

# Deformation stages of technical aluminum at reverse

**O Yu Vaulina, A N Durnovtseva, E V Shvagruckova**

National Research Tomsk Polytechnic University, Institute of High Technology  
Physics, 30, Lenin ave., Tomsk, 634050, Russia

E-mail: volgay@tpu.ru

**Abstract.** Durability and reliability of machines and mechanisms are determined, mainly, by their fatigue resistance as far as, in the most cases, variable load impacts on machine components. Accordingly, the problem of fatigue failure is extremely topical, still. Its complexity is connected with a wide range of factors. First of all, at cyclic load the compatibility relations of a material surface layer, which is loaded over the yield point and the elastic-loaded substrate layer, play a very important role. This fact determines involvement into plastic flow and failure of all the scale hierarchy of deformation structural levels. Reverse loading under the condition of the elastic-loaded substrate layer causes strong localization of plastic deformation in the surface layers. In the deformation localization areas the material reaches its limit state, when fatigue cracks arise and expand. The paper presents the mechanisms of fatigue deformation for technical aluminum at various fatigue stages.

## 1. Introduction

Undiminishing interest towards the fatigue problem is determined, firstly, by the applied significance of the utmost importance for understanding the physics of this phenomenon as far as it determines the operational life for the majority of work-pieces and structures in machine building industry. Secondly, this is an extremely complicated phenomenon, thereby, the insufficiency of the knowledge about the nature of the fatigue process is kept, in spite of a great number of scientific studies in this direction. The most known investigations connected with the fatigue mechanism have been carried out at the microscale level, using the analysis of forming dislocation structures.

At the moment, the problems of fatigue are considered in a broad fashion. But, nevertheless, the mechanisms of surface deformation at a meso-level [1] stay underinvestigated. Therefore, this paper is devoted to the determination of fatigue processes stages for technical aluminum.

The aim of the present study was to investigate the behaviour of laminated Al alloy-Al-Mg alloy joints under compression and tensile loads.

## 2. Materials and methods

The technical aluminum of A7 grade was investigated in the course of work with the following composition: 0.25%Fe, 0.18%Si, 0.05%Zn, with 0.03% Mn and Mg, 0.02%Ti, 0.01%Cu, and other elements, the rest aluminum ~ 99.6%.

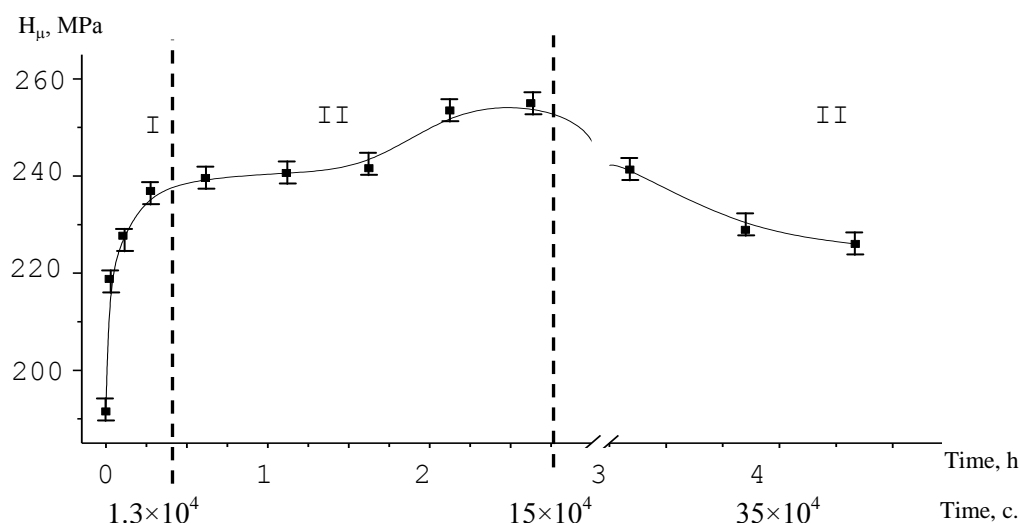
The aluminum surface was prepared, using electropolishing. Load distribution – reverse bending, a frequency of 7 Hz, an amplitude  $\pm 1.5$  mm. Structural changes while loading were observed with the help of metallographic microscopes LaboMet-I and Axiovert-25CA with an add-on device DIC for getting contrast. Microhardness was carried on GOST 9450-76 with the use of a PMT-3 microhardness tester.



### 3. Results and Discussion

One of the most important tasks in the physics of strength and plasticity is to understand the physical nature of plastic yield and deformation. The mechanism of polycrystal plastic deformation is extremely complicated, and it depends strongly on the load distribution, conditions and the material itself [1, 2].

