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# Effect of the homogenization and cold deformation on the mechanical performance of Al8006 aluminium alloy

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**Abstract.** In our study, the base material was the aluminium alloy of Al8006. Its application area covers amongst others the material for multilayer tubes. This alloy has been subjected to different technological paths consisting heat treatments (homogenization) and mechanical strengthening technologies: multiple forging, equal channel angular pressing. The aim of the technological paths was to refine the primary phase structure, and to look for the technology sequence that assures the highest strength and the highest toughness at the same time. To determine this, a complex performance index has been created that integrates these property characteristics.

## 1. Introduction

There is a legitimate demand from members of the consumer society that the market fulfils their expectations for products and services at high quality and value for their money. Members of society can only formulate their needs and expectations on basis of their own knowledge. As an example, one may define a requirement for a passenger car for a safe transportation, without defining what the chemical composition of the passenger car's B-pillar was and what type of heat-processed steel would be best to produce it. Therefore the performance or the capacity -- in lingo we use the word "performance" -- is the concept that defines the buyer/seller relationship regarding to a product.

Obviously, the performance is embodied in the properties of the product in question, such as: material or structure. The primary task of a materials or mechanical engineer is defining the characteristics of a product to meet the needs. By defining set of properties, it is possible to select a particular material quality that carries these properties, and to determine the technology for its production. This three-element process can be described by a chain model consisting of interconnected chain links representing performance, property set and substance.

We do not have a generally accepted method for measuring performances yet, therefore in this study we propose a method for a specific material development.

In this study, the base material was the aluminium alloy of Al8006. Its application area covers amongst others the material for multilayer tubes. This alloy has been subjected to different technological paths consisting heat treatments (homogenization) and mechanical strengthening technologies: multiple forging, equal channel angular pressing. The chemical composition of this alloy contains iron as the main alloying element at 1-2wt%, manganese and silicon besides aluminium. Iron, which is the main alloying element cannot be dissolved by aluminium, therefore it will form - as well as manganese and



silicon -, primary compound phases during crystallization. These phases, which are inconsistent with the matrix, make it considerably more difficult application of the alloy is some technologies and to produce product with required performance, in this case a multilayer heating floor tube intermediate film layer [1].

To resolve it, the cast ingot is homogenized to refine the primary phases delimited by the sharp corners and to dissolve some of the alloying elements back into the aluminium [2-3]. Since the aluminium is not alloyed at very high level in this case, the mechanical behaviour is ductile, and the industry actually considers Al8006 alloy as an unalloyed material. After the homogenization, through hot and cold rolling processes, approx. 200  $\mu\text{m}$  thick film/foil is produced. However, a problem remains, that in many cases the size of the primary phases is comparable to the film thickness, resulting in discontinuity or cracks during the utilization, and the lifespan of the product is strongly dependent on the alloy phase structure [4].

In the present study, we aimed to process Al8006 alloy to various technological paths and to refine further the primary phase structure, and optimize look for the technology sequence that assures the highest strength and the highest toughness at the same time. To determine this, we have been created a complex performance index that integrates these property characteristics.

## 2. Experiments

The chemical composition of Al8006 is shown in Table 1. From the base material, cylindrical specimens of diameter of 10 mm with a length of 60 mm were machined. By designing the experiments, we sought to study the effects of each industrial technological steps.

**Table 1.** Chemical composition of Al8006 alloy

Chemical composition (wt%)						
Fe	Si	Cu	Mn	Zn	Remainder (total)	Al
1,2 - 2	max. 0,4	max. 0,3	0,3-1	max. 0,1	max. 0,15	95,9 – 98,5

The initial state was the as-cast state, homogenization heat treatment as the first step of the technological route was only applied to one half of the samples. Thus, the subsequent deformation processes were performed on both as-cast and homogenized samples. Two variations of severe plastic deformation processes were chosen: (1) the multi axes forging (MF) executed on the Gleeble 3800 physical simulator, and (2) equal channel angular pressing (ECAP), wherein the cylindrical specimens were extruded using an ECAP die with a channel angle of  $110^\circ$  [5-6].

