68B22Y6Co4[26]  Fe68B22Y6Ni4[26]  Fe71B22Y6Mo1[29]  Fe71B22Y6W1[29]  Fe62B22Co10Y6[26]  Fe64B22Co8Y6[26]  Fe66B22Co6Y6[26]  Fe68B22Y6Mo4[29]  Fe68B22Y6W4[25]  Fe69B22Y6Mo3[29]  Mg65Ni20La15[25]  CoCrFeNiTi[30]  NbCrFeMnCoNi[31]  TiCrFeMnCoNi[31]  TiVCrCuFeMnCoNi[32]  Ti2CrCuFeCoNi[33]  AlTiVYZr[33]  ZrTiVCuNiBe[33]  CoCrCuFeNiTi0.8[34]  CoCrCuFeNiTi1.0[34]  Al0.5CoCrCuFeNiTi0.8[35]  Al0.5CoCrCuFeNiTi1.0[35]  Al0.5CoCrCuFeNiTi1.2[35]  Al0.5CoCrCuFeNiTi1.4[35]  Al0.5CoCrCuFeNiTi1.6[35]  Al0.5CoCrCuFeNiTi1.8[35]  Al0.5CoCrCuFeNiTi2.0[35]  Al0.5CoCrCuFeNiV0.6[36]  Al0.5CoCrCuFeNiV0.8[36]  Al0.5CoCrCuFeNiV1.0[36]  ZrHfTiAlCuNi[37]  AlCoCrFeNiTi1.5[38]  AlNbTiZr[39]  Al40Mg40Li10Zn10[40]  Al35Mg35Li15Zn15[40]  Al15Li35Mg35Ca10 Si5[41]  Al15Li35Mg48Ca1 Si1[41]  Al15Li38Mg45Ca0.5 Si1.5[41]  Al15Li39Mg45Ca0.5Si0.5[41]  Al58.5Mg31.5Zn4.5Cu4.5Si1[42]  Al63Mg27Zn4.5Cu4.5 Si1[42]  Al66.7Mg23.3Zn4.5Cu4.5Si1[42]  Al80Mg14Zn2.7Cu2.7Si0.6[42]  FeSiBAlNiCo0.2[43]  FeSiBAlNiCo0.8[43]  AlNbTiVZr0.1[44]  AlNbTiVZr0.25[44]  AlNbTiVZr0.5[44]  AlNbTiVZr[44]  AlNbTiVZr1.5[44]  Ti28Cu14Ni34.8Nb23.2[45]  Ti30Cu15Ni33Nb22[45]  Ti32Cu16Ni31.2Nb20.8[45]  Hf0.5Mo0.5NbTiZrB0.1[46]  Hf0.5Mo0.5NbTiZrB0.3[46]  Hf0.5Mo0.5NbTiZrB0.7[46]  Hf0.5Mo0.5NbTiZrB0.9[46]  CoNiFeAlTi[47]  CrNbTiZrAl0.25[48]  Al20Cr10Nb15Ti20V25Zr10[49]  Cr0.3Hf0.5Mo0.5NbTiZr[50]  CoCrMoNbTi0.4[51]  AlFeMgTiZn[52]  AlLiMgZnSn[40]  AlLi0.5MgZn0.5Cu0.5[40]  Al80Li5Mg2Zn5Cu5[40]  Al80Li5Mg2Zn5Sn5[40]  Al1.0CrFeMnTi0.25[53]  Al2.0CrFeMnTi0.25[53]  Al1.5CrFeMnTi[54]  Al2.0CrFeMnTi[54]  B4Co[55]  AlNbTiZr0.1[56]  AlNbTiZr0.25[56]  AlNbTiZr0.5[56]  AlNbTiZr1.5[56]  AlNbTiCr[56]  AlNbTiVCr0.25[57]  CoCrMoNb[58]  CoCrMoNbTi[58]  CoCrMoNbTi0.2[58]  CoCrMoNbTi0.5[58]  CrHfNbTiZr[59]  CrNbTiVZr[60]  CrTaTi0.17VW[61]  CrTaTi0.3VW[61]  CrTaVW[61]  BNi3[55]  NbCrZrTi[60]  NbCrVZrTi[60]  MoNbCrCo[58]  MoNbCrTiCo[58]  MoNbCrTi0.2Co[58]  MoNbCrTi0.4Co[51]  MoNbCrTi0.5Co[58]  Mo0.5NbVCrTi[62]  Mo0.5NbVCr1.5Ti[62]  Mo0.5NbVCr2.0Ti[62]  WTaMoNbVCr[63]  MoNbCrTi0.4[51]  NbHfCrZrTi[59]  NbTiZrVMo[64]  NbTiZrVCr[60]  NbTiZrVAl0.24[64]  Al4CrFeMnTi0.25[65]  Al3CrFeMnTi0.25[65]  NbMoTaWVCr[63]  Al1.5NbTiVZr[66]  CrFe[67]  AlCr1.5NbTiV[68]  AlCrNbTiV[69]  MoNbCrTi[70]  CrMoNbTiVWZr[71]  Cr0.3MoNbTiZr0.3[71]  Cr0.3MoNbTiV0.6Zr0.3[71]  Al12.5Cr25Nb25Ti25Zr12.5[72]  Al12Cr24Mo4Nb24Ti24Zr12[72]  Al11.5Cr23Mo8Nb23Ti23Zr11.5[72]  CrNbTiZr[60]  CrMo0.5NbTa0.5TiZr[73]  TiZrHfNbCr[59] | 6.35  11.08  11.27  6.85  9.29  15.25  18.14  15.71  13.74  7.84  9.25  7.29  11.22  12.52  12.47  10.33  10.43  10.23  6.97  5.5  8.67  7.46  8.65  13.98  9.08  18.56  11.02  11.85  13.55  18.41  12.16  9.64  13.45  17.6  18.94  18.07  18.1  18.57  18.07  15.52  16.92  17.15  19.14  13.71  14.68  16.94  16.01  14.76  13.99  15.05  15.54  17.09  14.61  13.19  10.29  10.55  