According to some data, the occurrence of γ-phase regions in the structure of copper-base alloys causes a sharp increase in cavitation resistance [2]. But the figures given in Table 5 show that the cavitation resistance may either increase or decrease according to the nature of the γ-phase.

The data shown in Table 5 also confirm the fact that hardness cannot be a criterion for the cavitation resistance.

CONCLUSIONS

1. The cavitation resistance of bronzes is determined by their structure and phase composition.

2. Resistance to failure depends on the kinetics of work hardening and the nature of the hardened layer obtained by the cavitation process.

3. The hardness of the material cannot be used as a criterion for judging the cavitation resistance of the bronze.

REFERENCES

1. I. N. Bogachev and other. Cavitation Failure of Iron-Carbon Alloys, Mashgiz, 1959.
2. M. G. Timerbulativ et al. "MiTOM", No. 1, 1960.

CRYSTALLIZATION OF ALUMINUM-COPPER ALLOYS AS A RESULT OF ULTRASONIC OSCILLATION

Eng. G. I. ESKIN and Prof. I. N. FRIEDLYANDER

The aim of this paper is to study the effect of ultrasonics on the crystallization of aluminum-copper alloys in different concentrations and to verify the effect of certain factors on the formation of the ingot structure in an ultrasonic field.

For our investigation we took aluminum alloys containing 0, 2, 4, 6, 12 and 33% Cu, made from AV000 aluminum. The metal was melted in a graphite crucible in a resistance furnace and was heated 50° above the liquidus point just before it was tapped. The specimens used were ingots weighing 800 g shaped like truncated cones, about 100 mm high and 70 mm in mean diameter. The metal was cast into chill and single-use molds made of a plaster-asbestos mixture. When casting into preheated chill molds, the mean solidification rate amounted to 120 - 150 deg/min, and when cold plaster-asbestos molds were used, it was 10 - 40 deg/min. Just before it was tapped, the metal was degassed until the vacuum test density was high. The degassing operation was carried out with refined $ZnCl_2$; when the degassing needed to be particularly thorough and also when a certain amount of modifier (titanium) had to be added, we resorted to ultrasonics [1].

The ultrasonic oscillations were produced by a UZG-10 generator and directed into the melt from below [2]. The working instrument - a waveguide for treating the melt - was made of V.T.1 titanium; the frequency of the oscillations ranged from 19 to 21 kilocycles per sec and the intensity was 18 - 20 watt/cm^2*. Furthermore, experiments were carried out with a piezo-electric device [3]; in this case the frequency was 800 kilocycles per sec and the intensity was 10 - 12 watt/cm^2. Two ingots were cast concurrently - a control and an ingot ultrasonically vibrated during crystallization. The experiment was repeated two or three times. For the 5% Cu alloys we made a comparative study of the effect of ultrasonics and low frequency vibrations during chill casting. The vibrations were produced by a ST-300 vibrostand (GDR), which made it possible to crystallize the ingot at 200 cps and an oscillation amplitude of 500 microns.

In order to study the structure, the ingot was cut into two parts, one of them being made into a longitudinal macrotemplet. After photographs had been taken, part of the macrotemplet was made into a microsection. The other half of the ingot was made into a Gagarin specimen. In the case of solid-solution type alloys, we analyzed the interdendritic liquation by the microhardness method using a PMT-3 tester at a load of 20 g. The liquation of copper was in addition studied spectrographically.

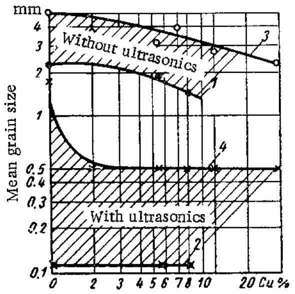

Fig. 1. Variation in mean macrograin size in aluminum alloys containing copper as function of copper concentration and application of ultrasonics:
1, 2 – with modifier; 3, 4 – without modifier

To pass ultrasonics through a melt, it is essential to make sure that the interface between melt and waveguide is wetted [4], [5]. The macrostructure of the ingot is suddenly refined in the zone through which the ultrasonics pass and remains coarse in the region which has either crystallized before the application of ultrasonics (for example, near the walls), or is too far away from the vibration source.

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*) The intensity was assessed by colorimetry in water; the amplitude was 18 μ.

