The method used here reliably reflects the effect of decarbonization on the strength of the cylindrical walls of pressure vessels, as was confirmed in tests: experimental cylinders free of any defects that might affect their strength had breaking pressures which were consistent with the values calculated by the above method. The cylinders fractured through the cylindrical walls.

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EFFECT OF THE PEAK TEMPERATURES AND OF THE COOLING RATE ON THE DAMPING PROPERTIES OF MANGANESE–COPPER BASE ALLOYS

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It was shown in [1, 2] that alloys of the system Mn–Cu–Zn are distinguished by a favorable combination of high damping ability, strength, and ductility. It is, however, very important that actual products made of these alloys have a high level of energy losses.

When structures are produced, the alloy may be subjected to various thermal effects (e.g., in consequence of the technological operation of welding) which may change its initial damping properties.

To determine the effect of various peak temperatures and cooling rates on the damping ability of copper–manganese alloys at normal temperature, we carried out the respective tests on an installation KD-1 [3].

We investigated alloys differing in chemical composition as well as by the regimes of heat treatment in the initial state (before heat cycling). Heat cycling consisted in heating blanks of a copper–manganese alloy to 200-850°C with subsequent cooling at rates of 5 to 150-200°C/sec. After the heat cycling, specimens for investigating the damping properties were made from the blanks.

Heat cycling was applied to alloys in different initial states (cast, hardened, hardened + tempered). The chemical composition of the alloys concerned is presented in Table 1.

The investigations showed (Fig. 1) that heating from 200 to 400°C and subsequent cooling at rates from 5 to 150-200°C/sec has practically no effect on the damping ability of the alloy in the cast state. Further heating to 600 or 850°C with the same cooling rates causes a noticeable lowering of the level of the dissipative properties of the alloy (by a factor of 1.5-2).

The cooling rate has practically no effect on the damping properties of the investigated alloys in the cast state after they have been heated to between 200 and 850°C. However, the peak temperature to which the alloy is heated causes a substantial change of its dissipative properties independently of the cooling rate. The greatest change in the damping ability of the alloys in the cast state is found when they are heated to 600°C or more.

Alloys of the system Mn–Cu–Zn in the cast state are characterized by general inhomogeneity and liquation in regard to the chemical composition, and the cooling conditions have the effect that the structure of the alloys, together with γ(fcc)-phase, also contains the tetragonal γ_t-phase whose presence is decisive for the high damping of these alloys. The γ_t-phase is distributed nonuniformly throughout the bulk, and in consequence damping is not

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TABLE 1. Chemical Composition, %, of the Investigated Alloys

Alloy No.	Mn	Si	C	Zn	Cu
1	53,55	0,09	0,17	7,8	Remainder
2	54,56	0,42	0,21	6,77	»
3	52,77	0,07	0,04	9,72	»
4	54,85	0,06	0,15	7,0	»
5	53,60	0,11	0,04	9,94	»
6	52,94	0,04	0,03	11,21	»
7	53,27	0,05	0,04	10,67	»
8	52,61	0,04	0,04	11,29	»

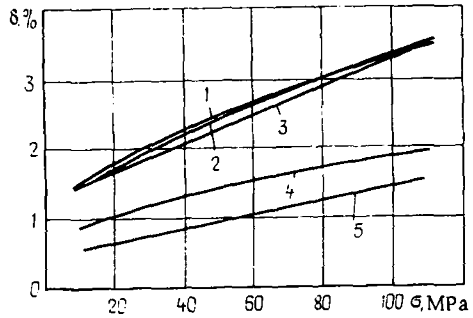

Fig. 1. Dependence of the vibration decrement of specimens of alloy No. 1 on the amplitude of the cyclic stresses in the cast state (1) and also after heating to 200°C (2), 400°C (3), 600°C (4), 850°C (5) and cooling at rates from 5 to 150°C/sec.

