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Modeling of ductile forming of forged aluminum alloy AW-6082

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ABSTRACT

Forging is a forming method without any chips development, which is mainly used for serial produced machine parts with improved mechanical properties. A finite element method (FEM) model was developed to analyze the behavior of specimens made of the most commonly used aluminum alloy (EN AW-6082) in the Hungarian practice. Here an optimal forging model was searched for, moreover the connection between the variation of the mechanical properties and the scale of the deformation. An 88 mm high cylindrical specimen of 90 mm diameter have been measured with 2 directional forming (it have been upset at 44 mm of its height), then samples were taken from it at different locations, and the local deformation with the change in the mechanical properties have been compared.

Introduction

The usage of fineable aluminum alloys spread rapidly in the last couple of years among the general and other mechanical industries and it didn't remain any more a privilege of the aerospace- or the automobile industries. A huge advantage of such alloys is the low density, which is only the third of that of the steel, moreover its high strength, which is with its Rm > 500 MPa value almost equal to that of the steel in some cases [Parvizian et al., 2010]. Its corrosion- as well as welding properties are excellent, it can be forged easily, however its behavior can be improved by plastic forming, because the forging loss can be minimized. Serial produced machine parts made of this material are produced mainly by forging because of the above advantages.

Plastic forming makes the material's strength higher and the refining heat treatment makes the material structure much more stable [Williams et al., 2010]. The literature gives several setting scenarios for the above methods (forming temperature, homogenization temperature, cooling temperature gradient during hardening, heat treatment time and temperature, conditioning time between two heat treatment process). On the other hand there are several other factors (such as forming rate, forming scale), which should all affect the mechanical properties of a machine part [Poletti et al., 2011].

1. Material and method

Specimens were forged according to the production procedure requirements of the general machine- and automobile industry for small or medium series production below 20 kg weight. For this case cylindrical row material is commonly used, however parts with complex profile can be produced from a form shaped row material, too. Both hardening and conditioning, as the two parts of a refining process, have crucial effect on the mechanical- and static properties of a produced part [Pedersen et al., 2008].

1.1 Specimen production

Specimen series have been produced by the Alutech Kft., hence the technology was identical to that of the series forged production.

- 88 mm high cylindrical specimens of 90 mm diameter were produced from aluminum alloy of EN AW-6082.
- Forging temperature was 500°C [Weronski and Gontarz, 2003].
- Upset was made until 44 mm specimen height, which corresponds to a main forming at $\varphi = 50\%$ scale.
- Hereafter normalization has been carried-out according to the common technology standards [Köves, 1984].

The following equipments and tools have been used for specimens' testing:

- cut parts have been warmed-up in a gas fired tunnel oven type BSN, where parts' temperature was measured by manual thermometer.
- the compactor was a friction type one of the Vaccary Company from the series PV270 (Pic. 1.)

Picture 1. Friction compactor of the Vaccari Company

- The compaction tool was a commonly used one, which was heated-up to 130°C before its operation, and its temperature remained during the whole testing above 100°C. The tool's surface has been greased before each use with a form separating emulsion.
- The specimen was heated-up at an adequate temperature corresponding to the typical hardening of this type of alloy. For this case a Balzer type oven was used, which was heated by an electric trace heating solution (Pic. 2.). In the next step the specimen has been hardened in water. Properties of this refining process have been summarized in Table 1.

Pic. 2. A Balzer-type oven.

- The second step of the refining was the relaxation by a gas fired Schmitz-type oven. In this way every tool made of one of both alloys could have been set at an optimal T6-state (according to the DIN EN 515) [Mrówka et al., 2005].