The method of microhardness testing, characterizing the resistance of material local volumes to plastic deformation, allows studying the changes of properties in the fatigue process. Therefore, it is widely used for fatigue processes investigations. For classification of structural changes at fatigue the dependence of microhardness on the number of loading cycles is chosen (Figure 1), which shows how the microhardness of a thin surface layer is changing with the increase of loading cycles.



**Figure 1.** Dependence of microhardness ( $H_\mu$ ) on the time of technical aluminum loading

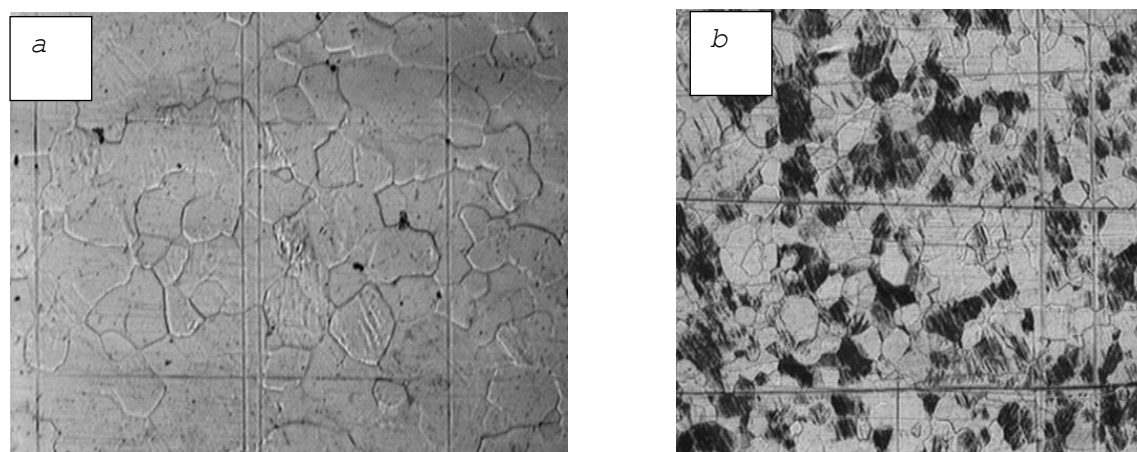
#### 3.1. Fatigue Stage I

At Fatigue Stage I for aluminum A7 the microhardness increases with the increase of loading cycles during a rather small number of cycles  $N=0 \div 1.3 \cdot 10^4$ . Only in separate grains of technical aluminum near the fixed grip the individual, rather thin, sliding lines in one system are formed, which cause stress fields on the boundaries, influencing on the given element from the area of the surrounding grains. They appear, first of all, in the grains, which are the most favorably pointed towards the applied stress. It is known that at cyclic load sliding occurs along the same atomic planes and in the same directions as under the influence of static load. However, at cyclic load the number of sliding systems, operating in the grain, is limited.

In polycrystal grains maximum two sliding systems operate. As a rule, the primary sliding in one grain is matched with the secondary one in the adjacent grain. Deformation in the reverse direction, initiating the matched system in the adjacent grain, leads to relaxation on the stress grain boundaries, which prevent a shear in the straight direction. As a result, when the sign changes, sliding may develop in the primary system again.

#### 3.2. Fatigue Stage II

Fatigue Stage II corresponds to the number of loading cycles  $N=1.3\div 15\cdot 10^4$ . It is characterized by the abrupt decrease of microhardness growth rate as a result of cyclic load. First of all, distinguishable expanding of sliding traces is observed (Figure 2a).



**Figure 2.** Structural changes in the technical aluminum A7: a – Stage II:  $N=11\cdot 10^4$  cycles,  $\times 200$ ; b – Stage III:  $N=26.7\cdot 10^4$  cycles,  $\times 80$

For reversal load it is typical to have heterogeneous deformation distribution in the sample, on the whole, as well as in the grains, particularly [1-4]. In aluminum A7 many grains of the surface layer stay non-deformable. A new deformation quality at Fatigue Stage II is an experimental fact, confirming that these grains are distributed along the polycrystal not randomly, but they are grouped in the couples, triples, etc. of the grains with self-consistent sliding. The origin for self-consistent shears in the adjacent grains of a polycrystal is as follows.

Individual sliding bands, leading to the shear of crystallographic planes, are accompanied by grain material rotation in the active grains. Due to the reaction of the adjacent grains the stress raisers appear on the boundaries. The interaction of short-range raisers leads to fine adjustment of active stressed adjacent grains in self-consistent deformable conglomerates.

