FEM, Equal Channel Angular Extrusion, Direct Extrusion, DEFORM 3D

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FEM SIMULATION OF COMBINED EXTRUSION METHOD (ECAE/DIRECT EXTRUSION)

Abstract

Equal Channel Angular Extrusion (ECAE) is known as a severe plastic deformation process and material is deformed without any geometrical change. It is widely used for obtaining high mechanical properties from the product. Direct Extrusion is another plastic deformation process in which a workpiece is reduced in cross-section by forcing it through the die opening of a small cross-sectional area than that of the original billet. In this study, these two processes are combined together via using DEFORM 3D which is a very specialized software for metal forming operations. Lead is used as workpiece material to simulate hot forming conditions and also process parameters (die angle and die land length) were investigated. The forming load and strain components were calculated from the FEM results obtained from DEFORM 3D software.

1. INTRODUCTION

Equal Channel Angular Pressing (ECAP) which is known as one of the most promising material processing techniques involves severe plastic deformation. In contrast to rolling, drawing, forging the main purpose of ECAP is to accumulate deformation in material without any reduction in workpiece cross-section. The process gives uniform grain structure because of shear stress effect on the product. The grain size can be smaller in the range of in the range of hundreds of nanometers applying multiple ECAP passes. Methods that employ severe plastic deformation (SPD) to produce nanostructured materials are more suitable for bulk production of fully dense materials. During the ECAP process, the grain refinement occurs together with significant dislocation hardening, enhances considerably mechanical properties for many engineering materials. Parshikov et.al. [1] the influence of die geometry

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and friction condition on irregularity of shear strain field in the cross section of the billet and therefore on mechanical properties distribution was studied. Balasundar [2] made a series of experiments using plasticine and tin have been used to validate the numerical modeling results and to gain further insight in to the process. Balasundar [2] and et al. also used FEM method to simulate the ECAP process and concluded the importance of corner angle and fillet radius at the inner channel surface to process a variety of materials has been realized. Basavaraj et.al. [3] carried out for different combinations of channel angle, inner and outer corner radii and realized that there exists an optimum outer corner for which strain inhomogeneity is minimum, which depends on the channel angle. Inner corner alone has no influence on the strain inhomogeneity but its interaction with channel angle has some influence. Figueiredo [4] proposed a FEA of a two pass ECAP processing of copper following route C. This processing route involves the shearing of the material in the same plane as in the first pass, but in a reversed shear direction. They concluded that the consideration of the strain path effects changed the final strain distribution in the material and led to a lower punch force in the second pass, in comparison with the results from the analysis considering a single stress–strain curve for all passes.

Direct extrusion is a plastic deformation process in which a workpiece is reduced in cross-section by forcing it through the die opening of a small cross-sectional area than that of the original billet. The direct extrusion of rods and solid shapes is the simplest production method in use for high production rate and accuracy. One-third of the annual world aluminum production of 20 million tons is delivered as extruded sections. Therefore extrusion method is a famous and effective method for among of all metal forming processes so many researchers studied on the direct extrusion. Azad-Noorani et al. [5] studied on the optimal die profile by using finite element method (FEM) analysis and experimental results with the comparison of the conical and curved die profiles. Many of the studies have been performed to investigate the effect of the die profile on the deformation load and the product quality. Reggiani et.al [6] used FEM method to predict the charge weld in hollow sections and validated their results with experiments. Karami [7] developed a new kinematically admissible velocity field for the forward extrusion of a square section from a round billet and compared the upper bound results with FEM and experimental results. Qamar et al. [8] analyzed the effect of the shape complexity on the dead metal zone and metal flow through the flat-faced dies by experimental and numerical methods using Ansys-LS-Dyna. Altinbalik and Ayer [9] studied theoretical and experimental study for forward extrusion of clover sections. Chandra et. al. [10] demonstrated how the extrusion ratio and ram speed affect the temperature evolution of the workpiece during extrusion of the AA6061 alloy by using the rigid-viscoplastic formulation of a 3D FEM program. They evaluated the results for selecting the process parameters to avoid extrusion defects and minimize the temperature variations along the extrudate and on its cross section. Ulysse [11], built a numerical model which uses the 3D finite element method combined with techniques of mathematical programming to design traditional die flow correctors used in flat-faced aluminum extrusion dies.the author showed that die design depends, among other factors, on process parameters such as ram speed and product parameters such as the type of alloy used. Peng and Sheppard [12] used a commercial FEM code FORGE to study the influence of the number and the distribution of die holes on extrusion parameters. They obtained the flow pattern, pressure requirements, and temperature histories developed are established and they reported that FEM simulations agree well with obtained experimental results.

