# MODELING OF DUCTILE FORMING OF FORGED ALUMINUM ALLOY

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Forging is a forming process without any turning demand, which is used mainly for serial production of machine parts with high quality static properties. The aluminum alloy type

EN-AW-6082 has been analyzed in our study, where several specimens of this material have been modeled with finite-element-method (FEM), too. As a result the varying static properties as well as its correlation with the deformation features have been detailed. Two-directional ductile deformation of a 90mm height round material as well as a 88mm height one have been tested. First its height has been pressed down to 42mm, then the specimen has been deformed again at 42mm but now in perpendicular direction. Both deformation have been carried-out by flat-shaped tools. Based on these results several tensile tests have been carried-out, which have been modeled, too, and then its deformation properties have been calculated. Several samples have been forged-out from the specimen, and its local deformation and the variation of its mechanical properties have been analyzed.

## Introduction

The usage of tempered aluminum alloys has become recently even more populate not only in the aerospace and automotive engineering but in the general and other engineering fields, too. The great advantage of these alloys is the low density, which is approximately one third of that of the steel, its high strength, which is near to that of the steel, and in addition some alloy has a tensile strength value of Rm > 500 MPa [9, 10]. The favorable corrosion properties of aluminum as well as its usability for welded structures are advantageous, too. Turning of this material is easy, but its properties can be improved by plastic forming, as the produced losses are minimal. The common manufacturing process of series of forged parts is the drop forging.

Plastic forming allows to achieve high strength, and the tempering forms a stable and high-strength material texture [8]. The literature gives a wide validity range for the technology parameters (temperature during manufacturing, temperature of homogenization, cooling rate during tempering, length and temperature of the tempering, rest time between two tempering stages, etc.) of these processes. In addition, there are other factors (rate and measure of deformation), that may affect the mechanical properties of the finished parts. The specimens in the experiment have been produced with a friction presser, where the most up-to-date settings of this high-tech manufacturing machine have been applied. The produced specimens have been produced with the highest strength because of the used tempering. In the same time a finite element analysis has been carried-out for tracking the deformation.

## Material and method

The forging preparation of test specimens was carried-out according to the standards of small and medium series parts for the automotive industry under 20 kg. The basic material is usually round material, however complex parts can be produced from different profiles, which suits the production more likely. The two stages of refining are the hardening and the subsequent tempering, and both of them have decisively influence on the mechanical and on the strength properties of a finished part.

### Production of specimens

The sample series have been produced by the blacksmith Alutech Ltd. according to its own industry standards applied for series part production.

- Accordingly round specimens of EN AW-6082 alloy were produced with 90 mm diameter and 88 mm height.
- The specimens were pre-heated at 500°C for forging [3, 4, 5].
- The upsetting was made at 44 mm length, which corresponded to a major deformation with a rate of $\varphi$=50%.
- Then tempering for refining was applied according to the valid industry standards.

The equipments used for the above test and for the preparation of specimens were as follows:

- Tempering of cut parts was carried-out in a BSN-made gas-fired tunnel kiln, where the temperature of each parts have been measured manually.
- A friction presser of VACCARI type PV270 was used for the above process (Fig. 1).

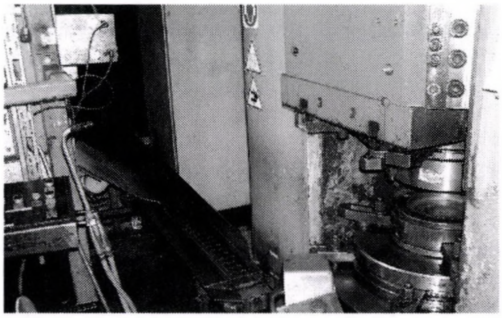


Figure 1. Friction presser of VACCARI type PV270

- An original upset tool used basically for industrial part production was applied during the experiments, which was heated up to 130°C, and the tool's temperature was kept always above 100°C during the production. Each tool's surface was emulsified before the part has been let to be broken down.
- The alloy was heated at a suitable temperature in a BALZER-made electric resistance heating furnace (Fig. 2) and when the tempering time was over the specimens were upset in water. All properties of the refining process have been listed in Table 1.

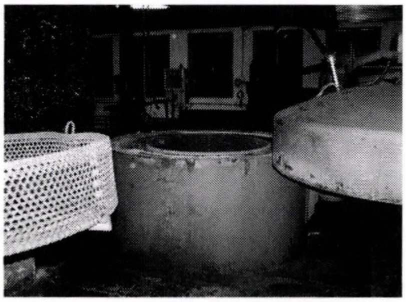


Figure 2. BALZER furnace

- The second step of the tempering and refining was the relaxing with a SCHMITZ-made gas-fired chamber furnace. Thus, both types of alloys were re-built into a T6 stage according to DIN EN 515, which is most appropriate for machine part production [6, 7] purposes.