Table 1. Properties of the refining process

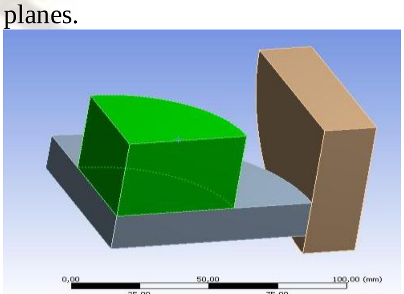
Properties of the hardening			
Alloy	Temperature of heat treatment (°C)	Time of heat treatment (min)	Temperature of cooling water (°C)
ENAW 6082	520	126	25
Properties of the relaxation			
ENAW 6082	180	390	Cooling by ambient air

Picture 3: First step of forming

Picture 4: Second step of forming

1.2 Input parameters of the numerical simulation

The formed material was modeled as aluminum and that of the tools as steel. Tools did not sustain permanent deformation during forming, because the developed material strength does not reach its yield strength, hence these were modeled as elastic materials. The aluminum sustain permanent deformation during forming, therefore here a bilinear elastic deformable material model was used. The process was made at different temperatures, therefore a yield strength of 100 MPa and a tangent modulus of 1 MPa were set as material properties [Koder et al., 1970]. The model geometry of the specimen takes its multiple symmetry into consideration, as well, hence 1/8-part of the whole real geometry of specimen and that of the tool was enough to build-up the model (Pic. 5.). The appropriate constraints were set at the symmetry planes.



Picture 5.: The simplified 3D-Model according to the multiple symmetry

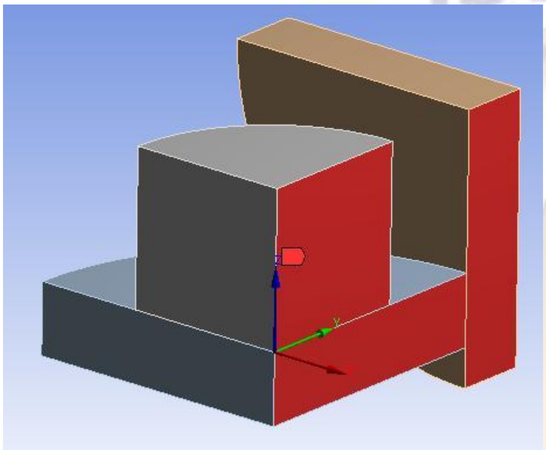
A real modeling approach needs the definition of the contact problem, too, and here there are at least two of them: between the specimen and the both of tools. Friction was set between the bodies at 0.1, and the rigidity matrix was set to re-calculate after each iteration step being the deformation huge.

The model was built-up by 20-node hexagonal elements (here were applied quadratic approaching polynoms), or by 10-node ones (with quadratic approach, too), where the geometry did not support the larger elements.

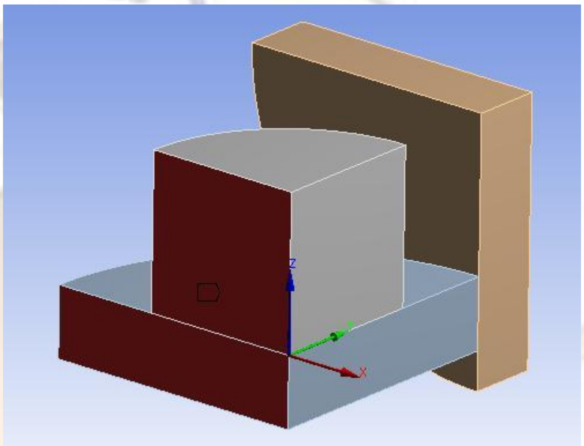
The following boundary conditions were set for the forging simulation:

- symmetry conditions,
- kinetically boundary condition of the first strike,
- kinetically boundary condition of the second strike,
- tools guiding.