Lately, researchers paid attention to combine two severe plastic forming methods which are Equal Channel Angular Pressure and Forward Extrusion in a single die and used for powder compaction. Mani and Paydar [13] applied hot forward extrusion and ECAP process together for consolidation of Al-SiCp premixed particles. They presented that products produced by FE-ECAP combined process have better mechanical properties in contrast with forward extrusion products. Addition to this, Paydar et.al. [14] investigated the possibility of performing Forward extrusion and ECAP in a single die and producing long bar samples with full density from particles. their results show that the FE-ECAP process is a promising method for producing bulk materials from particles with full density and excellent mechanical properties. Also they concluded from experimental results that FE-ECAP sample is because that the average grain size is about 4 μm which is finer than that of the FE sample 30 μm. In another study Paydar et.al. [15] aimed to produce fully dense bulk material with a good bonding properties by using single FE-ECAP die. They found that comparison of the properties of ECAP–FE samples with that of FE samples indicates that the percent elongation of the ECAP–FE sample (12.8%) is higher than that of the FE sample (5.8%). Nagasekhar et.al. [16] invtestigated in their research the deformation flow, strain homogeneity, and load requirements of FE and ECAP combined processes of FE+ECAP and ECAP+FE are numerically investigated and compared with those values in individual FE and ECAP processes by using DEFORM software.

In this study combined ECAP and Forward extrusion method was used as a metal forming process and it was simulated by using FEM based metal forming software DEFORM. Lead was chosen as prototype material because of its hot forming characteristics at room temperature. Three different extrusion ratios which is 2, 4 and 4 and three different die angle (15°, 20°, 25°) for each E.R. (Extrusion Ratio) were selected for die assembly. Maximum forming load values and strain distributions were investigated.

2. THEORY

The model was built in commercial CAD software and then exported to the FEM based metal forming software DEFORM which was selected for the simulations. The geometrical view of the die design is given in Fig. 1.

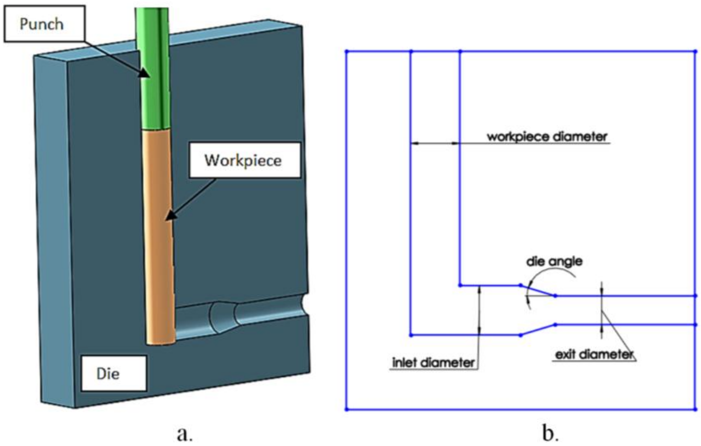

Fig.1. a) schematical view of die setup, b) die parameters [source: own study]

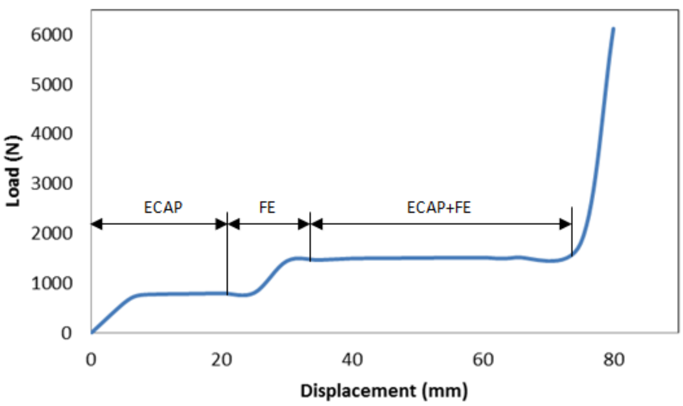

Fig. 2. A typical load-displacement curve for ECAP+FE process [source: own study]

The sample diameter was 12 mm. as it is same as container diameter and exit diameters were 10, 8 and 4 mm respectively. The die angles were 15°, 20°, 25° for each extrusion ratio. Since the model has a cylindrical workpiece, two dimensional analysis method was applied for the study. 2500 tetragonal element was chosen for meshing. Friction coefficient was 0.4 for all contact surfaces between die and sample, punch velocity was 5 mm/sec and all simulations were assumed to be performed at room temperature.