**Table 2.** Technological paths for Al8006 alloy samples

Homogenization Heat Treatment		Severe Plastic Deformation	
Temperature ( $^\circ\text{C}$ )	Time (h)	Type	Strain
-	-	- (as-cast)	-
-	-	ECAP route A 1x	0,81
-	-	ECAP route A 2x	1,62
-	-	ECAP route C 1x	1,62
605	2h	ECAP route A 1x	0,81
605	2h	ECAP route A 2x	1,62
605	2h	ECAP route C 1x	1,62
605	2h	MF	1
605	2h	MF	5
605	2h	MF	10

The multi pass ECAP processes were divided into two types. Either the route ‘A’ processing was performed, when the cylindrical sample after the first pass is reloaded into the extrusion die at the same position; or route ‘C’, when the cylindrical sample was rotated with degree of 180° along to the longitudinal axis for each subsequent passes [7]. Based on these concepts, the thermal and deformation processing of Al8006 alloy is summarized in Table 2.

To evaluate the mechanical properties of the processed specimens, samples were taken out for micro hardness testing with load of 0,3 kg (Wolper 401 MVD micro hardness tester), and tensile testing (Instron 5969) were accomplished. Out of the measured properties, the complex performance index (CPI) was defined as [8]:

$$\text{CPI} = \left( \frac{\text{HV}_{0,3}}{\text{HV}_{0,3\text{max}}} \right) * \left( \frac{\text{Rp}_{0,2}}{\text{Rp}_{0,2\text{max}}} \right) * \left( \frac{\text{R}_m}{\text{R}_m^{\text{max}}} \right) * \left( \frac{\text{A}}{\text{A}_{\text{max}}} \right) * 100 (\%) \quad (1)$$

where

CPI – complex performance index (%)

HV<sub>0,3</sub> – microhardness, load:0,3 kg

HV<sub>0,3max</sub> – maximum hardness of all technological routes

Rp<sub>0,2</sub> – yield strength (MPa)

Rp<sub>0,2max</sub> – maximum yield strength of all technological routes

R<sub>m</sub> – tensile strength (MPa)

R<sub>mmax</sub> – maximum tensile strength of all technological routes

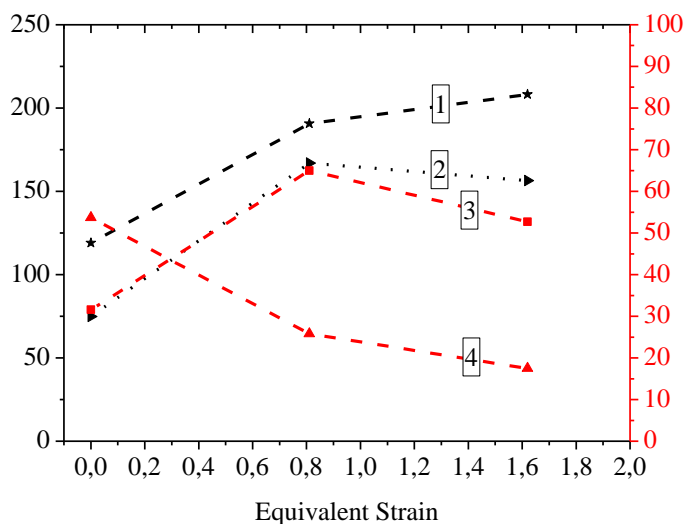
### 3. Results

#### 3.1. Mechanical properties of Al8006 alloy after different technological paths

Tensile testing was accomplished on the samples processed by different technological routes, furthermore, comparing the characteristics of cast state sample and sample deformed by traditional industrial technique (hot and cold rolling). According to the results, the hardness value of the cast state

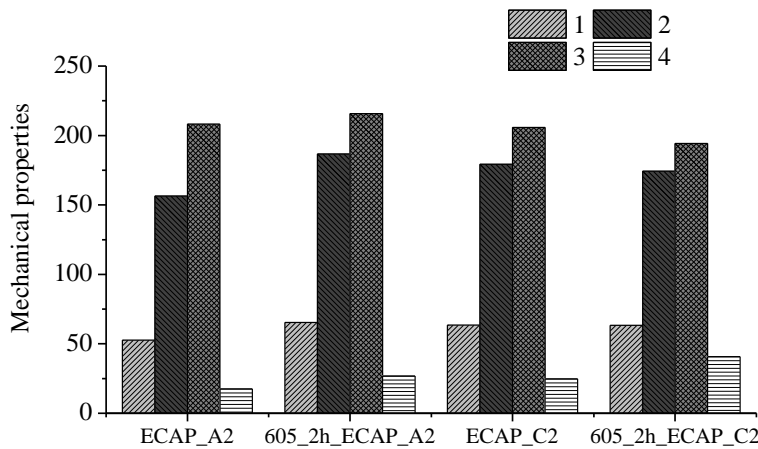
sample doubles after the first ECAP pass, furthermore the values of yield strength and tensile strength almost doubled. However, a drastic decrease in elongation values can be observed after the first pass.

