WORKABILITY OF MATERIALS FOR INSTRUMENTAL EQUIPMENT

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Abstract. In the present article original data on the efficiency and workability of the materials used in practice, working in conditions of thermal shock and low-cycle fatigue, is obtained and evaluated. Martensite aging steels and beryllium bronzes have been found to be significantly more durable than heat-resistant steels. Zirconium bronze despite its good thermal conductivity cannot reach the workability of beryllium bronzes.

Keywords: workability, thermal shock, thermal cycling, heat resistant steels, martensite aging steels, beryllium bronze, zirconium bronze.

1. INTRODUCTION

High, versatile and mutually exclusive requirements are imposed for the quality of the materials operating in the conditions of severe thermo-cyclic operating modes. The main contradiction, on the one hand, is the need to ensure the durability of the tool used, and on the other hand, minimal resources must be invested in it [1]. Instrumental equipment operating in severe thermal shock modes are subjected to short-term thermal cycles, for example, 120 °C–1000 °C in an interval of several seconds. The heat released from the processes must be removed from the tool in this short time. In this sense, the exact assessment of the possibilities of the materials used in practice, suitable for such operating conditions, is difficult and the data is in most cases contradictory. The difficulty also comes from the different nature of the materials used for the same operating modes. For example, the materials used to make molds for casting brass fittings use standard compositions of steel and bronze. In turn,

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different steels and bronzes have different properties and nature, as well as they are subject to different in nature technological modes of heat treatment. Some of the steels used for molds have carbide reinforcement, due to which they are hardened to high hardness and retarded to reduce the hardness in order to achieve a certain working hardness. Another part of the steels, as well as the bronzes used for similar purposes, have the so-called inter-metallic strengthening. They are hardened to a minimum hardness and then aged to increase the hardness until it reaches its working value. All this makes it difficult to predict the behavior of any material in operating conditions.

The aim of the development is to experiment with a methodology for comparative evaluation of the behavior of different materials designed to work under heavy thermo-cyclic and force load regimes.

2. MATERIAL AND METHODS

The object of study are four steels, the first two of which are with carbide, and the others with inter-metallic reinforcement, known in the literature as "super" alloys, etc. maraging steels. Three bronzes are also studied, the first of which is zirconium and the other two are beryllium. The chemical composition of the studied alloys is standard, and the designations are according to the European standards, as given in Table 1. The standard samples of corset type with dimensions – head diameter 14 mm and length 80 mm, suitable for the study of low-cycle fatigue are made from the alloys, Fig. 1. The heat treatment modes and the measured hardness of the test specimens are given in Table 1. To prevent oxidation of the samples during quenching, they were sealed in a glass ampoule under argon. In order to avoid possible stress concentrators on the surface of the endangered section, the working surface of the samples was ground and polished before the tests.

For the research computerized equipment with capabilities for the study of low-cycle or multi-cycle fatigue in metals and alloys developed at the IMSTCH "Acad. A. Balevski"– BAS was used, Fig. 2.

The equipment is built on the principle of compressive loading of a specimen based on its linear expansion between two fixed grips. The magnitude of the variable load of the samples is provided by the test temperature and the coefficient of linear expansion of the test material and in particular by the difference between the initial and final value of the temperature of the cyclic heating interval [2]. The temperature is recorded by a thermocouple welded to the central part of the sample. To determine the number of cycles, the change in the resistance of the sample during cyclic loading is also registered by two

Table 1. Regimes of heat temperature treatment and average values of hardness

Alloy	T [°C] hardening	T [°C]/time/tempering/ aging/, [h]	HRc/ HB
EN 1.2343, X40CrMoV5.1	1020	580 °C/2h tempering	HRc 48–50
EN 1.2365, X30CrMoV3.3	1050	560 °C/2h tempering	HRc 50–52
EN 1.2799 X2NiCoMoTi12.8.8 Maraging Steel	950	580 °C/6h aging	375–430 HB
EN 1.2709, X3NiCoMoTi 18.9.5.1-Maraging Stee	850	490 °C/6h aging	HRc 50–51
HOVADUR-CCZ Cr-0.3–1.2; Zr-0.03–0.30 EN CW106C	1020	480 °C/4h aging	135–155 HB
HOVADUR-CCNB Co-0.8–1.3; Ni-0.8–1.3 Be-0.4–0.7; EN CW 103C	960	480 °C/4h aging	240–260 HB
HOVADUR-CNB Ni-1.4–2.2; Be–0.2-0.6 EN CW110C	960	480 °C/4h aging	235–255 HB

welded copper conductors in the two ends of the sample. The appearance of a crack causes a sharp change in the resistance of the sample, which registers the exact moment of crack formation in the test body, Fig. 3, followed by the destruction of the test body, Fig. 4. The experimental equipment, the shape, the sizes of the samples, the technology for their production and the purity of the surface correspond to GOST 25502-79 or Cycle Fatigue-ASTM E 606 [3, 4].