The forming load of combined ECAP+FE process was investigated in this study to obtain the optimum die design. Since strain distribution affects material flow and that leads to change in the forming load, it was also investigated. Fig. 2. shows a typical load-displacement diagram and it can be clearly seen the sections of the combined method. At the beginning of the process the workpiece is forced to flow in the die and material is forced and compressed and then material flow 90^o degree angles. After a while the extrusion process behavior is active and the forming load is similar with the extrusion process forming. The two forming method is effective rest of the process.

3. RESULTS AND DISCUSSION

Fig. 3. shows the maximum forming load values of all processes according to extrusion ratio and die angle. It is clearly seen that forming load increases with higher E.R. as expected. Die angle is another important parameter which affects the load value. Load change is significant for the higher extrusion ratios as expected. The maximum forming load decreases with the increasing die angle. The load is about 5 kN for extrusion ratio of 2 and the load value doubles when extrusion ratio is 9 for the 15^o die angle. The load value decreases from 5.1 kN to 4.7 kN when die angle becomes 15^o for the extrusion ratio of 2 and this change is much more significant for higher extrusion ratio value of 9. The forming load of E.R. 9 decreases 600N for the bigger die angle. The state of change of the forming load looks similar for extrusion ratio of 2 and 4 but for E.R. 9 the drop of the forming load is so remarkable.

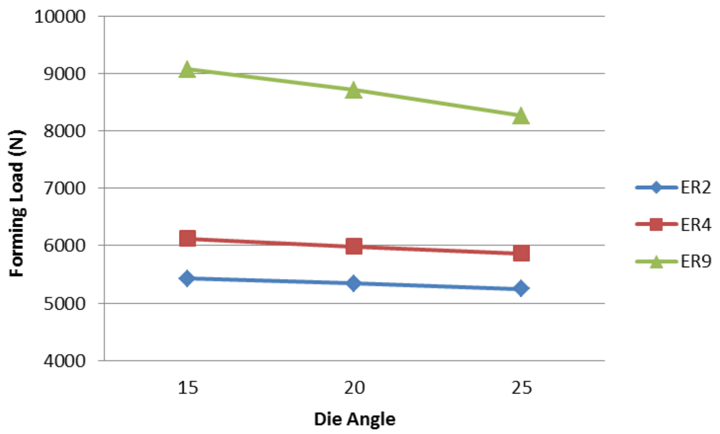

Fig. 3. Maximum Forming Load Values [source: own study]

The efficient strain value is important parameter not only material flow but also forming load. The better material flow results lower forming load for metal forming processes and for this study the effective strain diagrams were investigated in Fig. 4-12. which were given below.

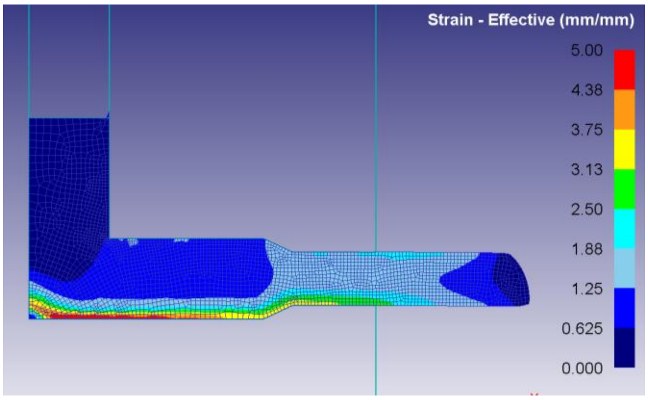

Fig. 4. Strain diagram for E.R.: 2 die angle: 15 [source: own study]

