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Influence of Intermetallic Phases on Fracture Resistance of Silumins

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Abstract

In secondary aluminium alloys iron is the main detrimental impurity. It forms intermetallic phases which have lamellar shape, high brittleness and weak crystallographic conformity with the matrix. In the work the influence of intermetallic phases on the initiation and propagation of microcracks, mechanical and service properties of aluminium alloys has been investigated.

Keywords: Aluminium alloys, Intermetallic phases, Fracture resistance

1. Introduction

Since the mid-sixties of the XX century aluminium and its alloys have reached the second place after iron-based alloys by the mass character of production and application. According to the data of the Russian technical journal "Metallurgy of Machine Building" [1] ~ 5.1 mln.t of primary aluminium per year and 5.2 mln.t of secondary aluminium are produced in the European Union nowadays. Production of alloys from secondary raw materials takes place in the whole world, even in those countries which have enough resources of primary ore raw materials. It is explained by significant economic efficiency. Primary treatment and metallurgical process stage of secondary metal require 6...10 times smaller capital investments than those which are needed to obtain the equivalent amount of metal from mineral raw materials. Ecological influence on the environment decreases as well. The main part of secondary alloys are silumins which are widely used in different manufacturing branches due to the favorable combination of physical, mechanical, technological and service properties.

As a result of impurity of initial raw materials with different non-metallic materials, oils, and impurity elements secondary alloys obtain unfavorable structure, which contains a great quantity of different complex intermetallic phases of diverse morphology and weak crystallographic conformity with the matrix.

Results of research of the influence of intermetallic phases on fatigue fracture resistance of secondary silumins are presented in this work.

2. Material and experimental investigation

The main detrimental impurity of secondary silumins is iron. Its solubility in aluminium is about zero at room temperature, and at 655ºC it reaches 0.9 at.% [2]. In alloys it is comprised into intermetallic inclusions of types β(Al_5SiFe), N(Al_7Cu_2Fe), π($Al_8Si_6Mg_3Fe$) and others. The quantity of phases is determined by iron content and it increases with its increase (Table 1).

Along with the increase of intermetallic phases' quantity, properties of silumins are significantly influenced by their shape parameter λ (the ratio of the maximal length of the inclusion to its width). Quite clear dependences between this index and the alloys' properties have been observed (see Table 1 and Figures 1 and 2).

An important index of service characteristics of structural materials is fatigue fracture resistance. In order to determine the influence of iron concentration on fatigue durability at cyclic loading, tests of the secondary silumin AK8M3 at loading frequency 18 kHz have been conducted. Fatigue tests have been carried out according to the requirements of GOST 25.502-79 [3]. Results of the experiments have been presented as fatigue curves in semi-logarithmic coordinates: cyclic stress σ – lg(number of cycles N) (Figure 3).

Fatigue characteristics' analysis has shown that fatigue curves were situated one under another with close angles of inclination (see Figure 3). With the increase of iron concentration in the alloy the decrease of the fatigue limit σ_{-1} has been observed in the whole range of test bases (Figure 4).

Table 1.
Characteristics of intermetallic phases of the AK8M3 alloywith different iron content

Iron content, mass %	Shape parameter λ of the intermetallic phases		Volume part of intermetallic phases, %
	limits of variation	average values	
0.40	1...10 1...5	1.23 1.71	4.17
0.64	1...13 1...16	1.90 2.11	5.27
0.92	1...20 1...20	3.19 4.40	6.18
1.11	1...40 1...30	4.37 5.27	7.65
1.45	1...46 1...36	6.68 8.64	11.89

Note: 1. numerators represent the indexes for as-cast metal; 2. denominators represent the indexes after heat treatment T5 (quenching and aging).

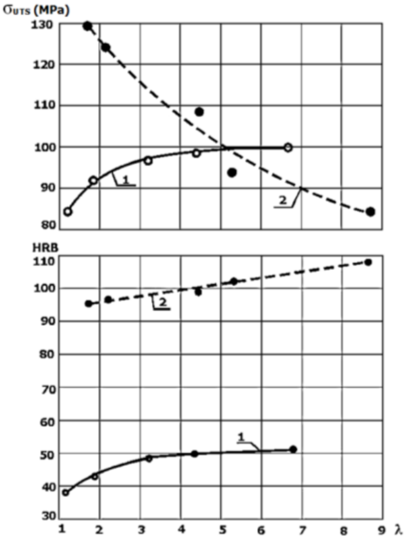

Fig. 1. The influence of the shape of the intermetallic phases parameter λ on the tensile strength σ_{UTS} and Brinell hardness HRB of the secondary alloy AK8M3: 1 – as-cast state; 2 – after heat treatment T5