The second pass no longer represents a double change/increment from the first pass, but the strength values are still increasing while the toughness values are not significantly reduced (Figure 1). The ECAP routes also influence the mechanical properties, and the C route (180 ° rotation) results in better elongation



**Figure 1.** Mechanical properties vs. the equivalent strain for the (non-homogenized) ECAP processed samples.

1-Tensile Strength (MPa), 2-Yield Strength (MPa),  
3-Hardness (HV<sub>0,3</sub>), 4-Total Elongation (%)

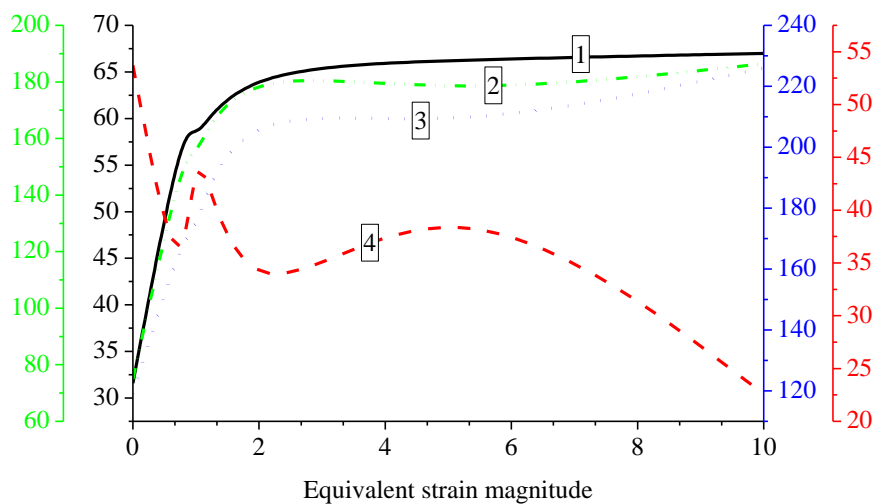


**Figure 2.** Comparison of mechanical properties via ECAP routes and application of homogenization

- 1- Hardness (HV0,3), 2-Yield Strength (MPa), 3- Tensile Strength (MPa), 4- Total Elongation (%)

beyond the same values in the cast sample (Figure 2).

In the case of samples in homogenized state, an increase in mechanical properties with the deformation were observed. Properties of sample deformed by a strain of 5 is near the same as the value of deformation of 1,6, but increasing the strain to 10, a drastic decrease in the elongation value was found. In these cases, material might be close to its deformation limit but it has not yet been reached the



**Figure 3.** Mechanical properties vs. equivalent strain for homogenized samples

- 1-Hardness (HV0,3), 2-Yield Strength (MPa), 3-Tensile Strength (MPa), 4-Total Elongation (%)

values than the A route. The effect of homogenization prior to forming can also be observed in the test results. Samples were homogenized at 605°C for 2h, as a result of which the hardness, yield strength and tensile strength values are lower after the first ECAP pressing compared with the cast state, also the uniformly deformed specimens, but after the second ECAP process, they are significantly larger than their cast samples/counterparts. Elongation data were improved with 1-2%. The beneficial effect of homogenization is most pronounced in the C route formation, where both the strength values and the elongation values are far

beyond the same values in the cast sample (Figure 2). In the case of samples in homogenized state, an increase in mechanical properties with the deformation were observed. Properties of sample deformed by a strain of 5 is near the same as the value of deformation of 1,6, but increasing the strain to 10, a drastic decrease in the elongation value was found. In these cases, material might be close to its deformation limit but it has not yet been reached the strength limit, as the yield strength and tensile strength continued to increase, with only the elongation halved (Figure 3).

Thus, the alloy has approached its forming limit state in selected technological paths. To classify the technological router, and to find out, which technological route leads to the performance limit of the material, we defined and calculated the complex performance index (CPI).