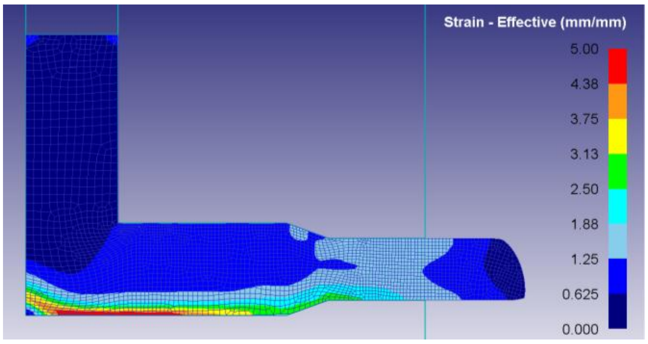

Fig. 5. Strain diagram for E.R.: 2 die angle: 20 [source: own study]

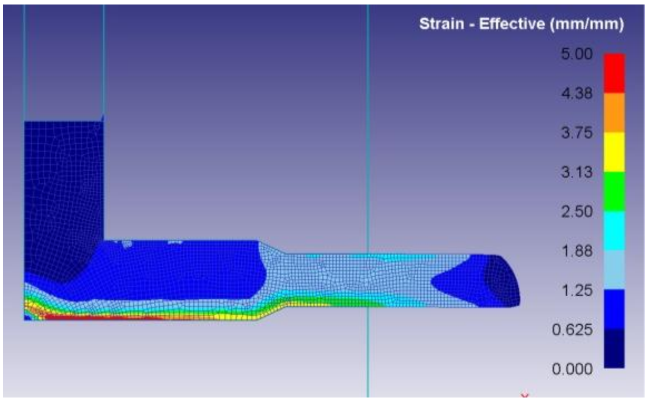

Fig. 6. Strain diagram for E.R.: 2 die angle: 25 [source: own study]

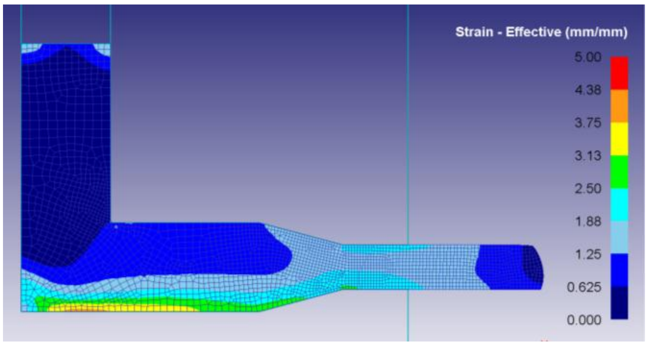

Fig. 7. Strain diagram for E.R.: 4 die angle: 15 [source: own study]

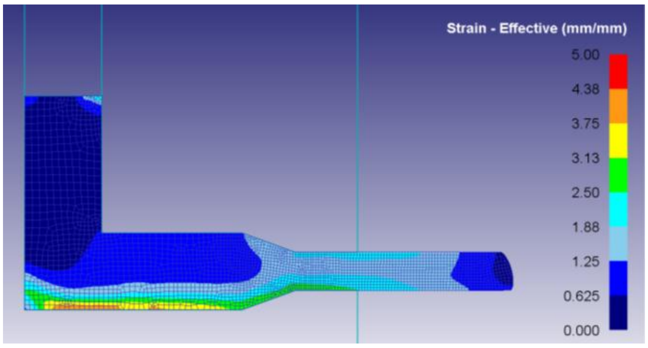

Fig. 8. Strain diagram for E.R.: 4 die angle: 20 [source: own study]

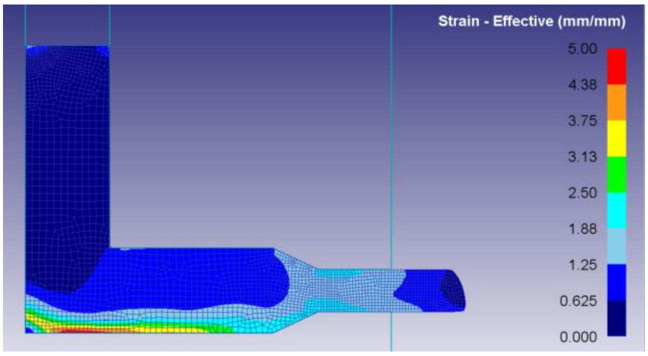

Fig. 9. Strain diagram for E.R.: 4 die angle: 25 [source: own study]

Forming load was investigated regarding to strain values and material flow of the ECAP and FE combined processes. The results were analyzed using the finite element simulations. When the diagrams analyzed together, the effective strain value which is selected as a main parameter of the study since its relationship of both material flow and forming load and it was not observed significant change which lead to the decrease in the forming load when the die angle increases for the same extrusion ratio of each die setup.

