Beryllium – Copper – Magnesium

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Introduction

[1939Pog] investigated the structure and properties of Cu based alloys containing up to 2.5 mass% Be (15.3 at.% Be) and 0.6 mass% Mg (1.6 at.% Mg). The alloys were annealed at 800°C for 3 h, quenched from this temperature and subsequently aged. According to microscopy observations magnesium and beryllium decreased the solubility of each other in solid copper. However, the (Cu) solid solution area was not outlined by [1939Pog].
[1940Gor] investigated crystals, segregated in Be-Cu-Mg alloys during solidification, using chemical analysis and X-ray diffraction. The composition of the crystals corresponded to the formula $Cu_4Mg_3Be_2$. The crystal structure of this phase belongs to the Cu_2Mg type, and it was considered to be a Cu_2Mg based solid solution.
[1940Pog] investigated the Be-Cu-Mg alloys in the Cu corner up to 2.5 mass% Be (15.3 at.% Be) and 2.8 mass% Mg (7 at.% Mg). Thermal analysis, microscopic methods and hardness measurement were used to characterize the samples. The phase equilibria in this part of the system were investigated and five isothermal sections of the phase diagram at 800, 725, 650, 500 and 250°C were constructed in the investigated concentration range. These sections show the solubility limits of the (Cu) solid solution at different temperatures and the connected phase areas. [1940Pog] also established the invariant eutectic four-phase equilibrium in the Cu corner area.
[1956Gla] presented a review on some intermetallic compounds. The solubility of Be in Cu_2Mg is approximately 1 at.% at 400°C.
[1967Sta] investigated the structure of an alloy with the composition $CuMgBe_2$ by X-ray diffraction. Two phases, Cu_2Mg, and a ternary compound with the Cu_2Mg type structure, were detected in the sample. For the ternary compound [1967Sta] gave the composition $CuMgBe_4$. The results of [1967Sta] were consistent with [1940Gor] concerning the existence of a ternary phase with the Cu_2Mg type structure; however, a different composition and lattice parameter were given.
[1945Los] studied the Be-Cu-Mg system in the Mg rich area. Copper and beryllium were both added to molten magnesium held at 900°C. After solidification the alloys were analyzed microscopically and the results of the observation were used to estimate the beryllium solubility in liquid magnesium in the presence of copper. Furthermore, [1945Los] used resistivity measurements to determine the beryllium solubility in solid magnesium alloys containing copper.
In the review [1979Dri] the data of [1940Pog] were reproduced.

Binary Systems

The binary phase diagrams Be-Cu and Cu-Mg are accepted from the MSIT Binary Evaluation Program [2006Wat] and [2002Iva], respectively.

Solid Phases

Experimental data reported by [1940Gor] and [1967Sta] concerning the $CuMgBe_4$ and $CuMg_3Be_2$ compounds with the Cu_2Mg type structure do not allow a distinction between whether these compounds are different ternary phases or correspond to two compositions of a single solid solution. According to [1945Los] the solubility of beryllium is less than 0.3 at.% in magnesium alloys containing 0.38 and 0.77 at.% Cu and 0.42 at.% in a magnesium alloy with 1.95 at.% Cu. However, the description of the experiments in [1945Los] does not allow a conclusion to be made about which solid phase contains beryllium.
Solid phases in the investigated parts of the ternary system are listed in Table 1.

Invariant Equilibria

The only reported ternary invariant equilibrium is of the eutectic type and is located in the Cu corner of the system [1940Pog]. The equilibrium reaction and compositions of the phases are given in Table 2. The equilibrium temperature was established roughly as the average of four values within the limits 656-694°C, determined by [1940Pog] for four alloys of different compositions. The composition of the (Cu) solid solution participating in the equilibrium was estimated from the double saturation points on the isothermal sections. The Cu_2Mg composition was accepted taking into consideration some solubility of Be in this phase, showed by [1956Gla], and the Cu-Mg binary phase diagram. The compositions of the liquid and β phases could not be estimated reasonably from the existing data.

