STUDY OF THE STRUCTURE AND MECHANICAL PROPERTIES OF TEST BODIES FROM ALLOY AlCu4Mg2 AFTER PLASTIC DEFORMATION

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Abstract. Test bodies of aluminium alloy AlCu4Mg2 (D16T) are subjected to cold and hot plastic deformation. The hot plastic deformation of the test bodies of the studied alloy was carried out at a temperature of 450 °C. The cold plastic deformation of AlCu4Mg2 (D16T) alloy test bodies was carried out immediately after their hardening. After deformation, the bodies are subjected to natural aging. The influence of technological processing modes on the structure and mechanical properties of the AlCu4Mg2 (D16T) alloy was studied.

Keywords: aluminium alloy, plastic deformation, structure, mechanical properties.

1. INTRODUCTION

Aluminium alloys are divided into two large groups – casting and deformable, according to the method of processing. Depending on their ability to thermally strengthen, aluminium alloys can be divided into those that are strengthened after heat treatment and those that are strengthened by cold plastic deformation. Deformable alloys that strengthen after heat treatment are most often associated with the AlCu4Mg2 alloy. Hardening of these alloys is carried out by quenching and subsequent aging. During tempering, an unbalanced amount of the secondary phase is fixed in the alloy, which spontaneously separates in the process of natural aging or when heated to certain temperatures – artificial aging. In the process of natural aging, the alloy attains maximum strength after 96–120 hours. The reason for the strengthening can be indicated in the formed zones and separations with a composition close to the equilibrium phase $CuAl_2$, or the so-called Guinet–Preston zones. The

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DOI: 10.7546/EngSci.LX.23.01.05

existence of these zones in the alloy corresponds to its maximum strength. When the Guinet–Preston zones become equilibrium phases, i.e. have a structure and composition corresponding to the $CuAl_2$ phase, the alloy begins to decrease its strength. This effect is known as alloy aging [1÷11].

After cold plastic deformation, recrystallization annealing is applied to remove scale – the changes in the structure and properties of the alloy. The criteria for the full progress of the recrystallization process are: a lack of deformed structure, a reduction of hardness and tensile strength, an increase of relative elongation, a reduction of the density of defects in the crystal lattice. The parameters of the recrystallization annealing process depend on: the nature of the metal (alloy), the degree of plastic deformation, the heating temperature and the duration of holding at this temperature. The recrystallization threshold depends on the purity of the metal, the homogeneity of the structure and the degree of deformation. There are no unambiguous dependencies between these parameters [12÷16]. In order to establish the optimal mode of recrystallization, it is necessary to conduct experimental studies.

The purpose of the present study is to determine the influence of the type of plastic deformation (at small degrees of deformation) on the structure and mechanical properties of AlCu4Mg2 (D16T) alloy.

2. EXPERIMENTS, RESULTS, DISCUSSION

The object of the present study is an aluminium alloy AlCu4Mg2 (D16T) with a chemical composition given in Table 1, and the mechanical properties of the hardened rod of alloy AlCu4Mg2 (GOST 21488-9), Table 2.

Table 1. Chemical composition of alloy AlCu4Mg2 (D16T)

Cu	Mg	Fe	Ti	Zn	Mn	Si	Al
4.02	1.31	0.36	0.04	0.06	0.51	0.22	res

Table 2. Mechanical properties of the hardened rod of alloy AlCu4Mg2 (D16T)

Alloy	Rm [MPa]	Re [MPa]	A_5[%]	HB
AlCu4Mg2 (D16T)	513	383	14.5	125

The specimens were prepared from a rod with a diameter of 40 mm and different lengths corresponding to different grades of plastic deformation, Table 3. The grades of plastic deformation are consistent with the technology currently used to produce the details. The experiments were carried out under the same conditions for all test bodies.