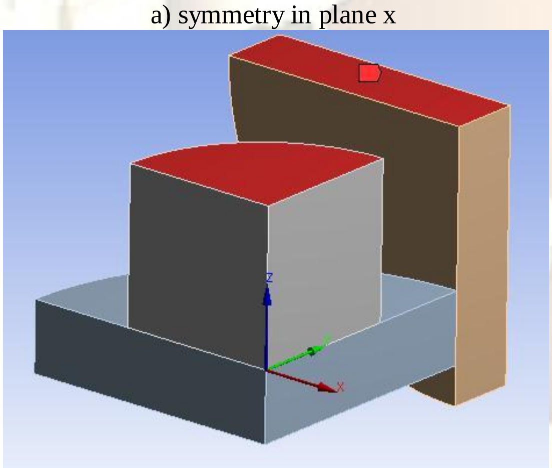
The following symmetry conditions were defined for each motion: x-directional movement was fixed as Pic. 6a, the y-directional one as Pic. 6b, and the z-directional one as Pic. 6c., respectively.



a) symmetry in plane x



b) symmetry in plane y



c) symmetry in plane z

Picture 6: Symmetrical boundary conditions of the model

The first strike was defined as a z-directional movement of the bottom tool. Being both strikes simulated in the same model, the tool must have been moved backward during the second strike. Each strike was modeled in 2 steps, and the backward movement in 3 steps, correspondingly.

1.3 Measurement of strength properties

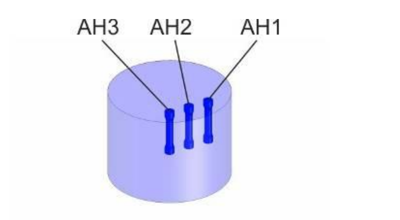
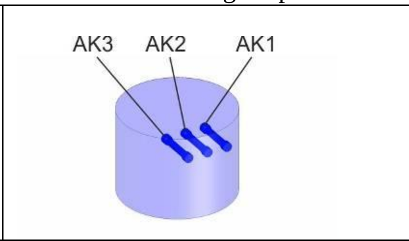
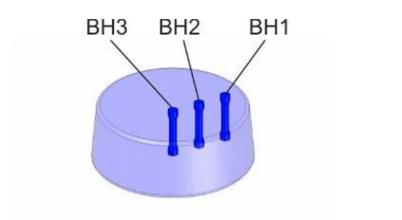
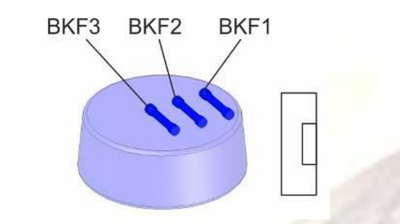
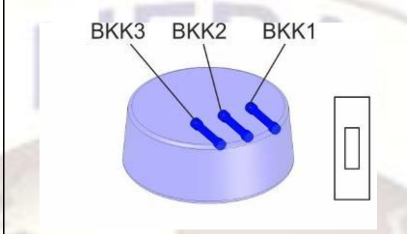
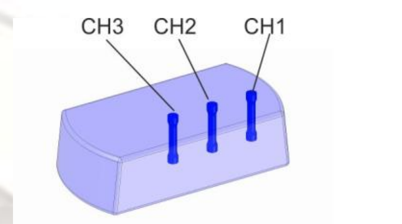
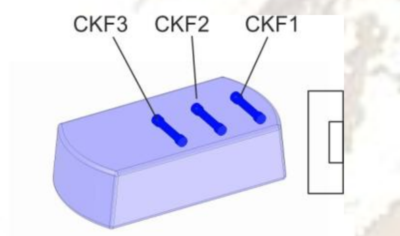
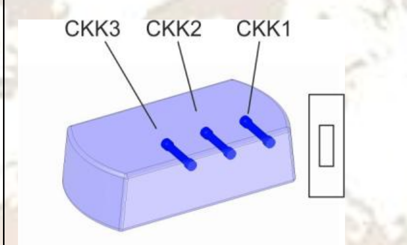
Mechanical measurements were carried-out in the laboratory of the Hungarian Institute of Agricultural Engineering by an INSTRON 5581-type universal material testing equipment [Csatár and Fenyvesi, 2008].

Every measurement was carried-out according to the valid standards (tensile test of metals at ambient temperature). Specimens as well as the clamping jaws were manufactured according to the above standards, too.

