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Analysis of the Possibility of Obtaining Aviation Profiles from 7039 Aluminum Alloy in the Extrusion Process

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Abstract

This article presents the process of extrusion shape of complex geometry cross-sectional 7039 aluminum alloy for use in aerospace industry. This study aims to characterize the properties of aluminum alloy as structural material and to determine the technological parameters of the indirect extrusion press and their influence on mechanical properties and the microstructure of the final product. It has been proved that the proper choice of parameters in the case of a specific profile extruded from 7039 aluminum alloy allows the manufacturing of products of complex cross- sections and the quality required in aerospace industry.

Keywords

backward extrusion, aluminum alloys, 7039 alloy, extrusion profiles

1. Introduction

Plastic-shaped aluminum alloys are one of the basic building materials used in aircraft construction. These alloys have particular advantageous features from the point of view of construction applications: good physical and mechanical properties, low density, high strength, impact strength and plasticity, high fatigue resistance, and easy machinability. For this reason, they are widely used in the aviation industry [1–4] on loaded elements of aviation structures such as girders, ribs, plating, compressor blades, fan disks, and others. The steady increase in interest in the use of these materials in aircraft constructions is dictated in particular by the possibility of reducing the weight of the structure [5–11], obtaining light, durable parts with appropriate stiffness or flexibility.

In the aviation industry, aluminum and copper alloys are most commonly used (duralumin 2xxx series). Aluminum alloys with silicon and magnesium (6xxx series) and zinc and magnesium (7xxx series) have even better strength properties used on the heavily loaded elements of aircraft structures. Due to the requirements for aeronautical materials (including the ability to transfer loads under given operating conditions at the smallest possible dimensions and weight of the structure, susceptibility to processing, ensuring high durability and reliability of elements and subassemblies), the key issue is the selection of the right material and the right selection of technological parameters.

Currently, most of the aluminum alloy components are produced in the machining processes [12–16]. This causes a high consumption of materials and energy and increases the load on the machines. Therefore, an increasing interest in the implementation of processes of plastic shaping of aluminum alloy products is observed. The use of the extrusion process in production will not only reduce the costs of manufacturing products but also improve their strength and fatigue properties due to the favorable shape of the internal structure. In addition, this process creates the possibility of choosing the optimal shape for semi-finished products to make elements with shapes that are as close as possible to the theoretical outline of the finished part. Therefore, it is expedient to implement plastic shaping processes for products made of aluminum alloys, with particular emphasis on the extrusion process. It should be emphasized, however, that the specific characteristics of aluminum alloys (e.g., relatively low plasticity, good thermal and electrical conductivity, a narrow range of process parameters enabling obtaining a product with the required characteristics) make their shaping and obtaining high-quality product a difficult task [5–11, 17, 18].

Therefore, the purpose of this article is the experimental development of extrusion technology for sections with a very complex cross-sectional geometry based on the characteristics of aluminum alloys as construction materials, analysis of the interdependence of technological parameters of extrusion of these alloys on a counter-rotating press, and their impact on mechanical properties, microstructure, and quality-performed product. The test results indicate that the conditions for carrying

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out the process leading to obtaining a product with high requirements and characteristics are selected.

2. Experiment

The material used for the study was 7039 aluminum alloy. Tables 1 and 2 demonstrate the chemical composition and mechanical properties of the 7039 alloy.

Table 1. Chemical composition of the tested 7039 alloys (percent of mass)

Si	Fe	Mn	Mg	Cr	Zn	Al
0.02	0.95	0.25	2.8	0.1	2.75	Remainder

Table 2. Mechanical properties of the tested 7039 alloys

$R_{0.2}$ (MPa)	R_m (MPa)	*A* (%)
380	450	13

$R_{0.2}$, yield strength; R_m, tensile strength; *A*, elongation at break.

The chemical composition of the tested alloy was determined by the method of optical emission spectrometry with glow discharge, using the Horiba GD-OES optical emission spectrometer in accordance with ASTM E23-07.

Backward extrusion process was subjected to billet with a diameter of 95mm and a length of 125mm using die with the shape of the working hole of profile (Figure 1). This is typical profile used in aircraft constructions.

Extrusion was carried out on a 5 MN hydraulic horizontal press. The parameters of the extrusion process are given in Table 3.

Before the extrusion process, the billets and the dies were heated to the temperature of 450˚C. The raw material input of the ingots was extruded by applying selected ram rates properly (from 0.1 to 0.25 mm/s) and dies in the shape of a working hole.