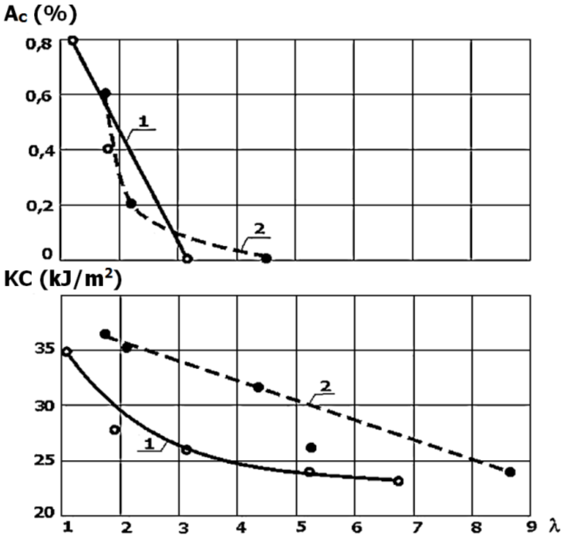

Fig. 2. The influence of the shape of the intermetallic phases parameter λ on the relative elongation A_c and impact strength KC of the secondary alloy AK8M3: 1 – as-cast state; 2 – after heat treatment T5

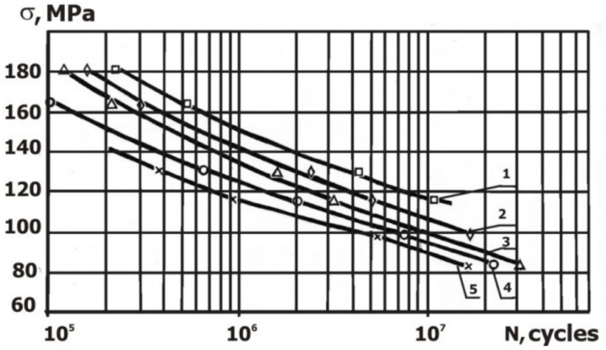

Fig. 3. Comparative fatigue characteristics of the alloy AK8M3 during tests at frequency 18 kHz: 1 – 0.40 % Fe; 2 – 0.64 % Fe; 3 – 0.92 % Fe; 4 – 1.11 % Fe;5 – 1.45 % Fe

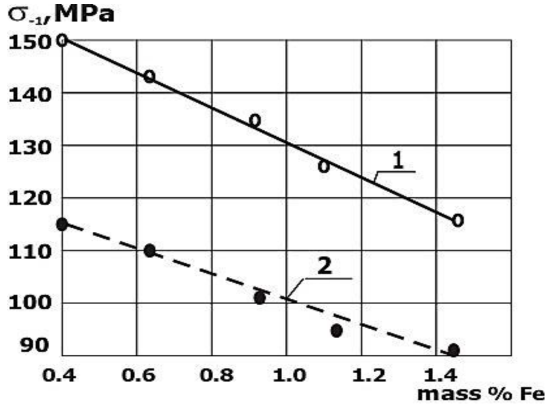

Fig. 4. Influence of iron on the fatigue limit of the secondary alloy AK8M3: 1 – test base of $1 \cdot 10^6$ cycles; 2 – base of $1 \cdot 10^7$ cycles

With the increase of iron concentration from 0.40 to 1.45 % this decrease for test bases of 10^6 and 10^7 cycles was almost the same and reached 22…24 %.

Initiation and propagation of fatigue cracks in the considered alloys occurred simultaneously according to a few mechanisms. More often the initiation of cracks originated on the specimen's surface in the spots with shape defects or in those spots where mass outflow of large quantities of dislocations to the surface took place.

The analysis of fracture micromechanism during tension of planar specimens – metallographic sections has shown that the first microcracks had been initiated on the intermetallic inclusions with high value of the shape parameter λ, and also in the areas of their storage (conglomerates) (Figure 5 a). During further loading microcracks which initiated in the intermetallides transitioned to the metallic matrix (Figure 5 b).