The specimens had 6 mm in diameter and 20 mm measuring length. The measurement rate was set according to the valid standards: the feeding rate was set at 10 mm/min until 100N load, and then 10 m/min. Every measurement was repeated 3-times.

Sampling from the row material and from the forged specimens was done according to Table 2.

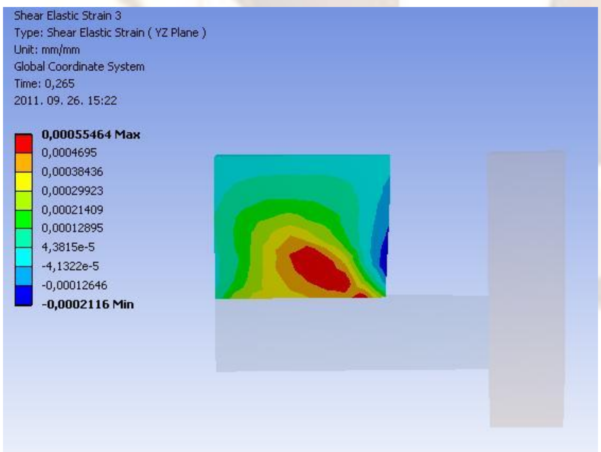
Table 2. Sampling from the row material and from the forged specimens