Table 3. Dimensions of the experimental specimens and degrees of deformation

Length [mm]	77	86	91	98
PD rate [%]	15	20	25	30

The process of plastic deformation is height compaction between deforming plates (uniaxial compression). The height compaction of the prepared experimental blanks is carried out on a "SMERAL" 1600 t press with a headstock travel limit, in which the minimum distance between the deforming plates is 66 mm. The conducted experiments with AlCu4Mg2 alloy are structured into two groups:

- Carrying out the hot plastic deformation of the specimens, which are heated to a temperature of 450 °C, and the time for holding them at this temperature is 150 sec. The times provided for in the technological process for transporting the specimens from the heating furnace, placing them on the press and carrying out the deformation process are of minimal values, which does not require the use of additional heating. To reduce the heat losses of the contact surfaces between the specimens and the tool, the deforming plates are heated to a temperature of 250 °C.
- Conducting cold plastic deformation of pre-hardened specimens. The tempering mode used includes: (i) heating the specimens to a temperature of 490÷500 °C, (ii) the heating is carried out in a chamber electric resistance furnace, (iii) the operating temperature is controlled by thermocouples and a thermoregulator with a digital display, and holding at this temperature for 40÷45 minutes. The cooling medium is water with a temperature of 10÷30 °C. The selected heating temperature for tempering the AlCu4Mg2 (D16T) alloy is in accordance with the recommended temperatures in the reference literature. The holding time of the specimens at the selected operating temperature is consistent with their dimensions and corresponds to the recommended holding of 1 min/1 mm. After hardening and cold plastic deformation, the specimens are subjected to natural aging for 96 hours.

To establish the influence of the degree of plastic deformation on the structure and properties of AlCu4Mg2 (D16T) alloy subjected to hot plastic deformation at a temperature of 450 °C, mechanical tests and microstructural analysis were carried out. The results of the performed mechanical tests show that the relative elongation at different degrees of plastic deformation is comparable, the same is observed for the macrohardness of the test bodies, Table 4. The highest values of the tensile strength and yield strength were found for the specimens with a degree of plastic deformation of 15%.

Table 4. Results of mechanical tests of alloy AlCu4Mg2 (D16T) after hot plastic deformation at a temperature of 450 °C

No	PD rate [%]	Rm [MPa]	Re [MPa]	A_5 [%]	HB
1	15	355	178	16.5	85.8
2	20	311	201	17.5	90.2
3	25	302	132	15.5	86.9
4	30	306	144	16.0	89.2

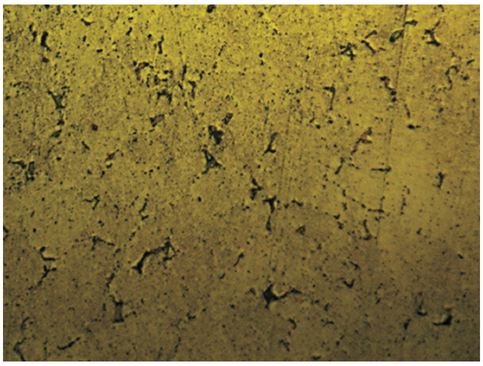

Fig. 1. Microstructure of a test body after PD at a temperature of 450 °C and a degree of PD15% ×200

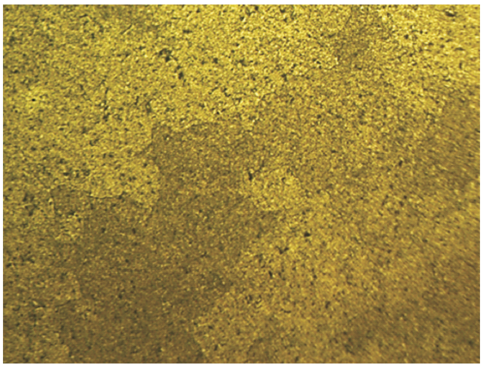

Fig. 2. Microstructure of a test body after PD at a temperature of 450 °C and a degree of PD 20% ×200

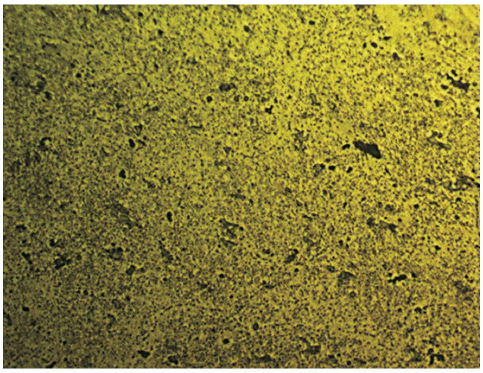

Fig. 3. Microstructure of a test body after PD at a temperature of 450 °C and a degree of PD25% ×200