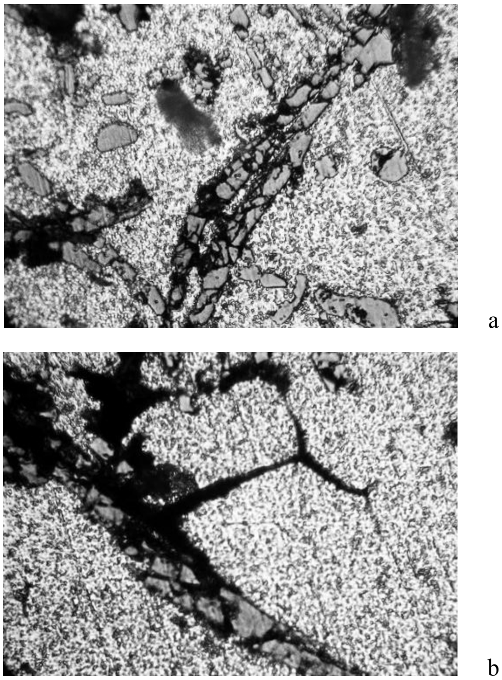

Fig. 5. Initiation and propagation of microcracks (×900)

According to the research results, inclusions of intermetallides Al_5SiFe have the most predisposition to exfoliation (Figure 6). This may be explained by crystallographic structure of this phase (lattice parameters a = b = 0.612 nm and c = 4.149 nm).

Considering the fact that microcracks are transitioned into metal from Al_5SiFe inclusions, herewith creating a defect system, δ_c-model by V.V. Panasyuk was applied with the purpose of fracture processes description and analytical calculation of heterogeneous alloy strength limit [4].

During modeling the aluminium alloy with intermetallic inclusions appeared as an endless body which contained a periodical system of coplanar elliptic inclusions similar in mechanical and geometrical parameters (Figure 7).

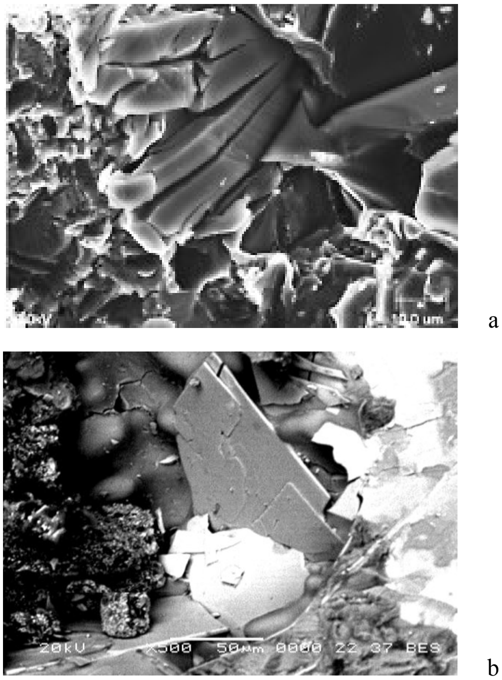

Fig. 6. Fracture surfaces of secondary alloy AK9M2: a – exfoliation of the intermetallic phase (×1500); b – lamellar phase on the fracture surface (×500)

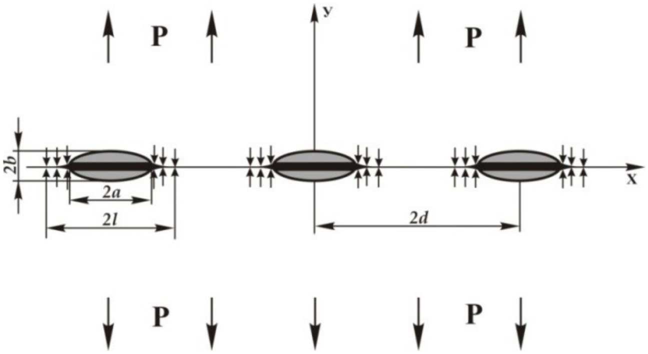

Fig. 7. Model of the structure of alloy with crack complex: P – tensile stress; 2α – inclusion's size; 2l – crack's size; 2d – distance between inclusions' centres