Table 1. Properties of tempering

| Properties of hardening | | | |
|---|---|---|---|
| Alloy | Tempering Temperture (°C) | Tempering Time (min) | Temperure of cooling water (°C) |
| ENAW 6082 | 520 | 126 | 25 |
| Properties of relaxing | | | |
| ENAW 6082 | 180 | 390 | Cooling with ambient air |

Figure 3. The original specimen (above left) and the forged specimen (bottom right)

### Input parameters of the numeric simulation

The formed material was modeled in the simulations as aluminum, and that of the tools as steel. The tools do not suffer permanent deformation during the forming, because the material strength is below its yield strength, hence these could have been modeled as linear elastic materials. The aluminum has had elastic deformation, that's why in this case bilinear elastic-plastic material model was used. Several working temperature were used during the production, where 100MPa yield strength and 1MPa tangent modulus were set as material properties. Multiple symmetry was taken into consideration during the modeling of the specimen geometry, therefore modeling of 1/8-part of the whole tool and specimen was enough, and corresponding constrains were applied onto the symmetry planes.

A real result requires the modeling of the contact problem in the finite element model, and for this sake two problems had to be defined between the part and both of the tools. Frictional contact was set between the bodies with a friction coefficient value of 0.1. The stiffness matrix was set to be re-calculated in each iteration step because of the large deformation and of the great vary of the contact surfaces during the modeling.

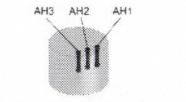
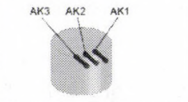
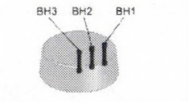
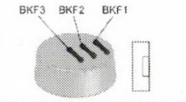
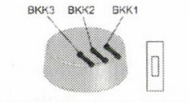
The model was built-up with 20-node hexagonal elements (quadratic approximation using polynomials), and if it were not possible due to the geometry settings, the 10-node tetrahedral elements (also quadratic approximation) were used instead of the 20-node one.

### Measurement of mechanical properties

The mechnical measurements were carried-out by an INSTRON 5581 universal material testing equipment in the Hungarian Institute of Agricultural Engineering [1], which has been calibrated according to the MSZ[1]-EN 10002-2 standard. All measurements have been carried-out according to the MSZ-EN 10002-1 standard (Tensile test of metals at room temperature). The sample design was done according to the above standard, too, like the used jaws do.

The diameter of each specimen was 6 mm in a length of 20 mm. The testing rate was set according to the valid standards. The feed rate was 10 mm/min until the load reached 100 N, and then it was set at 10 m/min. All measurements were repeated three times. The sampling method of raw as well as of forged specimens can be seen in Table 2.

Table 2. Sampling from the raw and the forged specimens

| | | |
|---|---|---|
|  <br>Sign: AH |  <br>Sign: AK |  <br>Sign: BH |
|  <br>Sign: BKF |  <br>Sign: BKK | |

### Results and discussion

### The elastic forming

The strength and deformation have been calculated by a simulation done by the above parameters. Distortion and sliding surfaces are determinative during the processing in point of the granularity, so these features have been examined basically.

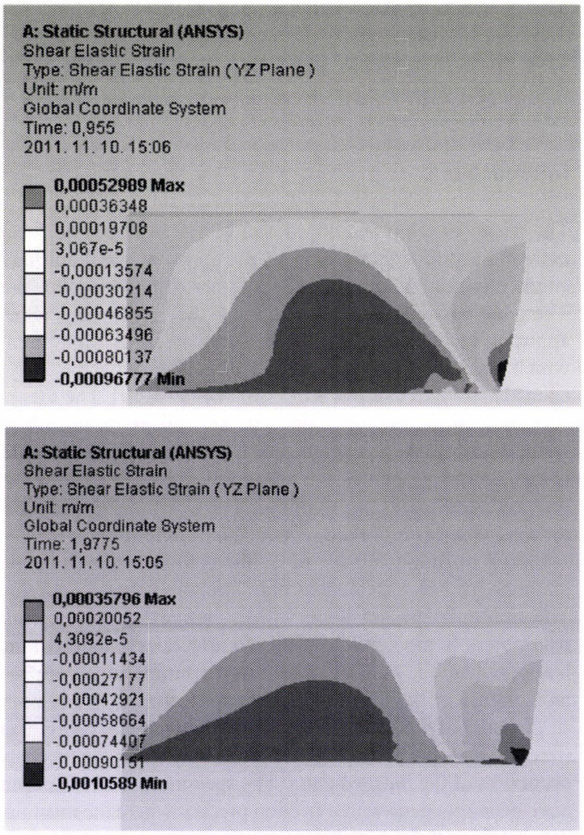


Figure 4. Distortion deformations in the YZ-plane during processing

The calculated deformations (see Fig. 4) show the presence of pushing cones, and the maximum deformations occur at the boundary of the cones. The deformation inside a cone is less because of the one directional processing. The distortions on the YZ-plane do not represent the entire deformation because of the axial symmetry of the part, but a numerical estimate of its value

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[1] MSZ = Hungarian National Standard

can be determined. The maximum distortion value calculated from the spatial strength state can be seen in Fig. 5. It shows that the deformation - especially at the beginning of the processing - was influenced by the pushing cones.