### 3.3. Fatigue Stage III

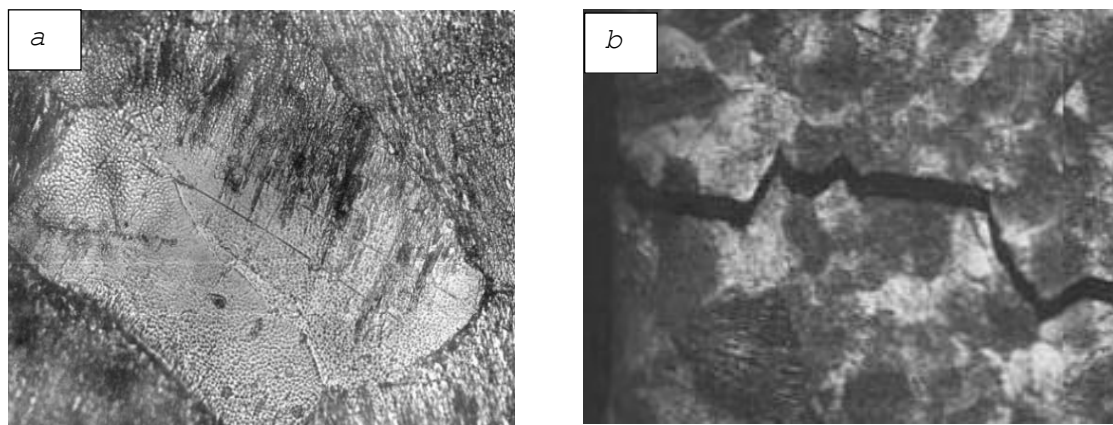
Fatigue Stage III is the main part of the process according to its duration. A new cyclic deformation quality in aluminum A7 is the beginning of the locking process for separate groups of self-consistent deformable grains into loop deformation conglomerates (Figure 2b), i.e. formation of new structural deformation elements on a much greater scale in comparison with the original grains. Rotation accommodation of these large structural deformation elements is carried out, initially, as fragmentation of the grains, composing a conglomerate (Figure 3a). Fragmentation is one of the most efficient mechanisms for stress meso-raisers relaxation. However, in this case, in the grains with coarse shear bands of one system only two fragments are formed, as a rule. Further sample loading is accompanied by the increase of a fragment turn. Consequently, this accommodation along with stress meso-raisers relaxation caused by the rotation of grain conglomerates forms the secondary stress meso-raisers connected with a strong turn of large-scale fragments.

When the opportunity to have fragmentation as an accommodative process of a rotation type is exhausted, a relaxation mechanism of cracking comes into action.

Consequently, while in the surface layer the self-consistent adjustment of plastically deformable grains is taking place, the compensation of material rotations of plastic shears occurs in each of these grains with keeping the continuity of the material.

Cracks arise in the area of the maximum bending, as a rule, on the boundaries of self-consistently deformable grains conglomerates. This makes perfect sense as far as at the rotation of such a large-

scale structural element as a grain conglomerate, the most powerful stress raisers are formed on its boundary. It could be observed in Figure 3b. This process is completed with a sample destruction.



**Figure 3.** Structural changes: A7: a -  $N=50 \cdot 10^4$  c.,  $\times 2000$ ; b -  $N = 56 \cdot 10^4$  c.,  $\times 200$

#### 4. Conclusion

Fatigue process development stages are determined, using the method of microhardness testing, as well as investigations connected with the character of mesostructure formation at various fatigue stages of technical aluminum. It is shown that microhardness dependence on the number of loading cycles consists of three (four) stages, which are distinct from each other according to the rate and the sign of microhardness value changes.

At Fatigue Stage I for technical aluminum the microhardness value increases abruptly while loading, the picture of deformation is presented by separate thin sliding lines in a small amount of grains.

Fatigue Stage II is characterized by the abrupt decrease of microhardness growth rate. In aluminum A7 in the favorably pointed grains the sliding bands are accumulated, which are grouped in the grain couples, triples with self-consistent deformation according to the increase of cycles' number.

At Fatigue Stage III, which is the main part of the process, the decrease of microhardness occurs. A new quality in the meso-structure nature at this stage is the formation of self-consistently deformable grains conglomerates, simulating the loops with the centers of non-deformable grains in technical aluminum.

Fatigue failure of technical aluminum at reverse bending has a mixed character: in some areas of its path a crack is propagating only along the grain or conglomerate boundary, in the other areas it propagates by the grain body along the direction of single sliding. This experimental fact proves that in the given conditions of loading in aluminum A7 the quantities of volume hardness and grain boundaries are commensurable.

#### References

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