Tensile stress P is applied to the endless plane and directed at the right angle to the inclusions' location plane. Such scheme corresponds to the most favorable conditions of fracture from tensile stresses, because in this case the inclusions weaken the metal's section at the greatest extent. Their orientation relatively to the tensile stress direction leads to inclusions' exfoliation and provides easy transition of the microcrack from the inclusion to the base's metal. Thus the model's deviation from the practical situation provides material's strength reserve. Under such circumstances the tensile strength limit σ_{UTS} of the silumin with intermetallides can be predicted according to the formula 1 [5]:

$$\sigma_{UTS} = \frac{2}{\pi}\sigma_{UTS}^{M} \arccos \frac{\sin\left(\frac{\pi\cdot\alpha}{2d}\right)}{\sin\left(\frac{\pi\cdot l}{2d}\right)} \qquad (1)$$

where σ_{UTS}^{M} – matrix tensile strength (alloyed α-solid solution without intermetallic inclusions); 2α – inclusion's size; 2d – distance between inclusions' centres; 2l – crack's size.

High coincidence of calculated and experimental results has proved the determinant influence of the shape, sizes and orientation of intermetallic phases on silumin fracture resistance (Figure 8).

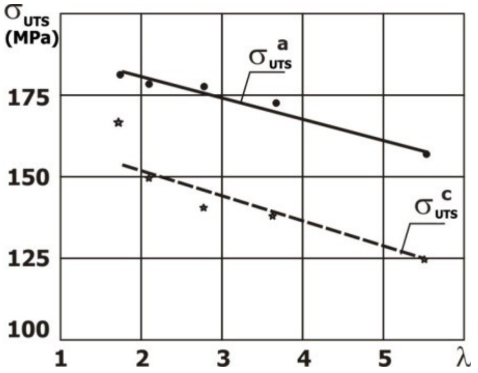

Fig. 8. Dependence of the actual σ_{UTS}^{a} and calculated σ_{UTS}^{c} ultimate strength on the shape parameter λ of intermetallic phases of secondary alloy AK8M3

Laser treatment (LT) is considered to be a perspective type of secondary silumins' treatment. LT in the fusion mode allows obtaining a layer on the surface which is close to homogeneous by its composition, with properties significantly different from the basic metal's properties. The layer's depth is 200...250 µm. The metal of this layer has higher microhardness (up to 2 times), wear resistance (by 1.25...2.0 times), cavitation resistance (by 1.5...2.0 times in sea water) and corrosion resistance (by 20...30 times in the water solution HCl) [6].

Specimens fatigue fracture resistance after LT depends on the surface roughness and presence of residual thermal stresses in the surface layer (Figure 9).

3. Conclusion

Investigation of micromechanisms of secondary alloys fracture has testified that the first microcracks appear in intermetallic phases of unfavorable morphology and with great value of the shape parameter, or on the "inclusion-matrix" interface, and then traverse into metal, forming macrocracks. If removal of unfavorable intermetallic phases is impossible it is necessary to control the process of structure formation with the purpose of obtaining of compact morphology phases. It ensures the increase of mechanical and service properties of aluminium alloys.

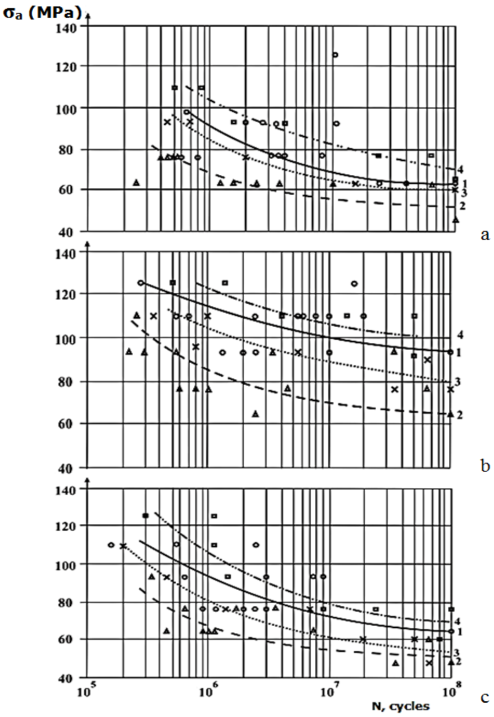

Fig. 9. Fatigue curves of secondary alloy AK8M3: a – 0.4 % Fe; b – 0.92 % Fe; c – 1.45 % Fe; 1 – initial state; 2 – after laser treatment; 3 – after laser treatment and grinding; 4 – after laser treatment, grinding and aging

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