DEPENDANCE OF STEEL AND ALLOYS PHYSICOMECHANICAL PROPERTIES ANOMALIES WITH PHASE RULE DIAGRAM

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Abstract. Plasticity anomalies relation of single-phase brasses with ~ 32 % Zn, cast with~ 8 % Sn and annealed with ~ 13 % Sn tin bronze, modified with ~ 14 % and non-modified with ~ 12 % Si silumin, aged duralumin with ~ 6 % Cu, annealed steel with ~ 0,5 % C as a result of qualitative changes in temperature extension crystallization interval are confirmed by comparing anomalies with equilibrium and non-equilibrium diagrams Cu – Zn, Cu – Sn, Al – Si, Al – Cu, Fe – C. Here, basing on the anomalies – intermediate phases of the most common alloys are declared – brasses, bronze, silumin, duralumin and steels.

1. Introduction

Having studied the properties of pure components alloys, A.A. Bochvar made a conclusion: “There is no unique dependence between the composition and properties at all”. [1]. I.I. Kornilov made the same conclusion: “It is difficult to determine any strict connection of firmness with equilibrium diagram” [2]. N.I. Belyaev and N.T. Gudtsov were more brief: “Apparent elastic limit (yield limit) has no connection with steel composition” [3]. To conceal obvious anomaly (maximum), E. Gudremon draw the yield limit curve past data point at ~ 0.5 % C [4]. P. Obergoffer in 1915 showed annealed steels yield limit maximum at ~ 0.5 % C [5], but as if did not notice it and made no comments.

Thus, properties anomalies and absence of their connection with alloys-mixtures structure and equilibrium diagram have been known for a century but still don’t have any explanation.

Meanwhile, equilibrium diagram lines are concentration dependencies of crystallization and recrystallization intervals. If these intervals change qualitatively (for example, in dystectic or eutectic points, at the ends of peritectic and eutectic horizontals), “outstanding” properties used commercially appear.

The purpose of our work is to ground the presence of intermediate phases in eutectic and eutectoid systems Cu – Zn, Cu – Sn, Al – Si, Al – Cu and Fe – C. Rarely, but these phases are present, for example, InZn6 (crystal grid is determined) [6] and Pt4Al (Kurnakov point is determined) [7].

2. Methods

As there is no unified classification of intermediate phases according to single characteristic, then the methodological basis of this work are:
1. N.S. Kurnakov, N.V. Ageev and S.A. Pogodin’s refusal in 1928 to use the rule of additive change of properties in eutectic systems (Kurnakov’s rule), “theoretically established by N.S. Kurnakov and S. F. Zhemchuzhniy” in 1908 [8].

2. M. Khansen’s statement: “An intermediate phase may have prominent chemical properties, similar to the properties of chemical compounds, not being a compound by its character and structure” [9].

3. Criteria of an intermediate phase presence – “maximum or minimum or just a fracture on the curve of the properties changes… but to use these curves the explanation of these deviations is not important” [10].

4. Absolute and self apparent connection of the congruent and incongruent melting phases with qualitative changes of crystallization intervals (QALS, where Q is qualitative change, L is liquidus, S is solidus, $\Delta$ is the difference between liquidus and solidus in degrees) [11], [12], [13]. In eutectic and eutectoid systems L stands for liquidus or liquidoid (GOS line in the system Fe – C), and S is solidus or solidoid (PSK line in the same system) [14].

5. Absolute QALS at the ends of the eutectic horizontal, in the eutectic and eutectoid points, at any nonmonotonicity (bend) L, as S in eutectic and eutectoid systems are horizontals [14].

6. As equilibrium diagrams of one and the same system are numerous, “its correspondence to the observed structure and properties” is considered as a “validation and applicability” criterion [15].

7. The pride of place is given to “old” data, which A.A. Bochvar – in the textbook – appreciated more than “new” ones [15].

3. Results
“Cuprum plasticity not only decreases but vice versa increases dramatically… maximal stretch is achieved at 30–32 % Zn”, “saturated $\alpha$-crystals contain about 32 % Zn». These quotes from the fifth issue of the textbook [16] show that there is no explanation of simultaneous enhancement $\delta$ (by $\sim$ 2 times) and $\sigma_c$ (by $\sim$ 1.5 times) of the single-phase brasses. But implicitly the anomaly $\delta$ is connected with the end of the eutectic horizontal ($1032^\circ$ C, 32 % Zn), where there is a qualitative elongation change according to crystallization interval temperature (QALS) with the second component increase or decrease (Fig. 1a).

In 30 years in the sixth edition [16] of the textbook this anomaly for solid solutions is only stated: “Zink increases brasses strength and plasticity” [16].