Liquidus Surface

Figure 1 shows isotherms of the liquidus surface, constructed using thermal analysis data from [1940Pog] and the binary systems. According to [1945Los] the solubility of beryllium in liquid magnesium increases with increasing copper content and is smaller than 0.40, 0.55, 1.1 and 3.90 at.% Be at 0.55, 1.35, 1.95 and 4.0 at.% Cu, respectively. The beryllium solubility in liquid magnesium seems to be too high and needs to be confirmed because of many unsuccessful attempts to make Be-Mg alloys by various methods [1987Nay].

Isothermal Sections

Figures 2 to 5 display isothermal sections of the Be-Cu-Mg phase diagram at 800, 725, 650 and 500°C. The sections were constructed after [1940Pog] with minor corrections to comply with the binary systems. In the sections at 725 and 800°C (Figs. 2 and 3) two supposed fields with the liquid phase are separated by a dashed line, instead of one "solid + liquid" field, given by [1940Pog]. The 800°C isothermal section is also slightly corrected to be consistent with other isothermal sections reported by [1940Pog].

Notes on Materials Properties and Applications

Mechanical properties and ageing behavior of Be-Cu-Mg alloys have been studied in [1940Pog]. The ageing slows down in alloys with 2 and 2.5 mass% Be at Mg content 0.4-0.8 mass%. Alloys containing 2.5Be-0.4Mg (mass%) and 1.8Be and 0.4-0.8 mass% Mg after quenching from 800°C and ageing at 350°C have the same hardness as alloys without Mg with 2.5 mass% Be, but have lower impact toughness comparing with non-magnesium bronzes [1940Pog].

References

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Table 1: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(Cu) < 1084.62	*cF*4 $Fm\bar{3}m$ Cu	*a* = 361.46	at 25°C [Mas2]
(Mg) < 650	*hP*2 $P6_3/mmc$ Mg	*a* = 320.94 *c* = 521.07	at 25°C [Mas2]
(βBe) 1289 - 1270	*cI*2 $Im\bar{3}m$ W	*a* = 255.15	HT, dissolves ≈ 17 at.% Cu at 1199°C [2006Wat]
(αBe) < 1270	*hP*2 $P6_3/mmc$ Mg	*a* = 228.59 *c* = 358.45	LT, at 25°C [Mas2] dissolves 9.5 at.% Cu at 1109°C [2006Wat]
$CuMg_2$ < 568	*oF*48 Fddd $CuMg_2$	*a* = 907 *b* = 528.4 *c* = 1825 *a* = 905 *b* = 528.3 *c* = 1824.7 *a* = 904.4 ± 0.1 *b* = 527.5 ± 0.1 *c* = 1832.8 ± 0.2	[2002Iva]
Cu_2Mg < 797	*cF*24 $Fd\bar{3}m$ Cu_2Mg	*a* = 702.1	64.7 to 69 at.% Cu [2002Iva]
β, Cu_3Be 900 - 618	*cI*2 $Im\bar{3}m$ W	*a* = 280	24.5 to 41.7 at.% Be at 850°C [2006Wat]
γ, CuBe < 933	*cP*2 $Pm\bar{3}m$ CsCl	*a* = 270.2 ± 0.3	46.2 to 49 at.% Be at 850°C

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
δ, $Cu_{1-x}Be_{2+x}$ < 1219	*cF*24 $Fd\bar{3}m$ Cu_2Mg	a = 595.2 a = 589.9	x varies from 0.071 at 930°C to 0.455 at 1090°C at 66.7 at.% Be at 75 at.% Be [2006Wat]
* $CuMgBe_4$	*cF*24 $Fd\bar{3}m$ Cu_2Mg	a = 600.4	[1967Sta]
* $Cu_4Mg_3Be_2$	*cF*24 $Fd\bar{3}m$ Cu_2Mg	a = 687	[1940Gor]