The idea of the research is not to study low-cycle or multi-cycle fatigue, but:

- To provide a cycle of force loading, which should correspond to the temperature-force influences, to which the material is subjected in the real molds;
- To provide a temperature cycle of loading, analogous to the operating conditions of the tool;
- The main criterion is the number of load cycles until the appearance of the first crack in the material, which actually determines the life of the molds.

The conditions for conducting the test experiments are consistent with the temperatures at which the molds operate during operation:

- It is conducted in the air;

Fig. 1. Standard samples of corset

Fig. 2. Equipment for the study of low-cycle or multi-cycle fatigue

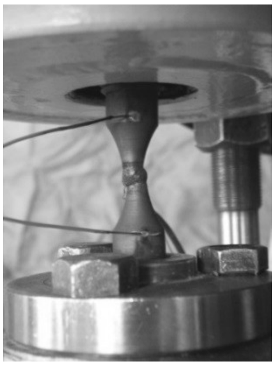

Fig. 3. Electro-resistance system for registering the beginning of the crack formation process

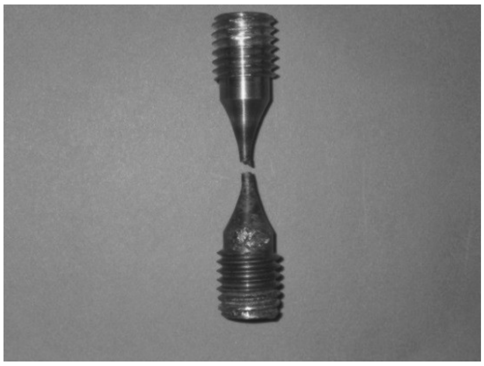

Fig. 4. Destroyed specimen after tests

- At axial tension-pressure load corresponding to the temperature cycle of the mold;
- In symmetrical deformation cycle;
- At load frequencies in the range from 7.10^{-4} to 1.10^{-2} Hz;
- At an operating temperature in the range 270–580 °C that is typical for the molds for casting brass fittings [5].

Six samples from each alloy were examined, and the reported number of cycles for the different experiments was arithmetically averaged. The average values are given in Table 1.

2. EXPERIMENTAL RESULTS

For each investigated alloy the average number of cycles that fractures the samples is given in Table 2. It was found:

1. Martensitic aging steels EN 1.2977 and EN 1.2909 are significantly more durable than heat-resistant steels EN 1.2343 and EN 1.2365 of the order of 30%.
2. Bronzes, in general, have increased properties in the conditions of low-cycle fatigue in comparison with steels.
3. Beryllium bronzes have about 35% higher properties than zirconium bronze.

These results are valid only in relation to the conditions of the specific tests and are in no way relevant for determining the durability of the material until they are substantiated and linked by relevant theory or analysis, which is the purpose of this study.

3. DISCUSSION

In methodological terms, the tests performed are close to the existing in practice deformation analysis for longevity (Strain Life Analysis) [8–11]. It is performed by standard methods such as: (i) tests of multi-cycle fatigue, High Cycle Fatigue (HCF) and (ii) those of low-cycle fatigue, Low Cycle Fatigue (LCF). These two methods characterize the material mainly in tests of cyclic mechanical loads at constant temperature.

In our case, the loads are stresses caused mainly by thermal loads. The tests are a combination of the two methods: the loads are usually below the yield strength of the material and the failure cycles are over 1000, and the value of the stresses (respectively the temperature) is controlled, which corresponds to the multi-cycle tests. In these tests, the thermal stresses may be above the yield strength depending on the test objectives, as observed for zirconium bronze CCZ from Table 2. The main evaluation criteria are the number of cycles until the crack originates, which meets the criterion in low-cycle fatigue tests.

Studies published in the literature on the influence of tool material on the life of low pressure die molds show that resistance to cyclic loading is not the only parameter determining the life of a tool [1]. Parameters such as thermal conductivity, yield strength, coefficient of thermal expansion, modulus of elasticity, etc. are also taken into account as factors.