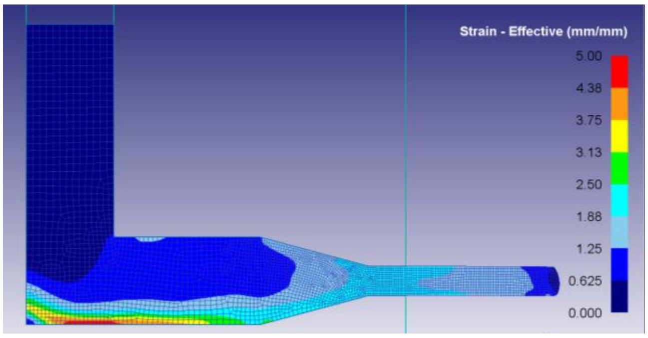

Fig. 10. Strain diagram for E.R.: 9 die angle: 15 [source: own study]

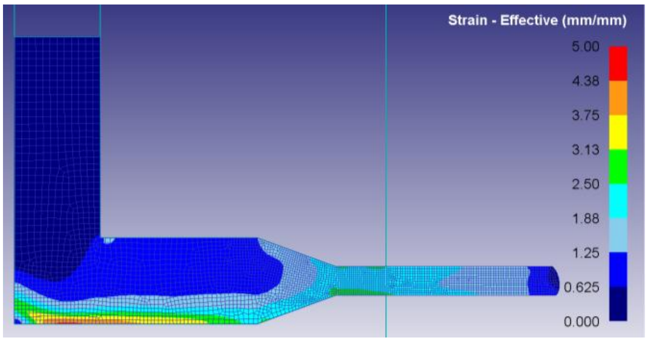

Fig. 11. Strain diagram for E.R.: 9 die angle: 20 [source: own study]

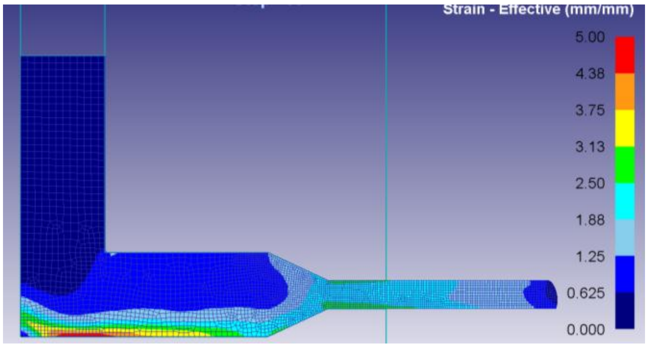

Fig. 12. Strain diagram for E.R.: 9 die angle: 25 [source: own study]

The friction factor (m) was selected relatively high both dry conditions and lead material characteristics were considered in the simulations and it can be conclude that for the lower die angles the contact surface between die and the workpiece is higher than that of the dies which have higher die angles. The frictional surface calculated from the geometry and it is seen that the frictional surface for die angle 15^{o} is 17% and 26% higher than that of the die angle 20^{o} and 25^{o} respectively for E.R. 9. The frictional surface change is about

16% between die angle 15º and 25º, when the E.R. is 2. The selected simulation conditions lead to dominant friction characteristics on the forming load results. Frictional behavior is more significant for the higher extrusion ratios and lower die angles. In this study, forming load is 8.9kN for highest extrusion ratio (9) and lower die angle (15º) but the load decreases with the increasing the die angle to 8.3 kN because of the smaller contact surface and less friction forces. When the extrusion ratio is 4, die angle 15º gives 6.1 kN maximum load value and for die angle 25º load value becomes 5.8 kN. The load is calculated as 5.4 kN for the lowest die angle and for the highest angle value (25º) the load decreases to 5.25 kN. It can be clearly observed that friction highly effects the maximum forming load of the ECAP+FE combined process for higher friction conditions.