10.22  9.4  9.67  9.64  10.72  8.36  11.06  9.49  9.42  6.91  10.58  11.27  9.86  9.03  10.64  10.86  6.3  10.5  9.17  7.32  7.53  7.73  11.27  7.91  9.1  9.86  10.03  10.5  9.86  10.41  9.96  10.02  10.27  15.23  16.19  16.17  16.42  15.08  15.36  15.77  19.93  19.89  19.9  19.73  19.73  19.76  19.77  19.74  19.74  19.74  19.86  19.86  19.83  12.06  6.68  5.49  6.29  5.5  7.24  10.95  11.49  5.7  6.12  6.26  6.53  6.76  6.94  7.09  7.21  7.31  4.09  4.06  4.04  9.43  7.5  4.8  5.58  5.54  10.94  5.43  5.35  4.71  6.49  6.27  6.04  4.81  16.72  15.84  4.42  4.96  5.6  6.34  6.71  7.18  7.17  7.16  9.05  13.14  18.08  19.81  7.46  8.51  6.81  6.97  6.24  8.13  5.89  7.38  3.33  3.54  6.29  6.37  6.65  6.53  19.02  2.22  3.12  3.97  5.16  6.04  4.71  5.79  6.53  6.05  6.31  8.62  8.67  5.16  5.28  4.96  16.19  8.77  8.67  5.79  6.53  6.05  6.24  6.31  5.92  6.21  6.36  4.65  5.81  8.62  6.84  8.67  6.85  6.01  6.22  4.65  6.06  0.32  6.29  5.9  5.92  7.55  5.74  5.95  7.72  7.61  7.49  8.77  8.03  8.62 | 0.12  0.2  0.29  0.16  0.16  0.26  0.35  0.26  0.3  0.11  0.22  0.13  0.3  0.29  0.3  0.27  0.25  0.26  0.14  0.12  0.23  0.26  0.24  0.22  0.14  0.3  0.3  0.28  0.25  0.29  0.18  0.17  0.26  0.37  0.4  0.38  0.38  0.39  0.39  0.31  0.37  0.37  0.42  0.26  0.28  0.37  0.35  0.32  0.27  0.29  0.32  0.38  0.32  0.28  0.26  0.26  0.26  0.27  0.26  0.25  0.23  0.23  0.25  0.23  0.22  0.19  0.24  0.24  0.22  0.2  0.24  0.24  0.13  0.34  0.14  0.28  0.27  0.25  0.17  0.18  0.19  0.34  0.28  0.28  0.27  0.27  0.27  0.29  0.28  0.33  0.33  0.33  0.35  0.35  0.35  0.35  0.22  0.19  0.21  0.18  0.18  0.18  0.19  0.18  0.18  0.18  0.19  0.21  0.19  0.27  0.14  0.14  0.15  0.15  0.15  0.16  0.2  0.13  0.14  0.14  0.14  0.14  0.15  0.15  0.15  0.15  0.12  0.12  0.12  0.24  0.15  0.11  0.21  0.23  0.27  0.23  0.24  0.23  0.16  0.16  0.15  0.12  0.14  0.13  0.05  0.07  0.09  0.11  0.12  0.17  0.17  0.17  0.27  0.28  0.3  0.3  0.15  0.12  0.09  0.25  0.22  0.17  0.33  0.28  0.16  0.17  0.11  0.1  0.1  0.1  0.06  0.05  0.07  0.09  0.12  0.04  0.04  0.22  0.23  0.22  0.23  0.14  0.12  0.33  0.33  0.34  0.06  0.12  0.12  0.22  0.23  0.22  0.22  0.23  0.18  0.17  0.16  0.32  0.25  0.14  0.27  0.12  0.12  0.08  0.09  0.32  0.11  0.09  0.04  0.04  0.25  0.34  0.28  0.26  0.1  0.15  0.19  0.12  0.22  0.14 | -22.58  -48.64  -23  -30  -23.68  -13.12  -13.11  -12.15  -37.6  -20  -21.28  -41.25  -3  -49  -4  -27.36  -15.2  -23.52  -17.18  -7.93  -34.08  -16.11  -32.19  -35.2  -24.88  -33.35  -8.45  -24.88  -34.92  -33.36  -25.88  -24.94  -14.26  -10.2  -11.3  -12.39  -13.29  -14.69  -10.92  -13.04  -10.2  -10.39  -11.75  -13.78  -16.22  -10.26  -9.6  -8.73  -15.03  -17.76  -17.83  -10.31  -8.55  -7.58  -5.71  -5.71  -5.71  -5.71  -7.21  -6.98  -7.17  -6.9  -6.37  -6  -5.46  -4.4  -41.93  -46.54  -35.04  -32.88  -39.62  -39.35  -32.16  -22.27  -22.72  -36.05  -30.97  -25.72  -26.37  -19.93  -25.96  -31.27  -24.97  -27.23  -23.89  -24.36  -23.14  -31.46  -25.18  -31.42  -33.6  -32.31  -28.79  -27.41  -26.95  -26.27  -19.19  -19.61  -19.21  -19.53  -19.72  -19.35  -19.27  -19.86  -19.75  -19.64  -19.55  -19.22  -19.48  -8.05  -16.32  -12  -13.44  -8.13  -14.04  -14.88  -24.89  -6.75  -8.44  -10.11  -11.6  -12.89  -14.02  -15  -15.86  -16.6  -4.07  -4.71  -5.25  -34.11  -23.91  -21.5  -2.68  -3.08  -8.95  -2.72  -3.15  -2.13  -2.7  -2.52  -2.34  -1.48  -30.98  -30.75  -16.51  -16.83  -17.19  -17.44  -17.32  -23.05  -22.48  -21.88  -5.78  -15.34  -29.71  -35.1  -26.4  -10.08  -16.61  -2.2  -12.77  -6.4  -6.08  -3.35  -0.96  -0.28  -12.07  -14.8  -17.98  -19  -15.36  -20.81  -21.21  -21.55  -20.94  -17.5  -15.83  -11.75  -13.44  -12.34  -12.94  -4  -4.64  -4.46  -4.59  -4.25  -18  -5  -4.64  -11.75  -13.44  -12.34  -12.77  -12.94  -4.35  -4.8  -5.02  -4.89  -5.74  -4  -2.72  -4.64  -5.99  -14.99  -15.31  -4.89  -21.55  -1  -13.75  -14.56  -5.5  -5.55  -4.28  -3.8  -14  -13.5  -12.99  -5  -4.92  -4 | 16.01  13.25  5.76  5.76  13.38  13.38  14.9  14.53  13.38  13.38  13.38  4.68  5.76  5.76  5.76  13.38  13.38  13.38  16.01  14.7  13.38  14.9  17.29  12.18  10.64  13.66  9.45  8.79  11.26  12  11.6  10.55  7.37  9.05  8.67  10.06  10.04  10.04  8.56  10.04  8.46  8.29  7.7  8.29  8.24  8.04  7.9  7.8  7.87  7.47  6.7  7.12  7.37  7.12  7.12  7.12  7.12  7.12  8.01  7.81  6.79  6.81  6.61  6.84  6.07  5.31  11.51  8.95  7.8  7.47  9.63  9.3  5.58  6.61  8.77  10.56  10.31  9.92  11.3  9.77  10.31  10.85  10.85  10.85  10.85  10.49  10.49  10.49  9.41  9.23  9.44  10.02  8.98  8.81  8.62  8.17  7.86  7.65  7.65  7.42  7.42  6.58  6.58  8.55  8.23  7.86  7.42  7.42  7.18  7.37  13.38  14.9  14.9  17.29  14.53  13.38  14.9  14.87  14.9  16  16.01  15.97  15.91  15.82  15.72  15.6  15.93  16  16.01  14.9  14.79  11.53  9.92  10.84  11.64  9.12  9.15  8.85  8.34  8.06  7.77  5.65  14.22  14.87  12.2  12.71  13.15  13.38  13.25  11.12  11.18  11.21  13.6  14.17  14.54  14.55  13.38  12.71  14.43  14.17  13.01  13.38  13.38  12.89  5.8  5.8  12.71  12.14  13.25  12.98  4.16  10.02  10.69  11.24  11.38  11.53  12.71  11.53  13.38  12.57  13.15  13.38  13.38  12.47  12.83  11.53  4.68  11.53  13.38  11.53  13.38  12.57  13.01  13.15  13.15  12.95  12.6  14.9  11.07  13.38  13.38  13.38  12.68  10.51  11.31  14.9  13.25  5.76  13.25  13.38  11.53  16.18  12.32  13.97  12.97  13.84  14.25  11.53  14.53  13.38 | AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  AM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  IM  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Supplementary References

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