Table 2: Invariant Equilibria

Reaction	T [°C]	Type	Phase	Composition (at.%)		
				Be	Cu	Mg
L ⇌ (Cu) + β + Cu_2Mg	~656 to ~694	E	L	?	?	?
			(Cu)	~9.3	~86.0	~4.7
			β	?	?	?
			Cu_2Mg	~1	~66	~33

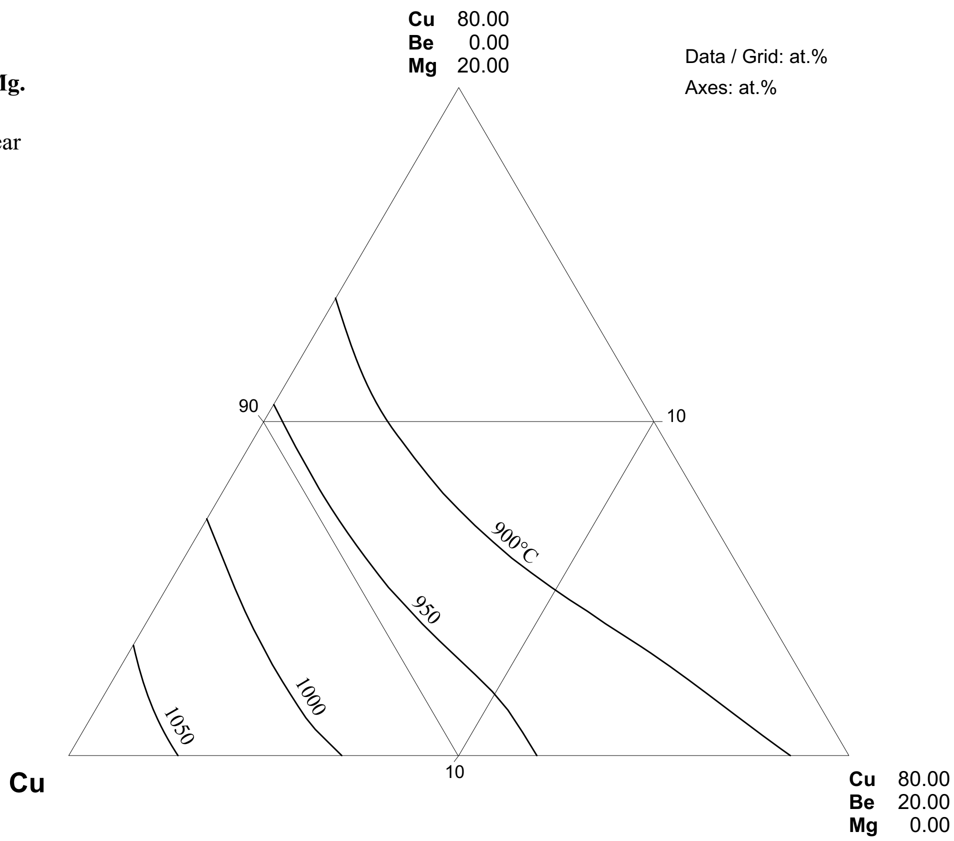