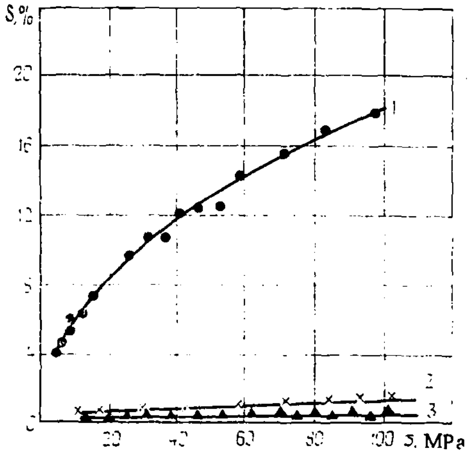

Fig. 2. Dependence of the vibration decrement of specimens of alloy No. 3 on the amplitude of the cyclic stresses after the full heat treatment regime (curve 1) and also after additional heating to 600°C with subsequent cooling at rates of 35-50°C/sec (curve 2), 5 and 150-200°C/sec (curve 3).

optimal. Heating to 200°C practically does not change the structure of the cast alloy but it causes relaxation of the internal stresses arising in consequence of the nonuniform cooling of all volumes of the material after casting, and this leads to a slight lowering of the damping ability. Heating to 400°C also causes relaxation of the internal stresses in the alloy, and this manifests itself in a slightly lower damping ability of the alloy.

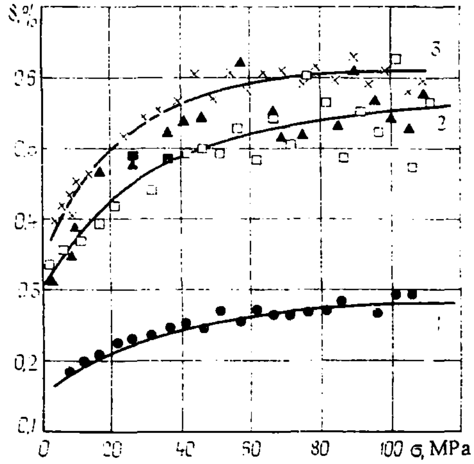

Fig. 3

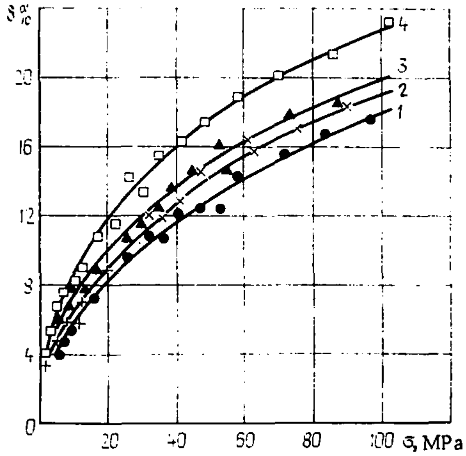

Fig. 4

Fig. 3. Dependence of the vibration decrement of specimens of alloy No. 3 on the amplitude of the cyclic stresses after hardening (curve 1), and also after additional heating to 400°C with subsequent cooling at rates of 35-50°C/sec and 150-200°C/sec (curve 2), 5°C/sec (curve 3).

Fig. 4. Dependence of the vibration decrement on the amplitude of the cyclic stresses for specimens of alloy No. 3 subjected to tempering at 400°C, 4 h after being heated to 600°C and cooled at different rates: 1) hardening + tempering (without heat cycling); 2) cooling at the rate of 5°C/sec; 3) 150-200°C/sec; 4) 35-50°C/sec.

It was shown previously [1] that the temperature of 400°C is close to the critical temperature at which spinodal decomposition of the γ(fcc)-solid solution occurs, i.e., we find segregation of the atoms of the solid solution (of manganese and copper) and the formation of regions enriched with and deficient in manganese. In regions enriched with manganese, at temperatures close to 400°C, γ_t-phase is bound to form, and consequently also twins which cause high damping of the alloy.

As a result of rapid heating to 400°C and fairly high cooling rates at which the process of heat cycling proceeds, the γ_t-phase in reality did not manage to form, and the damping properties did not increase; on the contrary, in consequence of the reduced internal stresses, they even decreased slightly.

When the temperature is raised to more than 400°C (to 600 or 850°C), spinodal decomposition of the γ-solid solution with formation of γ_t-phase is impossible. Heating to such high temperatures possibly leads to partial decomposition of the γ_t-phase ($\gamma_t \rightarrow \gamma + \alpha$ Mn) contained in the cast alloy, and this causes a substantial lowering of the dissipative properties of the alloy.