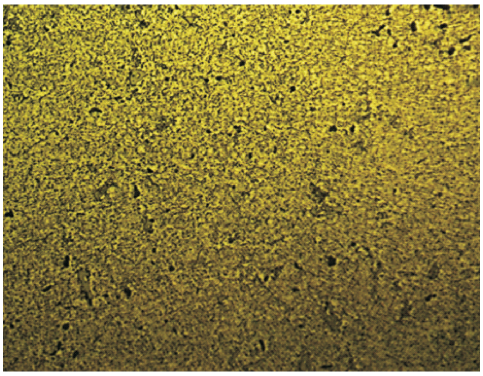

Fig. 4. Microstructure of a test body after PD at a temperature of 450 °C and a degree of PD 30% ×200

On the examined field of the metallographic cut of D16T alloy after plastic deformation carried out at a temperature of 450 °C and a degree of PD of 15%, the α phase, in which the strengthening phases were located, was observed, Fig. 1. The microstructure of a test body with a degree of plastic deformation of 20% of D16T alloy after plastic deformation at a temperature of 450 °C is unevenly hardened, Fig. 2. A hardened structure and a minimal amount of recrystallization zones are observed in separate areas of the cut, which are concentrated only on the outer surface of the specimen body. Figure 3 shows the microstructure of the specimen body with a degree of plastic deformation of 25% of D16T alloy after plastic deformation at a temperature of 450 °C. It is again uneven, but the recrystallization area at this degree of plastic deformation is larger. It can be seen in Figure 4 that the microstructure of the alloy thus deformed with a degree of plastic deformation of 30% is a more uniformly distributed on the reinforcing phases, the shape of which is the most compact of all the test bodies with different degrees of plastic deformation, after hot plastic deformation carried out at a temperature of 450 °C.

The most likely reason for observing a structure characteristic of the hardened D16T alloy is the insufficient time to hold the test pieces at a temperature of 450 °C, at which the high-pitching is carried out. The holding time of 150 s provided for in technological process at this temperature is not enough in order to take place the diffusion processes. This is a prerequisite for the existence of an initial hardened structure in individual sections of the test body, in which the plastic deformation takes place completely at a 15% degree of deformation. Bearing in mind that the technological process carried out is height plastic deformation, no defects are observed on the test body. But when conducting plastic deformation, such as open stamping, improper heating the test pieces at the prescribed working temperature would be a prerequisite for obtaining defects in the product (incomplete forming or cracks). After carrying out the mechanical tests of standard test bodies from the blanks of the experiments conducted in this way, a decrease in the values of the mechanical and plastic characteristics of the alloy was observed compared to the same of the original material tested. To increase the values of the studied characteristics, subsequent heat treatment is necessary: quenching and natural aging.

After the mechanical tests of test bodies made of details produced by cold plastic deformation, in which they were previously hardened, it was found that the strength and plastic characteristics of the alloy after the experiments conducted in this way were of the highest values, including those of the starting alloy D16T, Table 5.

After quenching, the structure of the alloy consists of a saturated α-solid solution and intermetallic compounds in the composition of which the impurity elements of the alloy participate. During natural aging, the so-called Guinet–

Table 5. Results of mechanical tests of alloy AlCu4Mg2 (D16T) after cold plastic deformation

PD rate [%]	Rm [MPa]	Re [MPa]	A_5 [%]	HB
15	538	427	15.0	144
20	494	416	14.0	156
25	527	442	13.5	156
30	534	428	15.0	154

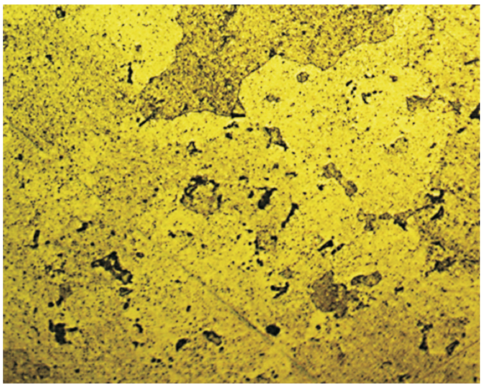

Fig. 5. Microstructure of a sample with a degree of PD 15% (before cold plastic deformation) ×400