Fig. 1: Be-Cu-Mg. Isotherms of the liquidus surface near the Cu corner

Fig. 2: Be-Cu-Mg. Part of the isothermal section at 800°C near the Cu corner

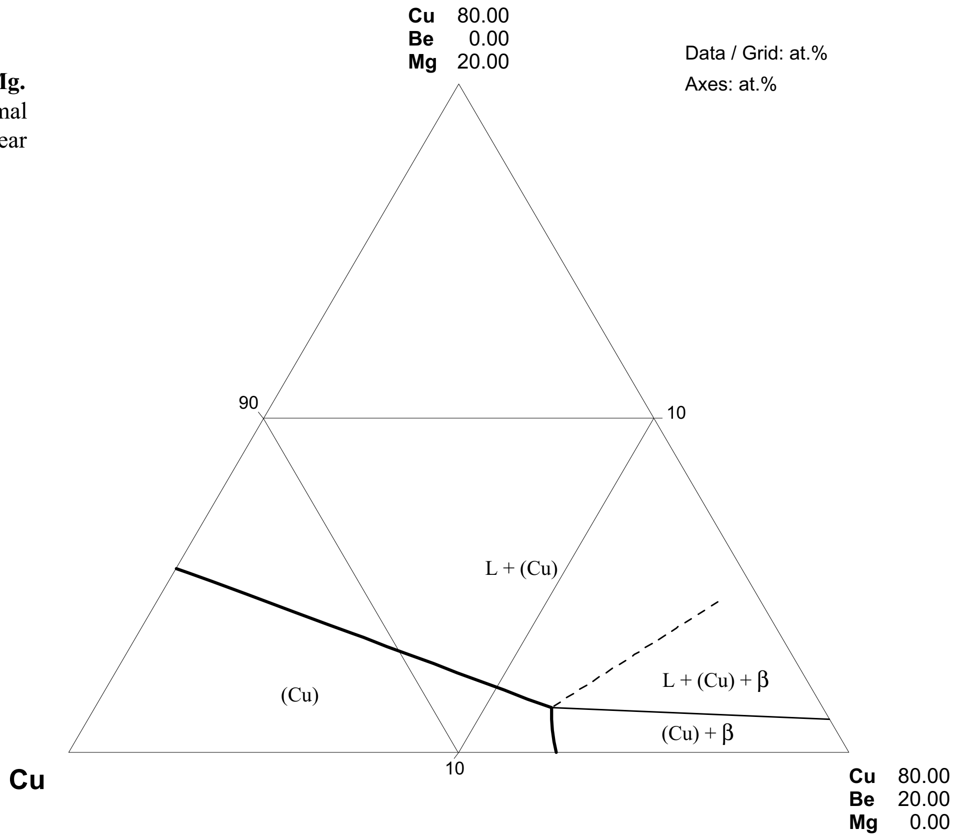

Fig. 3: Be-Cu-Mg. Part of the isothermal section at 725°C near the Cu corner