Qualitatively analogous results were obtained in the investigation of the effect of different heat cycling regimes on the dissipative properties of alloys that had been subjected to the full regime of heat treatment, which consisted of hardening at 800°C, 4 h in water, and tempering at 400°C for 4 h with cooling in air. Heating to 400°C and cooling at rates of 5 to 150-200°C/sec had no substantial effect on the damping ability of the investigated alloys.

Raising the temperature to 600°C with subsequent cooling at rates from 5 to 150-200°C/sec lowers the level of energy losses of alloys that had been subjected to the full heat treatment regime by approximately two orders of magnitude. As an example, Fig. 2 presents the results of investigations of the amplitude dependence of the vibration decrement for specimens of alloy No. 3 (Table 1) in the initial state (after the full heat-treatment regime), and also after being heated to 600°C with subsequent cooling at rates of 35-50°C/sec, 5 and 150-200°C/sec. The cause of such an abrupt decrease of damping ability of the fully heated-treated alloy, as well as of the alloy after casting, is the same: heating to temperatures above 400°C causes disintegration of the γ_t-phase ($\gamma_t \rightarrow \gamma + \alpha$ Mn), which ensures a high level of energy losses of the alloy.

Heating to 850°C with subsequent cooling at rates from 5 to 150-200°C/sec leads to a substantial decrease (by a factor of approximately five) of the damping properties of the alloys compared with the initial state; nevertheless, the decrease is somewhat smaller than after heating to 600°C with subsequent cooling at the same rates.

If after all heat-cycling regimes of the investigated cast and fully heat-treated alloys they are subjected to complete heat treatment (hardening at 800°C, 4 h in water and temperature at 400°C for 4 h with cooling in air), the damping ability of the examined alloys can be raised or restored to the initial level (curve 1 in Fig. 2).

Since real finished structures cannot be hardened and tempered because of the change of their geometric dimensions and shape, it is also inadvisable to use a production technology involving the heating of cast and fully heat-treated alloys to temperatures above 400°C (e.g., by welding, etc.) because that might cause an abrupt decrease of the damping ability of the alloy.

From the practical point of view, the most interesting results were obtained in the investigation of the effect of heat cycling on the damping ability of alloys in the initial state after hardening. X-ray structure analysis showed that hardening fixes the γ(fcc)-phase, and there are practically no microtwins which would be responsible for the high level of damping in alloys of the system Mn—Cu—Zn. The level of energy dissipation in hardened alloys of this system is therefore very low (curve 1 in Fig. 3) and represents in fact background internal friction. Heating to 200°C with subsequent cooling at rates from 5 to 150-200°C/sec practically does not change the structure of hardened γ-solid solution; however, in consequence of reduced internal stresses [2], the damping ability of the alloy even decreases slightly. When the temperature is raised to 400°C and the subsequent cooling is carried out at the same rates, the level of energy losses of alloy No. 3 (Table 1) approximately doubles (curves 2 and 3 in Fig. 3), nevertheless the dissipative properties are insignificant (vibration decrement $< 0.7\%$). In this connection it should be noted that the highest damping level is attained with the lowest cooling rate (5°C/sec). The level of energy dissipation after heat cycling at 600 and 850°C is practically the same as after heat cycling at 400°C.

If after all heat-cycling regimes of hardened alloys they are tempered at 400°C, 4 h with cooling in air, then the level of energy losses increases by approximately two orders of magnitude (Fig. 4).

Thus the obtained results show that the nature of the effect of different heat-cycling regimes on the damping ability of copper—manganese base alloys is different in dependence on the initial state. Ways were shown of ensuring high damping ability of manganese—copper alloys after various regimes of heat cycling, e.g., after welding; this is of great practical interest.

Heat cycling (e.g., welding or some other technological operation involving heating of the material of a product or semiproduct to a temperature above 400°C) of copper—manganese alloys is expediently carried out in the hardened state. To ensure high damping ability of the material of a structure made of copper—manganese base alloys, it must be tempered at 400°C for 4 h with cooling in air.

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