3.2. Complex performance index for different technological paths

Using the test results for the material properties, the complex performance index was determined by comparing the given mechanical characteristics of the samples produced by each technological path to the maximum of each parameter. On this basis, we created four ratios, then calculated the their product,

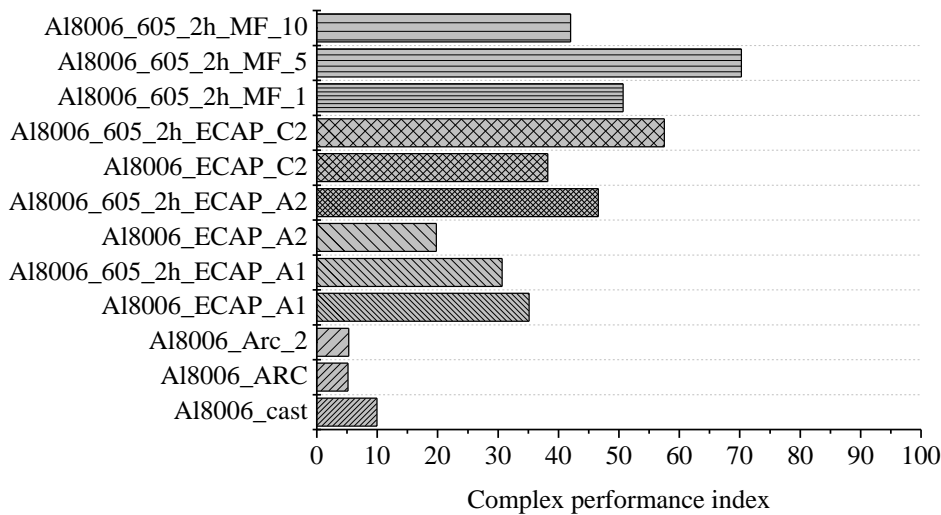


Figure 4. Complex performance index based on the material testing results

increasing the amount of strain, the complex performance index increases, and a third-order function can be fitted on the results. At the strain of 0.81 CPI is 30%, while at the strain of 1.6 it is already 46%,

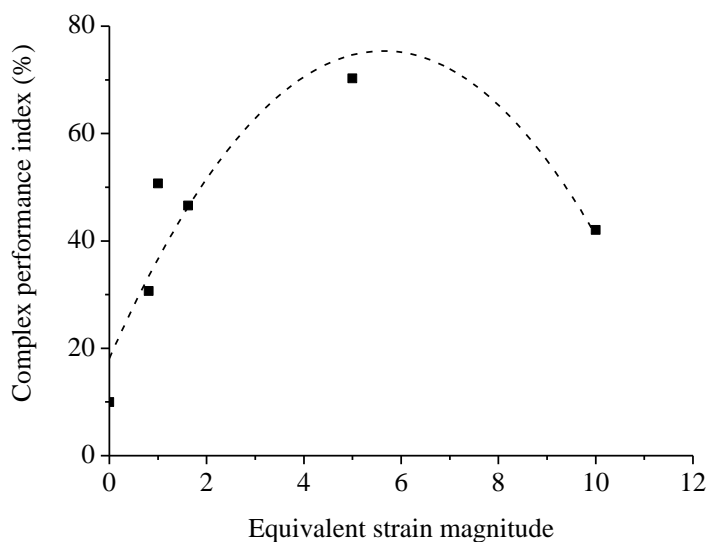


Figure 5. CPI values via equivalent strain magnitude for homogenized samples

where each attribute was taken with equal weight into the equation, and the performance index was generated. The CPI in percentages are plotted in the bar chart in Figure 4.

According to the CPI, the effect of homogenization on the ECAP specimens only appears intensively after the second pass, forming dominates in the first pass. By

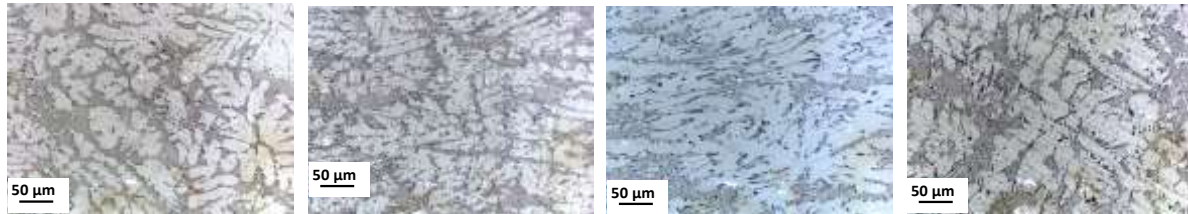
but increasing the strain to 5, it is already 70%, and finally at a strain of 10, a drastic decrease occurs, which is attributed to the extreme decrease in elongation values (Figure 5).