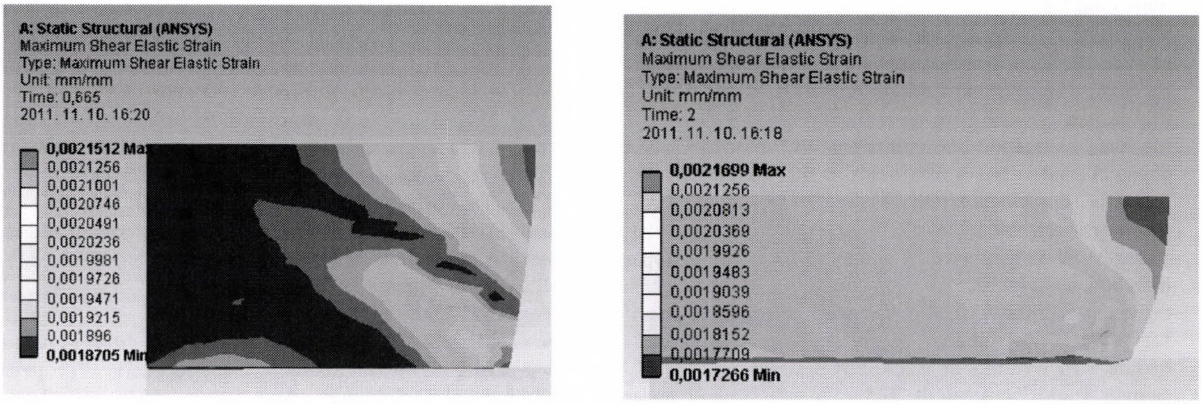

Figure 5. Absolute extreme of the distortion deformations during processing

**Discussion of the tensile tests**

Fig. 6 shows a tensile test of the raw material.

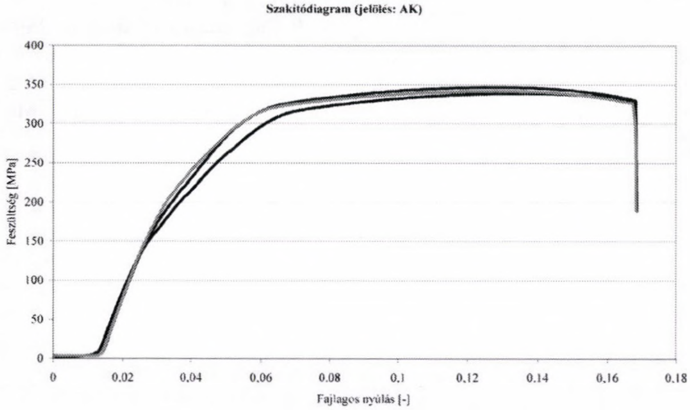

Figure 6. Tensile test diagram AK2 (material sample across a quarter of the diameter)

Table 3 summarizes the material strength test results taken from different locations of a sample in MPa.

Table 3. Material strength values of samples

| | AK1 | AK2 | AK3 | AH1 | AH2 | AH3 |
|---|---|---|---|---|---|---|
| 1 | 346,4 | 339,0 | 347,8 | - | 386,0 | 386,6 |
| 2 | 340,5 | 346,9 | 347,6 | 382,2 | 390,1 | 386,5 |
| 3 | 350,3 | 342,0 | 348,2 | 386,3 | 379,1 | 381,3 |
| **Average:** | **345,8** | **342,6** | **347,9** | **384,2** | **385,1** | **384,8** |

Table 4. Material strength values of forged samples

| | BKK1 | BKK2 | BKK3 | BH1 | BH2 | BH3 | BKF1 | BKF2 | BKF3 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 335,6 | 327,3 | 340,3 | 319,9 | 330,2 | 331,8 | 356,2 | 340,1 | 337,6 |
| 2 | 348,6 | 342,7 | 345,2 | 326,6 | 333,2 | 322,6 | 346,9 | 344,7 | 342,1 |
| 3 | 357,0 | 338,5 | 340,1 | 333,7 | 335,8 | 350,9 | 334,4 | 344,4 | 341,5 |
| **Average** | **347,1** | **336,1** | **341,9** | **326,7** | **333,1** | **335,1** | **345,8** | **343,1** | **340,4** |

Conclusions from the results of the measurements and the calculations:

- the longitudinal material tensile strength was greater than the transversal one (the difference is approx. 40 MPa, which is more then 10%);
- according to Table 4 it can be determined, that the material texture has been homogenized through forging, furthermore the slight longitudinal strength reduction is due to the axial processing;
- the nearly constant strength along the diameter has been changed, and it has a maximum in the sample taken at its maximum deformation (BKK1; see Fig. 5);
- it can be determined, that the forging quality and the material strength can be improved by an other processing in any other direction, as before;
- the strength of the formed part is nearly identical to that of the high quality raw material, and it has homogeneous material texture, which cannot be reached by casting;
- sample "BKK1" has had the highest tensile strength under the transversal ones, and its location is identical to that of the calculated highest distortion in Fig. 5.

## Acknowledgements

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