Figure 1 shows the variation in macrograin size in alloys of the aluminum-copper system both modified (0.2%) and unmodified with titanium. When ultrasonics are passed through an alloy with a modifier, the effectiveness is considerably increased. This is observed during the crystallization of pure AV000 aluminum (Fig. 2).

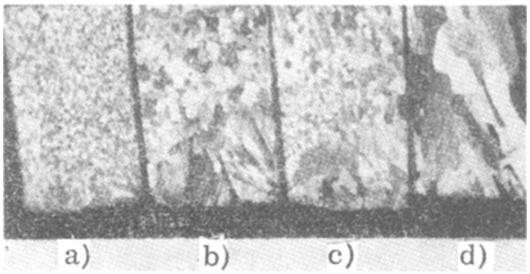

Fig. 2. Microstructure of AV000 aluminum. Etching with iron chloride, modified with 0.2% Ti; a, b — with ultrasonics, c, d — without ultrasonics

As can be seen from the graph, when the Ti content is 0.2%, the refinement due to the ultrasonics is increased by almost one order of magnitude. According to data in [6], low-frequency vibration effects the modified alloy by disrupting the modification and coarsening the structure.

Similar data have been obtained for aluminum alloys containing copper and silicon. Figure 3 shows the variation in the micrograin size as a function of the copper content

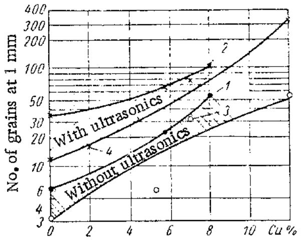

Fig. 3. Variation in micrograin size of aluminum-copper alloys with concentrations of copper content and application of ultrasonics; 1, 2 — with modifier; 3, 4 — without modifier

and the application of ultrasonics in both modified and unmodified alloys. It can be seen from this graph that the precipitation of a second phase toughening the alloy and refining its structure levels out the action of the modifier. This is confirmed by mechanical test data.

In the investigations described in [7, 8], it is pointed out that the effect of the oscillations transmitted to the melt does not depend on the frequency, but only on the intensity of the ultrasonics. The use of low-frequency vibration (50 - 20 cps) shows that an increase in intensity leads to a porous ingot [9], since the metal begins to splatter and air is sucked in. Our comparative experiments on casting an alloy containing 5% Cu in a vibration field and an ultrasonic field shows that the results differ (Fig. 4). In the vibration experiments, the ingot vibrated together with mold fixed to the lathe; in the case of ultrasonics the mold was stationary and the oscillations were only transferred to the liquid metal. The crystallization time amounted to 40 or 50 sec. In the case of the ultrasonically-vibrated ingot, we observed a sudden refinement of the whole volume of metal, except for the walls which had solidified before the ultrasonic waves had reached them.

Fig. 4. Macrostructure of aluminum ingots with 5% Cu. Etching with ferrous chloride: a — without ultrasonics; b — crystallization in ultrasonic field; c — crystallization in vibration field

During low-frequency vibration the refinement of the grains seemed less than when using ultrasonics; clearly, in vibration the movement of the metal inside the melt is slight. In crystallization due to ultrasonics there is intensive motion within the melt, since the ultrasonic wave is transmitted directly to the metal. The microstructure of an alloy which has been ultrasonically vibrated during crystallization not only differs considerably by having a fine structure, but also from the point of view of greater homogeneity of the solid solution.

Of great importance in forming structure in an ultrasonic wave field is the crystallization rate. In slow solidification the refinement is not always observed, whereas during rapid solidification we observe refinement of all the alloys (from the pure metal to the eutectic). Clearly, an increase in time over which the solid-liquid state continues to exist means that the crystal formations obtained by ultrasonic machining can be remelted. Furthermore, the crystallization range and the associated ratio between the amount of solid and liquid phase is also important for the continued existence of the crystal centers formed. For example, the effect of ultrasonics on slow crystallization of the aluminum alloy containing 2 and 4% Cu proved to be different: in the case of the 2% Cu alloys the microstructure did not become refined, whereas for the 4% Cu alloy there was a very fine structure after ultrasonic treatment. This difference in the ultrasonic effect was detected in solid-solution type alloys.