Table 3. The parameters used for backward extrusion

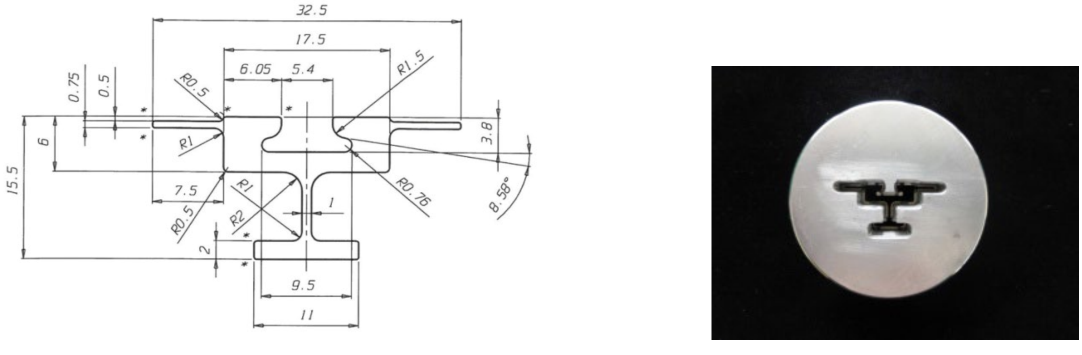
Preform dimensions	
d_0 (mm)	95
h_0 (mm)	125
State	Extruded
Process parameters	
Heating temperature of the preform (°C)	450
Heating time (min)	~40
Extrusion temperature (°C)	460
Extrusion rate (mm/s)	~0.25
Extrusion ratio l	60
Die temperature (°C)	450

Operating parameters of the press were recorded automatically by a microprocessor built into the control panel. Reading files and their processing made it possible to determine the dependence of the extrusion force as a function of the punch displacement and extrusion speed.

The hardness measurements were done with the use of hardness tester Zwick ZHU 250, and the load employed was 625 N and the ball of 2.5 mm in diameter.

The surface of the samples for macrostructure tests and metallographic specimens for microstructure observation were prepared by standard methods according to ASTM E3-11, and the alloy was etched with chemical reagents according to ASTM E407-07.

The prepared cross-sectional surfaces were subjected to observations using a stereoscopic light microscope at low magnification (~1.5¸5×) to reveal the macrostructure, and then metallographic specimens were made of them which were observed at magnification from 200× to 5,000×.



(A) (B)

Figure 1. (A) The shape and dimensions of the extruded profile and **(B)** image of extrusion die.

High-vacuum mode, secondary electron (SE) and backscattered electron (BSE) detectors, 20 kV accelerating voltage, and spot size <10 nm were used during scanning electron microscopic (SEM) testing.

Grain size assessment was performed using a Nikon Epiphot 300 metallographic light microscope by a comparative method in accordance with ASTM E112-13 (Plate I). Samples were digested with Keller reagent (according to ASTM E407-07) and heated to 50°C.

3. Results and Discussion

As long as the extrusion ratio was l=60, the results were positive, that is the extrusion force was lower than the nominal force of the press, and satisfactory quality of the extrudate. A characteristic feature that was observed during the process was the initial rapid growth of the extrusion force, connected with the formation of deformation zone, and then a drop to the minimal value followed by a slight increase in the process of extrusion (Figure 2). In order to decrease the initial extrusion force, the die was additionally heated to the temperature of 450°C. The extrusion rates were selected not to cause any damage of the finished surface, which would prove the disturbance of the extrusion process or negative structural phenomena in the material (e.g., hot cracking). The manufactured sections were characterized by smooth surface finish with no visible defects.

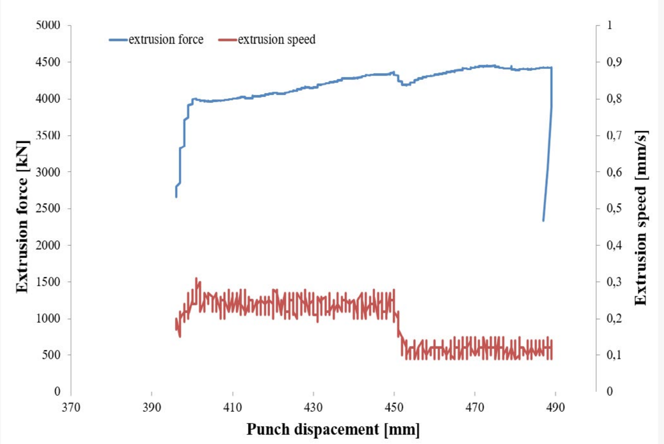


Figure 2. Relationship of the force, punch displacement, and extrusion speed in the process of extrusion of 7039 alloy profile.