Based on the calculated CPI results, it can be concluded, that the performance limit state of optimal strength and elongation can be found in the homogenized state sample after MF process with the strain of 5 (Fig. 4), therefore this is the technological path that leads to the performance limits of the Al8006 alloy. Of course, further increasing the diversity of forming paths would give a more comprehensive picture of the limits of this alloy. Expanding the technology paths is part of further research work.

3.3. Microstructure of Al8006 alloy

The effect of homogenization is clearly evident in the "spheroidizing" of the primary intermetallic phase and in the deformation of samples in the homogenized state (Figure 6). Partially dissolved or finer needle shaped phases during homogenization crumble during forming sequentially, hence the life of the end-product is reduced. In the non-homogenized samples, the size of the needle shape phases is comparable to the thickness of the end-product.

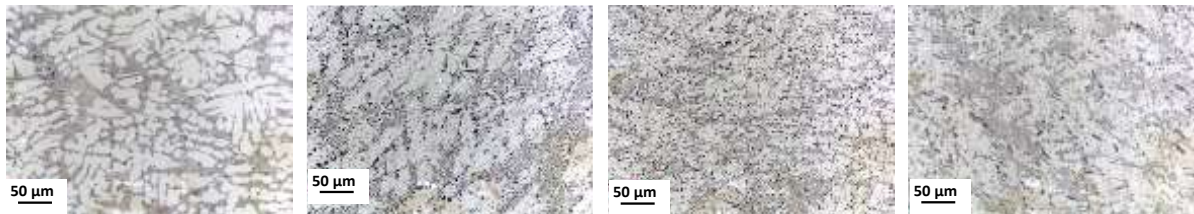
**CAST**



**ECAPA1x**

**ECAPA2x**

**ECAP C2x**



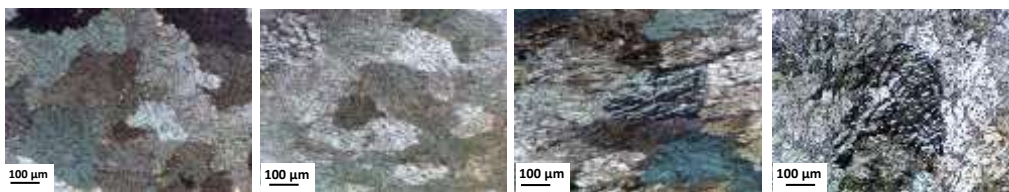
**HOMOGENIZED**

**Figure 6.** Phase structure of cast, homogenized and ECAPed samples

If the primary phase structure has already been refined by homogenization, and the needles characteristic of the cast structure are thinner than without homogenization. However, the actual change in the phase structure can be achieved by forming processes.

During ECAP, the cell structure of the 1x pass sample is nearly the same as that of the as-cast or homogenized ones. Deformation occurs only in the local cells and subcells with different orientations -