In the case of the pure metal and the eutectic alloy the cooling rate was not observed to have any such effect. Figure 5 shows the dependence of the strength of alumina alloys containing copper on the cooling rate, the copper content and the application of ultrasonics. For alloys rich in second phase the effect of ultrasonics is reduced, this evidently being due to the over-all alloying effect of the copper.

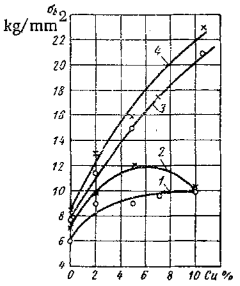

Fig. 5. Variation in ultimate strength as function of copper concentration, cooling rate and application of ultrasonics: 1, 2 — cooling rate 30 deg/min; 3, 4 — 140 deg/min; 1, 3 — without ultrasonics; 2, 4 — with ultrasonics

In [8] an attempt was made to explain the coarsening of the eutectic component by the vibration. Our experiments showed that the effect of ultrasonics is confined to refinement of the solid solution crystals; no coarsening of the eutectic structure proper was observed.

Observation of the liquation of copper in the aluminum-copper system shows that ultrasonics have an extremely slight effect on the distribution of copper and may even intensify the liquation if the content of it is very small.

Ultrasonic vibrations greatly speed up diffusion, hence, it may be assumed that during the crystallization of solid solutions of aluminum and copper the effect of ultrasonics reduces or even eliminates liquation within the grain.

Figure 6 shows a microphotograph of a grain of 5% Cu aluminum alloy. The pyramid indentations show that the crystallization in the ultrasonic field results in more uniform properties in the metal grain.

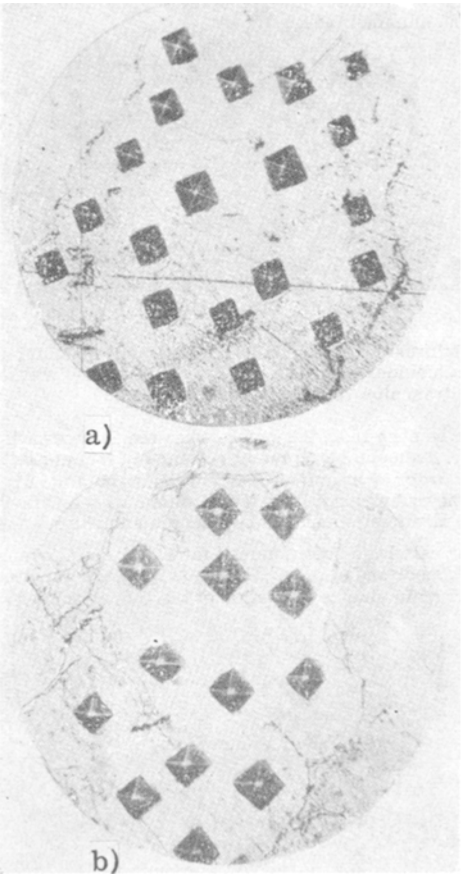

Fig. 6. Distribution of microhardness within one grain (5% Cu alloy) × 600: a — without ultrasonics; b — with ultrasonics

We studied crystallization of pure aluminum at 820 kps. The table shows the results of mechanical tests on the Gagarin specimens.

MECHANICAL PROPERTIES OF ALUMINUM
AV000

Casting temperature, C	Frequency in kcps	Mechanical properties		
		σ_b kg/mm^2	δ %	HB
740	—	6.0	27	18
740	20	7.3	32	22
730	—	5.0	22	15
730	800	12.0	32	22

Examination of the microstructure of the ingots showed that the ultrasonics fade considerably at a frequency of 800 kgt. Even 2 cm from the radiating surface there was no refinement. For the 10 cm high ingots used to study the process at 20 kcps, no attenuation was detected.

It is known that refinement of the macrostructure is not always accompanied by an increase in strength and plasticity. It has been established [10] and [11] that an increase in the cooling rate, which leads to improved mechanical properties, refines the internal structure of the grains as a whole.

Analysis of data for the effect of ultrasonics on the structure and properties of aluminum-copper always shows that within the concentrations studied, ultrasonics have the greatest effect on solid-solution type alloys. When the copper concentration is higher, the effect of the ultrasonics is reduced; this is confirmed by variation in microstructure and chemical properties. Refinement of the macrostructure is observed for all concentrations.