Increase in the extrusion force results from the specific design of the press and the implementation of the extrusion process using it, for example, change in the friction coefficient during the process, sealing the gap between the die and the container through which squeezing of the material occurs.

Metallographic tests were conducted on samples cut out from extruded profile. The cross sections of the samples were subjected to micro sections (Figure 3).

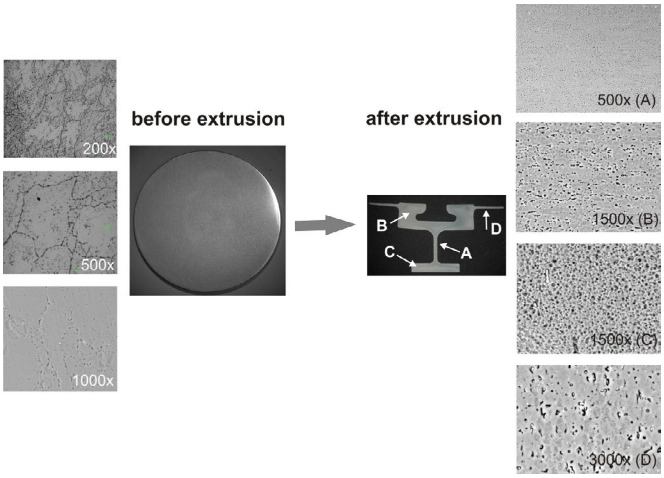


Figure 3. Macro- and microstructure of the 7039 alloy, before and after extrusion.

Evaluation of microstructure was carried out based on the results of the identification and measure of macro- and microstructure of 7039 aluminum alloy after plastic deformation in the process of extrusion. It has been noticed that the macrostructure of the investigated alloy was subject to homogenizing – fine-grained and uniform alloy was achieved (Table 4).

Table 4. Extruded profile with indication of zones A, B, and C for determining grain size and grain size of the billet and extruded product

Cross shape of extruded profile	Grain size G, Plate I (ASTM E 112)	
Billet Ø 100 mm	2.5	
Profile	Zone A	9
	Zone B	8
	Zone C	8

The microstructure of investigated alloy is typical of its type and grade. No morphology or chemical composition diversification of the phases was observed in the investigated cross sections. The plastic deformation in the extrusion process caused a significant homogenization in terms of distribution and refinement of the particles in intermetallic phases and also a slight increase in the size of particles in hardening phases, whereas their dispersion character remained the same. No changes in the chemical composition of intermetallic precipitation and hardening phases were observed.

In addition, HB hardness to demonstrate mechanical features resulting from uniform microstructure of extruded profile has been measured. It is important to obtain uniform microstructure especially when the geometrical parameters of extruded profile are very different, for example, very thin wall and thick part of the cross section and symmetrical or nonsymmetrical cross section.

The Brinell hardness test results shown in Table 5 prove the homogeneity of the structure and mechanical properties of the profile cross section.

Table 5. HB hardness test results of billet and extruded profiles

HB hardness 2.5/62.5 (average values)		
Billet (preform)	164	
Profile	Zone A	112
	Zone B	119
	Zone C	114

The average values of the hardness measured in specific characteristic regions of the extruded profiles cross sections demonstrate the homogeneity of the mechanical properties on the cross section, both in the thick-wall regions and in the remaining area of the section.

4. Conclusions

The correct selection of parameters of the 7039 alloy extrusion process allows obtaining products with a complex cross-sectional shape and the required properties as well as high quality desired in aviation. Macro- and microstructure tests have confirmed the positive effect of plastic forming of the alloy and the purposefulness of its use in the production of light aircraft components corresponding to its features. The most favorable range of temperature for extrusion of 7039 alloys is 460–470°C.

Taking into consideration the complexity of the cross sections of the extruded profile, the force initializing the process of Al alloy backward extrusion may reach very high values, close to the nominal press force. The decrease of the force may be achieved by decreasing the extrusion rate at the stage of deformation zone formation.

The plastic working process under extrusion conditions caused a significant homogeneity in terms of distribution and fragmentation of intermetallic phase particles and a slight increase in the size of the strengthening phase particles while maintaining their dispersive character. There were no changes in the chemical composition of the separations of intermetallic phases or strengthening phases.

Macro- and microstructure of the investigated alloy after extrusion is highly homogeneous in terms of the grain size and morphology of the phase components, compared with the macro- and microstructure in the initial state. This is also demonstrated in the hardness test results which prove the homogeneity of the cross-sectional mechanical properties of the extruded section.

Based on the tests carried out, very good processability of the tested alloy by backward extrusion was found. In the tested and defined range of temperatures and extrusion speed, sections with the required characteristics were obtained, which is the basis for the possibility of their implementation for production and use in aircraft structures.

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