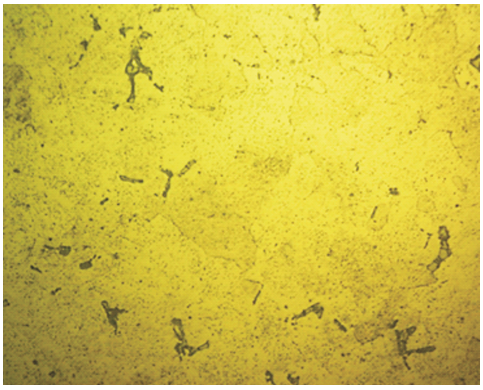

Fig. 6. Microstructure of a sample with a degree of PD 20% (before cold plastic deformation) ×400

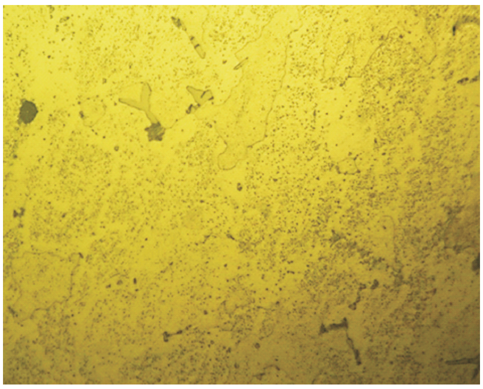

Fig. 7. Microstructure of a sample with a degree of PD 25% (before cold plastic deformation) ×400

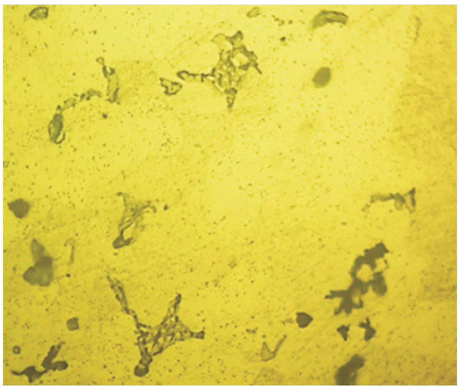

Fig. 8. Microstructure of a sample with a degree of PD 30% (before cold plastic deformation) ×400

Preston zones are formed, which are rich in the main alloying elements copper and magnesium, and the stable strengthening phases are formed and separated. Figures 5, 6, 7 and 8 show the structures of the studied alloy quenched before plastic deformation (15, 20, 25, 30%) and subjected to natural aging after quenching. At high magnifications (×400), grain boundaries and separated strengthening phases are clearly visible. The $CuAl_2$ phase is colored in gray and the S-phase in black. When conducting experiments with relatively small values of the degree of plastic deformation, comparable values of the strength and plastic characteristics of the alloy were recorded. No particular differences were observed in the structure of the investigated aluminium alloy.

CONCLUSIONS

When conducting hot plastic deformation of D16T alloy, it is necessary to increase the holding time at the operating temperature due to the initial (hardened) state of the test bodies, so much as to ensure uniform heating of the test bodies. The time required to achieve uniform heating is the subject of upcoming research. The expected effect is to obtain a structure that has recrystallized during the technological process, as a result of which values of the strength and plasticity characteristics corresponding to the specific task can be achieved. To increase the values of the studied characteristics, subsequent heat treatment is necessary: quenching and natural aging.

After quenching immediately before carrying out plastic deformation of test specimens with relatively small values of the degree of plastic deformation, commensurable values of the strength and plastic characteristics of the alloy were recorded. No particular differences are observed in the structure of the investigated D16 aluminum alloy. The alloy has the highest values of tensile strength, yield strength, relative elongation and macrohardness. This gives us reason to recommend the technological process used for the production of details through plastic deformation (with relatively low values) from D16 alloy with requirements for increased strength and plastic properties. The proposed process is economically expedient due to the fact that we save the technological operation of heating the test specimens before plastic deformation.

ACKNOWLEDGEMENTS

The scientific research, the results of which are presented in this publication, was financed by project BG05M2OP001-1.002-0023 – Competence Center

“Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies” of TU-Sofia, branch Plovdiv.

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Received December 15, 2022