The effect of ultrasonics in the presence of a modifier is considerably strengthened, and the micrograin of pure aluminum is refined by almost a factor of 12.

The present-day composition of aluminum alloys are complex, ternary and quarternary systems with the addition of rare earth and high-melting metals which impart the desired properties to the alloy.

In order to gain a correct idea of the effect of ultrasonic vibrations on the structural components of an alloy, it is important to know the mechanism by which the oscillations act on the solid solution, eutectic and primary crystals of the intermetallide components.

In intricate-shape and continuous casting of aluminum, magnesium and other alloys, it is still difficult to obtain a fine equiaxial structure, but one which can be solved by using ultrasonics. Data on the effect of ultrasonics on different structural components in aluminum-copper alloys are of importance for analysis of the effect on alloys of other systems.

CONCLUSIONS

1. In the Al-Cu system, the greatest effect gained from ultrasonics is in alloys of the solid-solution type.

2. Experiments on the effect of ultrasonics on pure metal and metal with the addition of a modifier confirm the theory that the primary solid nuclei are destroyed. However, apart from the destruction process, we have to assume the possibility of accelerated formation of crystal nuclei due to the energy fluctuations transmitted to the melt by the ultrasonic wave, or else through activiation of the impurities.

3. Ultrasonics reduce inter-dendritic liquation by speeding up diffusion of the copper during crystallization of the solid solution.

4. Ultrasonic oscillations greatly affect the microstructure of the alloy, whereas low-frequency vibrations only change the macrostructure.

REFERENCES

1. M. P. Al'tman and others. Izvestiya ANSSSR, Ser. Metal. i Top., No. 3, 1959.
2. Ya. B. Gurevich and others. "Stal'", No. 5, 1957.
3. V. I. Slotin and other. Izvestiya AN SSSR OTN, No. 9, 1957.
4. V. V. Zaboleyov-Zotov and other. "Metallography and Metal Working", No. 1, 1958.
5. I. I. Teumin. Theory and calculation of the addition of elastic oscillations to molten metal. Problems of metallography and physics of metals, Issue 4, Coll. TsNIIChermet, Metallurgizdat, 1955.
6. L. Kubtschek and other. "Foundry Production", No. 5, 1959.
7. G. Schmidt and A. Roll, "Zeitschrift Electroche.", Bd. 45, No. 10, 1939.
8. K. V. Garlik and J. F. Wallace, "Modern Castings", Vol. 35, No. 6, 1959.
9. I. G. Polotskiy and other. Effect of sonic and ultrasonic frequency oscillations on crystallization. Proc. All-Union Conference on Use of Ultrasonics in Industry, Dzerzhinskiy DNTP Press, 1957.
10. V. I. Dobatkin. Aluminum Alloy Ingots, Metallurgizdat, 1960.
11. I. N. Friedlyander. Study of effect of solidification rate on structure and properties of aluminum alloys. Proc. Conference on Theory of Casting Processes, "Solidification of Metals", Mashgiz, 1958.

HEAT TREATMENT AND MECHANICAL PROPERTIES OF ALLOYS IN THE SYSTEM Ti-Mo-Al

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The aim of our research was to study the properties of alloys in the system Ti-Mo-Al after heat treatment. We prepared alloys with a total content of up to 9% molybdenum and aluminum with respect to the radial section of the titanium angle of the system, the ratio between the molybdenum and aluminum being 3:1, 1:1 and 1:3, and also binary titanium - molybdenum and titanium-aluminum alloys. For purposes of comparison we also studied nonalloyed titanium.

To melt the alloys, we used titanium sponge TG0 (ultimate strength 40 kg/mm^2), A00 aluminum and molybdenum powder (99.9% Mo). The materials were melted by the double-melting method in a vacuum-arc furnace with consumable electrodes. Ingots weighing 5 kg were made by conventional techniques into sheets 1.2 mm thick and also forged into billets 12 × 12 mm as the specimens. The chemical composition of the alloys is shown in Fig. 1.

The mechanical properties of the alloys were determined from the sheet specimens cut across the direction of rolling. Two annealed specimens with a working area 10 mm wide and 5 mm long were tested each time.