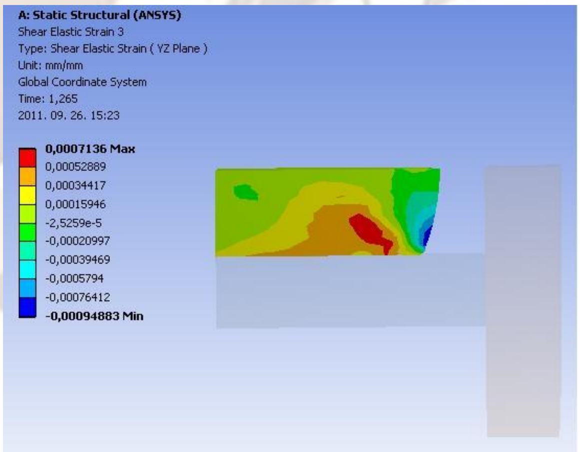
		
Legend: AH	Legend: AK	Legend: BH
		
Legend: BKF	Legend: BKK	Legend: CH
		
Legend: CKF	Legend: CKK	

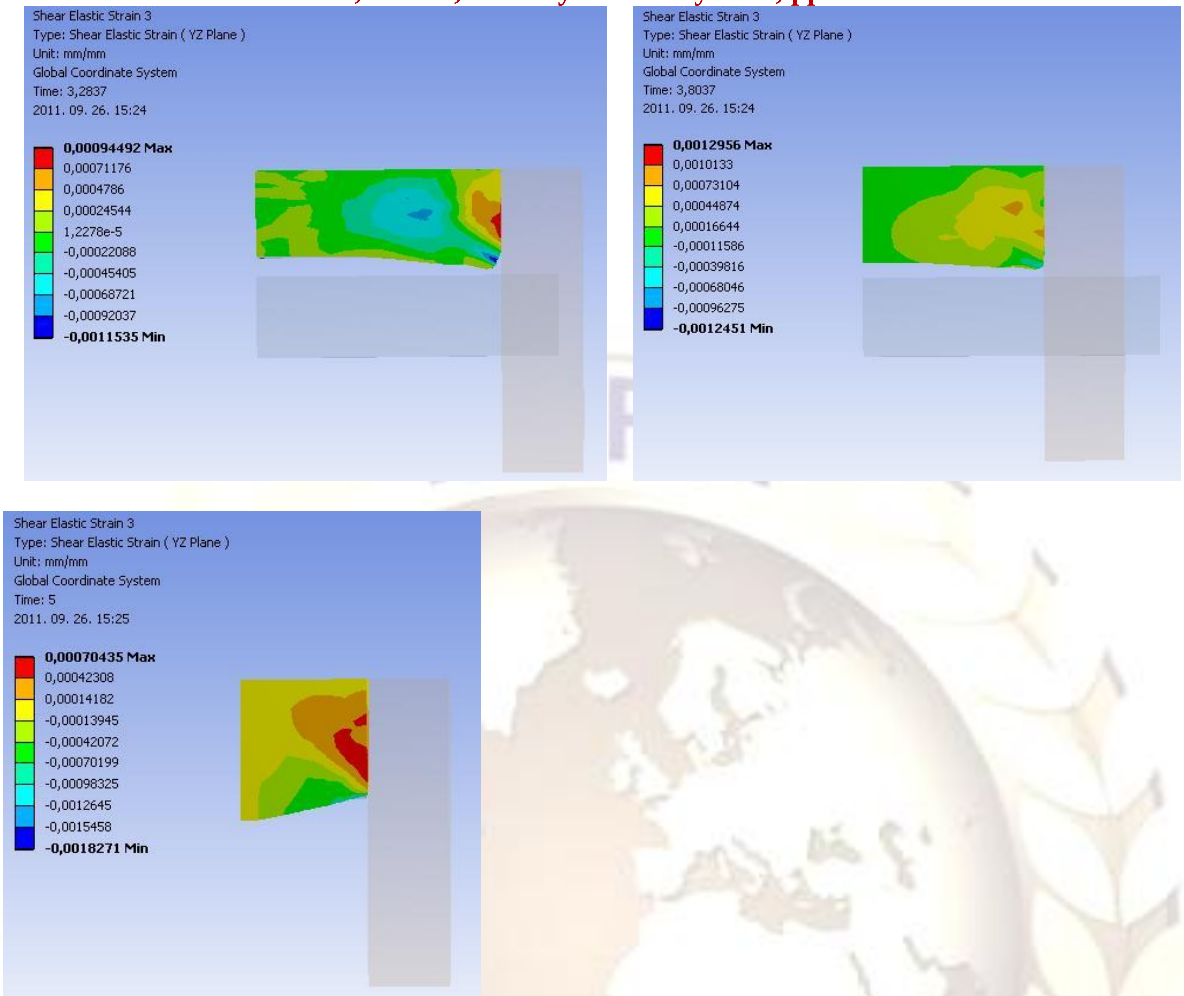
2. Results and discussion

2.1 Elastic forming

Strength and deformation were calculated during the simulation by the above detailed settings. Essentially deformations and creeping planes determine the corn grinding rate of the manufacture, therefore these two parameters were analyzed, too.