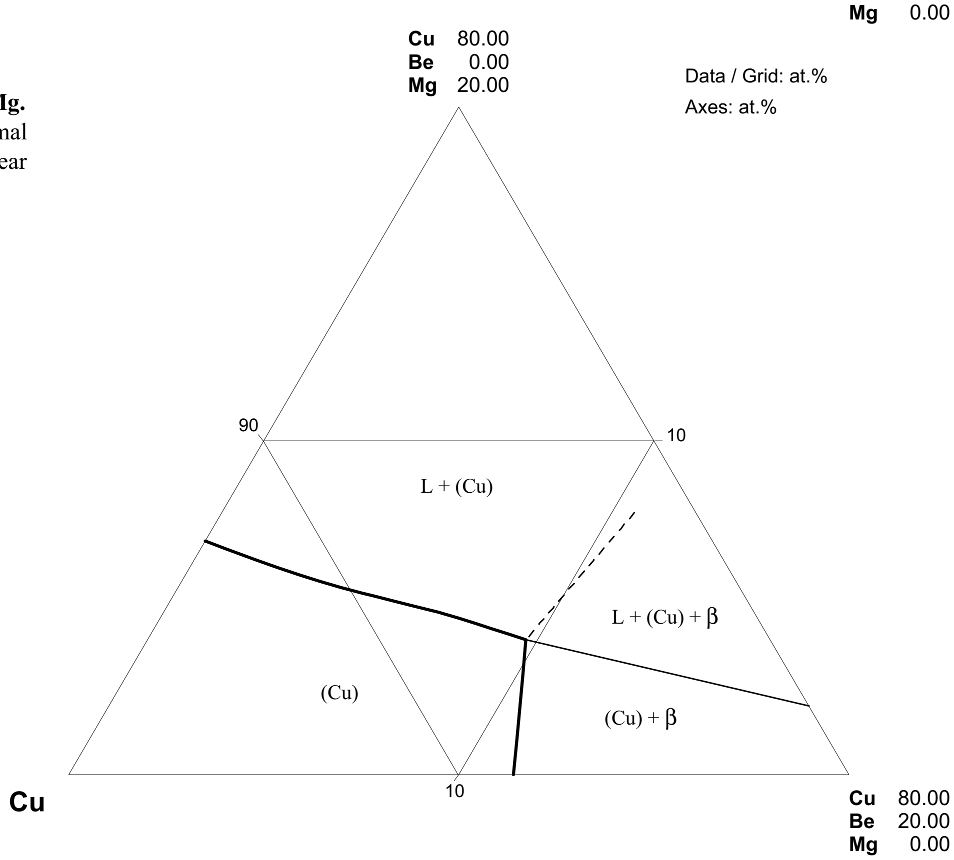

Fig. 4: Be-Cu-Mg.
Part of the isothermal section at 650°C near the Cu corner

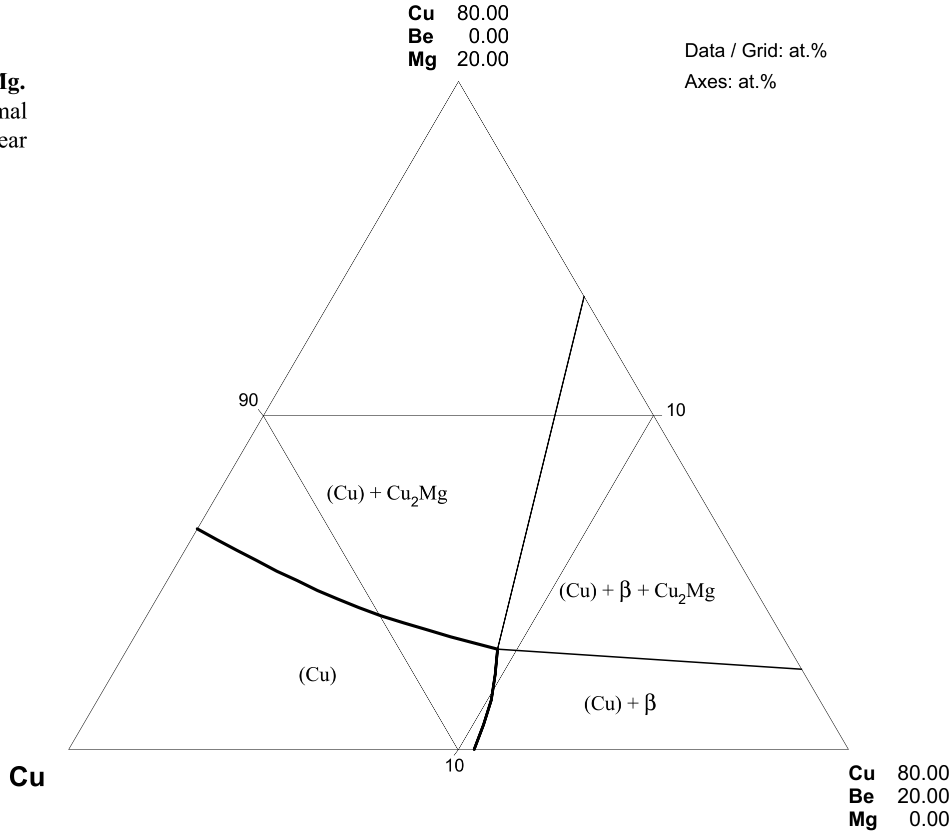

Fig. 5: Be-Cu-Mg.
Part of the isothermal section at 500°C near the Cu corner