Prof. Mikel [1] created a theory in which a prediction for the durability of molds made of different materials can be made only by the value of the

Table 2. Data for calculating the efficiency of materials at 500 °C

Material	n Cycles [number]	W_S Thermal stress 270–580 °C [N/mm^2]	TSR Factor	TC Coefficient of thermal conductivity [W/m K]	SS Yield point 0.2 at 300 °C [N/mm^2]	α Coefficient of linear dilatation [10^6/K]	$E.10^3$ Module of elasticity [N/mm^2]
1	2	3	4	5	6	7	8
EN 1.2343	51 675	687	9233	30	650	12.6	176
EN 1.2365	66 912	701	10974	34	730	12.85	176
EN 1.2799	73 452	496	17263	28.5	970	10.2	157
EN 1.2709	71 376	693	13195	27.3	1080	14.7	152
CCZ	107 452	458	56529	310	Min 270	17.0	87
CCNB	127 223	490	69514	220	Min 500	17.2	92
CNB	134 523	501	68514	220	Min 500	17.2	94

Note: Data on the properties of alloys are taken from literature references, [6–7]

expected thermal stress associated with the operation of the material. It can be calculated depending on the yield strength of the material according to the formula:

$$W_S = \Delta T.\alpha.E, \tag{1}$$

where W_S is the thermal stress [N/mm^2], ΔT – temperature difference between two operating levels of the tool [°], α – coefficient of linear dilatation [1/°C], E – modulus of elasticity [N/mm^2].

The data from the calculations on the dependence (1) are given in Table 2. They show that no direct relationship can be found between the cyclic durability of the material and the thermal stresses calculated by Mikel's theory.

Therefore, we have used another approach to assess the suitability of the material for thermal shock requirements [1], related to the so-called TSR-factor. Other parameters also take into account, such as the yield strength of the material and its thermal conductivity. A higher value of the coefficient means a higher resistance of the material against the appearance of hot cracks. The dependence is:

$$[TSR] = TC.SS/\alpha.E, \tag{2}$$

where TC is the thermal conductivity [W/m K], SS – yield strength [N/mm^2], α – coefficient of linear expansion [10^6/K], E – modulus of elasticity [N/mm^2].

The results from calculations of the TSR-factor given in Table 2 are compared with our results obtained for the number of cycles, Fig. 5. There is a linear relationship between them, which can be described by the dependence:

$$[n] = 51078 + 1.12 * [TSR]\,.$$

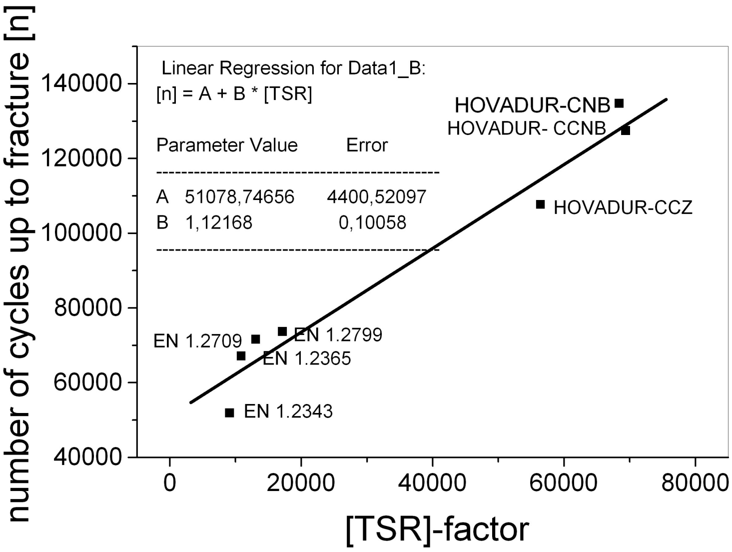

Fig. 5. Relationship between TSR-factor and number of the cycles until the pattern is destroyed

4. CONCLUSION

From the performed research and calculations of the workability of the materials used for molds for casting of non-ferrous alloys, it was found:

1. Martensitic aging steels are 30% more durable than heat resistant steels under conditions of thermo-cyclic fatigue.
2. Bronzes, in general, have increased performance under conditions of thermo-cyclic shock, compared to steels.
3. Zirconium bronze despite its good thermal conductivity cannot reach the expected performance of the beryllium bronzes CuCoNiBe and CuNiBe.

4. Thermo-cyclic fatigue follows the values of the TSR-factor, i.e. thermal cycling is an authoritative method of determining the workability of tool materials.

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