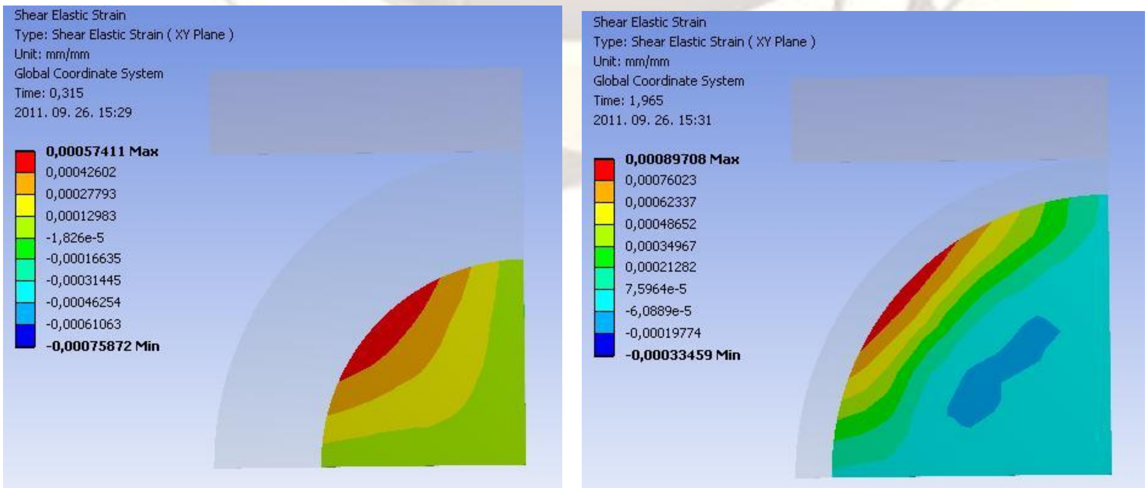


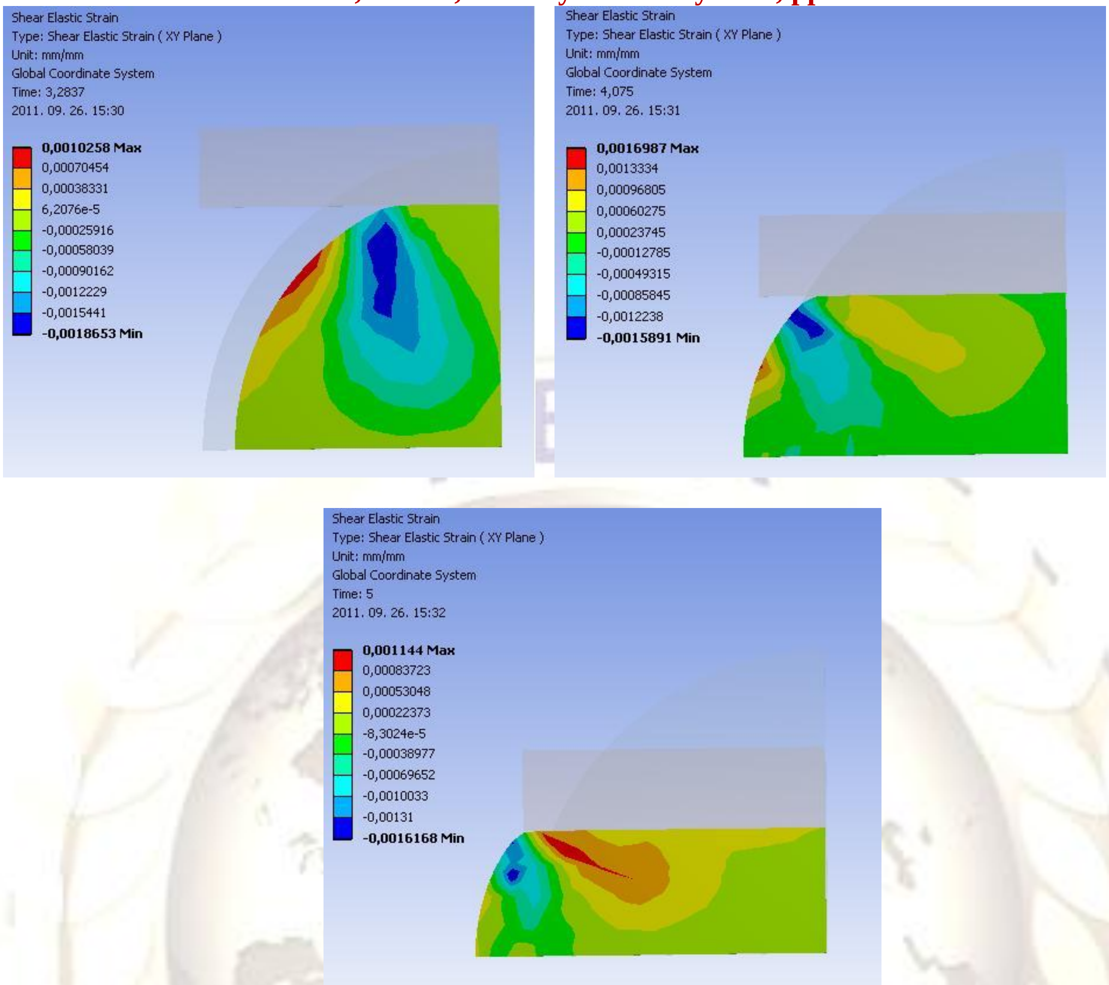




Picture 7: Deformations in YZ plane during the manufacture

The calculated deformations in Pic. 8. show the presence of pushing cones during the forging, and the deformation is along its surface maximal. Inside a pushing cone is the deformation smaller being it only one-directional. Distortion in the YZ plane does not show the whole deformation because of the axis-symmetry of the specimen, although here a numerical estimation can be given. Maximal distortions from the space strength state are shown in Pic. 5, which shows, that a pushing cones have influence onto a specimen mainly only at the beginning of the manufacture.

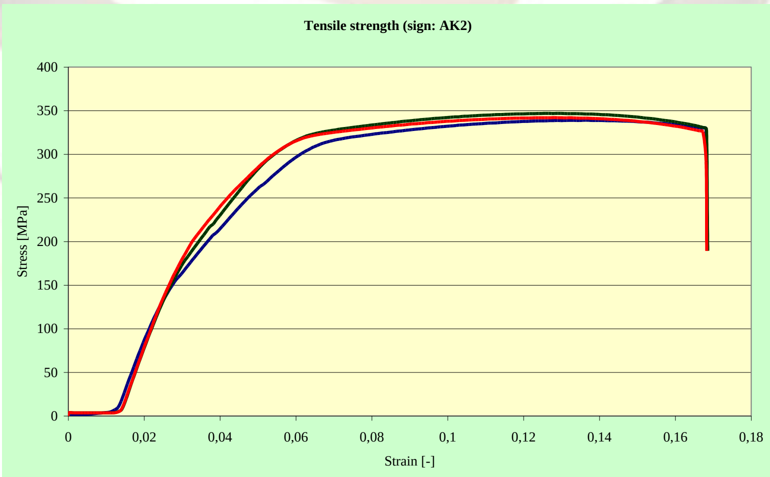




Picture 8: Distortional deformation in XY-plane during the manufacture

2.2 Evaluation of tensile tests

Pic. 9. shows a tensile test diagram of a specimen.



Picture 9. Tensile test diagram AK2 (sampling from the row material crossways, from a quarter of the diameter)

Table 3 shows the tensile strength values of samples taken from different places in MPa.

Table 3. Tensile strength values taken from the basic material

	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
Avg.	**345,8**	**342,6**	**347,9**	**384,2**	**385,1**	**384,8**

Table 4. Tensile strength values of the forged sample

	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