In the textbook [17] the anomaly $\delta$ of a single-phase brass is not even mentioned, but the curves $\sigma_c$ and $\delta$ for it and tin bronze in annealed and cast states are given. The annealed bronze maximum $\delta$ is at the end of the peritectic horizontal ($799^\circ$C, ~ 13 % Sn) of the equilibrium diagram Cu – Sn (Fig. 1b), and a cast at $\sim$ 8 % Sn (Fig. 1c), that is corresponds to the displaced $\sim$ 8 % Sn to the end of the same peritectic horizontal [14]. In both cases QALS at horizontal ends are obvious.
According to the textbook [17], non-modified silumin of the eutectic composition (~12 % Si) has simultaneous and non-commented maximum $\sigma_c$ and $\delta$ (Fig. 1d), and the modified at ~14 % Si (Fig. 1e). As modifying displaces eutectic point from ~12 to 14 % Si, then in both cases the anomalies $\delta$ are connected with eutectic points, where QALS is obvious. As modifying changes silumin structure, then simultaneous maxima $\delta$ and $\sigma_c$ do not relate to the metallographic structure. Let’s note that in the reference book [18] these curves with maxima $\delta$ and $\sigma_c$ are commented as: “tensile strength increases steadily… percentage elongation declines with silicon increase”, that is wishful thinking takes place.

On the curve $\sigma_c$~Cu of tempered and aged duralumin ~6 % Cu there is a distinct maximum, but $\delta$ at 4~8 % Cu changes insignificantly (Fig. 1f) [19]. L.F. Mondolfo does not comment this anomaly. At ~6 % Cu there is an end of eutectic horizontal (548°C), where QALS is evident. The liquid melt with ~6 % Cu has maximum viscosity [20]. According to the textbook, this maximum “should exist”, if “there is a chemical compound” [20].

P. Obergoffer does not comment annealed steel yield limit absolute maximum $\sigma_S$ with ~0.5 % C, which is an anomaly, and the curve $\psi$~% C draws lower the experimental point at ~0.5 % C [5], that conceals steel high plasticity with ~0.5 % C. Both anomalies on the curves $\sigma_S$ and $\psi$ (Fig. 1h) correspond to abscises of points B and O (~0.5 % C) diagrams Fe~C, which show qualitative changes in intervals and crystallization and recrystallization (due to the bend in the line GOS at point O) [21].

P. Obergoffer results seem to be right: $\psi$ of the normalized steel with 0.6 % C (43.2 %) is greater, than that one of the nearest investigated with 0.49 and 0.69 % C (36 and 27.2 % correspondingly), which is anomaly, as steel yield limit maximum with 0.6 % C (Fig. 1i) [5].

As according to the textbook for metallurgical universities, “There is no comprehensive classification of the intermediate phases according to single characteristic nowadays” [23], than to explain these plasticity anomalies phases ~ Cu4Zn (~32 at. Or mass. % Zn), ~ Cu11Sn (~8 at. or ~13 mass. % Sn), ~ Al:Si (~12 at. or mass. % Si), ~ Al5Cu (~2.5 at. or ~6 mas. % Cu) and ~ Fe2C (~2.3 at. or ~0.5 mas. % C) are declared [13].

These phases have two fundamental characteristics – properties anomalies elongation qualitative changes according to crystallization and recrystallization temperature intervals correspond to them.

Figure 1. Schematic dependance of the mechanical properties on the second component content: a – single-phase brass; b, c – annealed and cast tin bronze; d, e – non-modified and modified silumin; f – hardened and aged duralumin; g, h – cast annealed and normalized steel.
(see., for example, congruent and incongruent melting phases, compositions of type σ-phase in alloys Fe–Cr [23]).

Let’s note that brass with ~ 32 % Zn, differently to silumin ~ 12 % Si or steel with ~ 0.5 % C, is single-phase but all the three have connection of plasticity anomalies with QALS. It corresponds to D. A. Petrov’s observation: “The results received for alloys with continuous series of solid solutions, are easily applicable to the systems forming eutectic mixtures” [25], that is to mixtures-alloys. (D. A. Petrov edited the Russian translation of the famous reference book [9]).

Qualitatively similar dependence of two structural antipodes of the elasticity modules – products of hardening and annealing illustrate D.A. Petrov’s observation: minimum at 0.5–0.6% C and maximum at ~ 0.9 % C [26]. A. M. Samarin with co-authors who found these dependences make the following conclusion: “On the whole this flow of module curves can be explained only admittedly” [26].

Of course, the intermediate phases are also hypotheses. Their formulas should be taken as “convenient denotation” [27] of plasticity anomalies of brass, tin bronze, silumin, duralumin and steel.

### 4. Conclusion

Declared phases ~ Cu₂Zn, ~ Cu₁₁Sn, ~ Al₅Si, ~ Al₉Cu and ~ Fe₄C satisfy two requirements accepted in the physic-chemical analysis – properties anomalies correspond to them and they are close to elongation qualitative changes according to crystallization and recrystallization temperature intervals.

Equilibrium diagrams of silumin, steels and duralumin with the declared phases are at least useful “if the degree of their correspondence to the observed structure and properties is taken as the validation criteria and availability” [1].

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