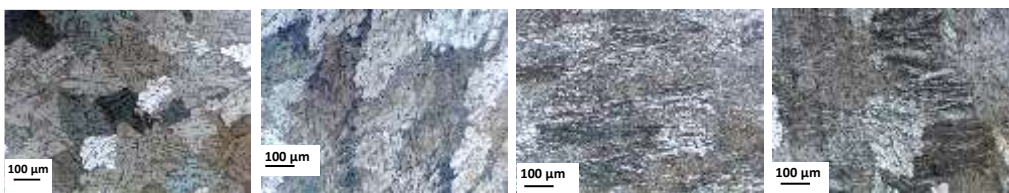
**CAST**



**ECAPA1x**

**ECAPA2x**

**ECAP C2x**



**HOMOGENIZED**

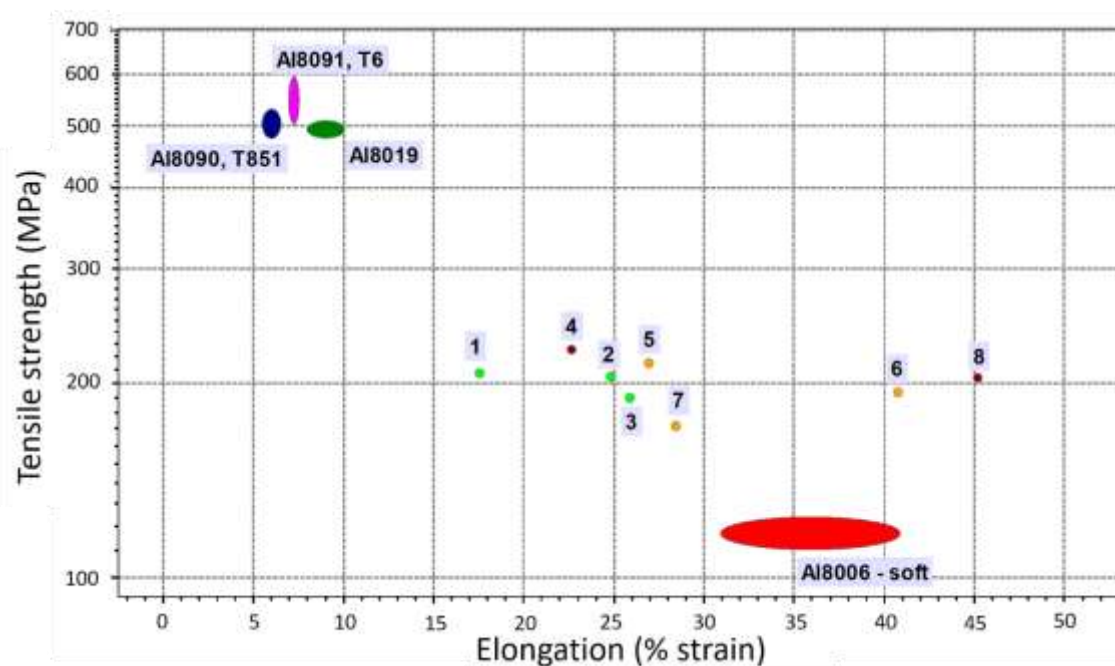
**Figure 7.** Grain structure of cast, homogenized and ECAPed samples

appearing in different colours on the recordings, also the band structure. However, the primary phase structure is broken after the first pass. Homogeneous and single ECAP processed sample shows much finer phase structure than

cast and ECAP 1x sample. By increasing the number of passes, the initial cell structure disappears after the second ECAP pass samples. Elongated subcells/subgrains arranged in the direction of deformation are observed. The effect of the forming paths can also be traced on the microstructure. In fact, the phase structure does not suffer the same degree of refinement in the route C processed sample as in the route A processed sample (Figure 7).

### 3.4. Findings comparing with industrial data

In addition, the results were compared with the CES EDUPACK software material database. As no data was found for the test alloy, comparisons were made with Al8xxx alloys based on maximum strength (tensile strength) and maximum elongation (total elongation). Figure 8. shows the result of the comparison.



**Figure 8.** Comparison our results with the database of CES EDUPACK software

- 1 – Al8006, cast ECAP A2, 2 – Al8006, cast ECAP C2,  
 3 – Al8006, cast ECAP A1, 4 – Al8006, 605°C 2h, MF  $\phi=10$ ,  
 5 – Al8006, 605°C 2h, ECAP A2, 6 – Al8006, 605°C 2h ECAP C2,  
 7 – Al8006, 605°C 2h ECAP A1, 8 – Al8006, 605°C 2h MF  $\phi=5$

The data in the database did not apply to Al8006, but it is also clear from the test results that the homogenized samples multiple forged with the strain rate of 5 has achieved the highest tensile strength-elongation combination.

## 4. Conclusions

In the present study, we aimed to subject Al8006 to various technological processes and refine the primary phase structure to find out the technology sequence that provides the highest strength and



toughness at the same time. To determine this, we have created a complex performance index that combines these property characteristics.

Based on the results, the following conclusions can be drawn:

1. The same amount of strength and approx. three times higher elongation values were obtained for Al8006 formed by severe plastic deformation processes than those obtained by the conventional forming technique in the H19 (full hard) state.
2. Based on the experiments and in the light of the defined complex performance indices, the Al8006 alloy has the best combination of properties with 605 ° C 2h homogenization and multiple forging with the strain rate of 5.
3. As the effect of the homogenization, the sharp/thick needles of the primary intermetallic phase structure become thinner, they can get broken by the forming processes and consequently, the ductility and usability of alloy improves.
4. As a result of the forming, the cast cell structure disappears partially (after the 1st pass) and then completely (after 2nd pass) and the sub-cell structure parallel to the forming direction is formed.
5. The complex performance index for a given alloy qualifies the applied technological path according to customer needs.
6. In the improvement of the performance index value, we take into account the elongation on necking values for the future because that is where the properties of the individual states are revealed.

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