Avg.	**347,1**	**336,1**	**341,9**	**326,7**	**333,1**	**335,1**	**345,8**	**343,1**	**340,4**

Table 5. Tensile strength values of the twice formed sample

	CKK1	CKK2	CKK3	CH1	CH2	CH3	CKF1	CKF2	CKF3
1	338,8	336,6	343,2	326,2	334,7	327,9	319,7	325,2	328,5
2	338,5	343,0	345,5	327,3	331,1	331,4	322,2	322,2	320,0
3	346,4	351,2	349,9	322,4	323,0	332,9	331,8	329,9	330,9
Avg.	341,2	343,6	346,2	325,3	329,6	330,7	324,6	325,8	326,5

* Legend see in Table 2.

2.3 Discussion of the measurements and the calculation

Discussion of the measurements and the calculation:

- tensile strength of the basic material is lengthwise larger as crosswise (the difference is about 40 MPa, which amounts more then 10%),
- results of Table 4 and Table 5 show, that the material was homogenized by forging; the axial manufacture resulted in a small lengthwise strength loss,
- the appropriate constant strength along the diameter has changed: the sample taken from a maximal deformed location had the largest strength (Pic. 7, BKK1),
- strength and forging quality could have been improved by a forming in the other direction,
- it can be stated, that strength of the forged sample is quite equal to that of the basic material, and it is homogeneous, which neither can be approached by casting.
- the sample BKK1 owns the largest strength value under the crosswise ones, which was taken from a location with a maximal distortion.

Acknowledgement

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