Effect of Composition and Distribution of Phases after Aging on Stamp Ability for Aluminum Alloy D16 (AA2014) Sheets

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Abstract—The relevance of this research is connected to the increasing requirements for accuracy in stamped parts produced from aged aluminum alloys, and can also be applied for making layered composites. Indexed requirements can be provided by controlling the structure of sheet blanks, particularly by the phase composition and distribution behavior. Results of experimental research into the effect of aging modes on composition, dispersion behavior, and stamping number of sheet samples of the D16 aluminum alloy (AA2014) are presented. Heat treatment includes quenching from a temperature of 500°C into water of room temperature and further aging: natural aging for 7 days and artificial aging at temperatures of 50, 100, 150, and 200°C with a duration at each temperature of 15, 30, 60, 120, and 240 min. A method of estimating the quantity of the characteristics of dispersion phases is proposed for the microstructural picture. Stamp ability is evaluated using the stamping number, which is the ratio between yield stress and tensile strength. It is found that increasing aging temperature and duration leads to the growth of the stamping number, which shows a low ability for sheet-stamping operations of alloy. Aging at 50°C did not lead to the sedimentation of dispersion phases for either optical metallography or scan electron microscopy. The inhomogeneity of phase dispersion inside the grain grows at the initial stages of aging, when duration is less than 1 h and temperature is 100, 150 and 200°C. Further increasing duration to 4 h leads to inhomogeneity decreasing. There is no correlation between the uniformity of phase dispersion and the stamping number. The chemical composition of phases plays the main role in stamping number, outside of phase-dispersion uniformity. The phase-composition changes depend on the mode of heat treatment: at an annealed and naturally aged state, the θ and S phase is sediment. After aging at a temperature lower 150°C after a short duration of less than 1 h, the θ, S and T phases are revealed; the θ phase appears after aging at temperatures higher than 150°C and long duration reaching 4 h.

Keywords: aluminum alloy, structure, stamping number, aging, phase composition, phase dispersion

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INTRODUCTION

Despite the development of new aluminum alloys in Russia and abroad, including these achievements into the design of aircrafts is constrained due to the conservatism of the industry and the combination of high properties of traditional alloys. One example is D16 (the international analogue is AA2024), the most popular alloy in engineering, which is used for basic force elements of the airframe, especially in airplanes with a long life and in places not accessible or difficult to inspect.

In recent years there have been developments connected with the creation and treatment of metal–polymer layered composites based on alloy D16 [1, 2]. These developments are directed at achieving special properties in the final products due to the grades and thicknesses of the initial materials, schemes of their assemblage, and treatment of the composites. In fact, for the production of the final parts and assemblies, technologies are used which combine the operations of sheet punching, which makes it possible to significantly increase the limiting possibilities of material shaping [3–5]. However, at the same time, it has been established in a number of works that the ability of sheet composite materials to perform sheet-stamping operations directly depends on the technological properties of the metal matrix.

The increase in manufacturability of worked aluminum alloys is based on the study of technologies for producing sheet blanks, the effect of rolling regimes, and heat treatment on the features of the structure of semifinished products. For example, research [6, 7] present the results of an investigation into the effect of aging on the mechanical properties...
and structure of alloys W319 and AA2024, which shows a dependence of disperse phase distribution in the process of natural aging on cold working and quenching modes.

Research [8] present results which show both the composition of alloying elements Mg and Si and the effect of copper addition on the limited characteristics of form changing of lean Al–Mg–Si alloys. However, the disperse structure was assessed visually, without the use of quantitative evidence.

The authors of [9] determined how the intense plastic deformation and aging regimes affect the strength and ductility of the 2024 alloy, an analogue of D16. On the other hand, the authors of [10, 11] showed that the structure of alloys can be described by means of the entropy approach. Thus, the results of the study [10] show that an increase in the orderliness of the structure in alloys leads to increases in strength and decreases in plasticity, which adversely affects the plastic deformation capabilities of materials. This suggests the influence of grain size and its heterogeneity, the distribution pattern of disperse phases, and the type of texture components on the stamping of sheet blanks from the same material but after various treatments (annealing, deformation, quenching, and aging).

Studies [12] have established that the dissolution of the S phase (Al2CuMg) with the subsequent aging of the D16 alloy gives the greatest hardening when compared to the effect of the θ phase (Al2Cu) of this system.

Various methods and indices are used to evaluate the stamping ability of semifinished sheet products: Eriksen’s technological samples, the ultimate draw ratio, the elastic recoil angle, the minimum bending radius, the number of stamping, etc. As a rule, these indicators are scattered. For example, high values of the coefficient of stamping, minimum bending radius, and the angle of spring indicate a low propensity of materials for sheet-stamping operations. Conversely, large values of the limiting coefficient of drawing and the height of the well in the Eriksen tests indicate good stamping parameters.

The purpose of this work was to study the effect of the aging regimes of the D16 sheet alloy on the composition and distribution of disperse phases for improving the technological properties in sheet-stamping operations using the example of the yield number.

### MATERIALS AND EXPERIMENTAL PROCEDURE

Sheet blanks of D16 alloy with a 1.8-mm thickness without plating were used as the initial materials, which were cut along the rolling direction into samples for uniaxial tensile testing and technological samples. The chemical composition of the studied pieces obtained by the energy-dispersive console of a Tescan-Vega SEM microscope (Czech Republic) is presented in Table 1.

Heat treatment took the form of annealing at a temperature of 500°C for 1 h and cooling in a furnace for all pieces. After annealing, evident (control) pieces were left aside which did not undergo subsequent heat treatment. For the rest of the pieces, the quenching was performed by heating up to 500 ± 5°C, holding for 1 h, and quenching in room-temperature water. Then the pieces were divided into three parts, for which natural aging was conducted for 7 days and artificial aging at temperatures of taging = 50, 100, 150 and 200°C for 15, 30, 60, 120, and 240 min at each temperature. Cooling after aging was done in air.

To evaluate mechanical properties, the uniaxial tensile test was used in accordance with Russian Standard GOST 11701 “Metals. Test Methods by Tensile of Thin Sheets and Films.” The stamping ratio was determined (σθ/σ0) based on the data on tensile stress (σ0) and yield stress (σθ).

Samples were prepared from the sheet-plate surface for microstructure research. Etching was done in solution consisting of H2O 95%, HF 2%, and HNO3 3%. Etching durance was 5 s at room temperature of 20°C.

Disperse-phase distribution behavior was evaluated as follows. The choice and fixing of the microstructure were made under conditions ensuring there was only one whole grain in the observed field. The observation at chosen treatment modes was provided by a magnification of 650× on an Axiovert optical microscope (Germany). After the microstructure was fixed, three horizontal and three vertical lines were drawn from the border of one grain to another. Disperse sediments were marked by dots, which were on the nearest distance to the drawn lines. Strain line segments joined these dots together. As a result of drawing, six broken lines were obtained. Figure 1 shows an example of the microstructure after quenching and aging and one of the broken line segments is marked, which

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