4. CONCLUSIONS

The combined Equal Channel Angular Extrusion Method + Forward Extrusion method was investigated in terms of forming load results and the effect of die angle on the forming load. The three die angle was selected for three different extrusion ratios. Because of the material is lead the friction factor was m = 0.4 and the results were obtained from the DEFORM software.

It can be concluded from the results that the forming load is effected highly from the frictional conditions and the die with higher die angles gives lower forming load since the die which has lower die angle has bigger contact surface. The research can be expanded with experimental study and different die and process parameters.

REFERENCES

[1] PARSHIKOV R. A., RUDSKOY, A. I., ZOLOTOV A. M., TOLOCHKO O. V.: *Technological Problems of Equal Channel Angular Pressing*. Rev. Adv. Mater. Sci. 34, 2013, pp. 26–36.

[2] BALASUNDAR M., SUDHAKARA R., RAGHU T.: *Equal channel angular pressing die to extrude a variety of materials*. Materials and Design, vol. 30, 2009, pp. 1050–1059.

[3] PATIL BASAVARAJ V., UDAY CHAKKINGALB, PRASANNA KUMAR T. S.: *Effect of geometric parameters on strain, strain inhomogeneity and peak pressure in equal channel angular pressing – A study based on 3D finite element analysis*. Journal of Manufacturing Processes, vol. 17, 2015, pp. 88–97.

[4] FIGUEIREDO R. B., PINHEIRO I. P., AGUILAR M. T. P., MODENESI P. J., CETLIN P. R.: *The finite element analysis of equal channel angular pressing (ECAP) considering the strain path dependence of the work hardening of metals*. Journal of Materials Processing Technology, vol. 180, 2006, pp. 30–36.

[5] AZAD-NOORANI M., BAKHSHI-JOOYBARI M., HOSSEINIPOUR S. J., GORJI A.: *Experimental and numerical study of optimal die profile in cold forward rod extrusion of aluminum*. Journal of Materials Processing Technology, 164–165, 2005, pp. 1572–1577.

[6] REGGIANI B., SEGATORI A., DONATI L.: *Prediction of charge welds in hollow profiles extrusion by FEM simulations and experimental validation*. Int. J. Adv. Manuf. Technol., vol. 69, 2013, pp. 1855–1872.

[7] KARAMI P., ABRINIA K.: *An analytical formulation as an alternative to FEM software giving strain and stress distributions for the three-dimensional solution of extrusion problems*. Int. J. Adv. Manuf. Technol. 71, 2014, pp. 653–665.

[8] QAMAR S.Z., ARIF A.F.M., SHEIKH A.K.: *A new definition of shape complexity for metal extrusion*. J. Mater. Process. Technol. 155–156, 2004, pp. 1734–1739.

[9] ALTINBALIK T., AYER Ö.: *A theoretical and experimental study for forward extrusion of clover sections*. Materials & Design, vol. 29, 2008, pp. 1182–1189.

[10] CHANDRA T., ZHOU J., KOWALSKI L., DUSZCZYK J.: *3D Fem Simulation of The Thermal Events During AA 6061 Aluminum Extrusion*. Scripta Materialia, vol. 41, no. 2, 1999, pp. 195–202.

[11] ULYSSE P.: *Extrusion die design for flow balance using FE and optimization methods*. International Journal of Mechanical Sciences, vol. 44, 2002, pp. 319–341.

[12] PENG Z., SHEPPARD T.: *Simulation of multi-hole die extrusion*. Materials Science and Engineering A., 367, 2004, pp. 329–342.

[13] MANI B., PAYDAR M.H.: *Application of forward extrusion-equal channel angular pressing (FE-ECAP) in fabrication of aluminum metal matrix composites*. Journal of Alloys and Compounds, 492, 2010, pp. 116–121.

[14] PAYDAR M.H., REIHANIAN M., BAGHERPOUR E., SHARIFZADEH M., ZARINEJAD M., DEAN T.A.: *Equal channel angular pressing–forward extrusion (ECAP–FE) consolidation of Al particles*. Materials and Design., vol. 30, 2009, pp. 429–432.

[15] PAYDAR M. H., REIHANIAN M., BAGHERPOUR E., SHARIFZADEH M., ZARINEJAD M., DEAN T. A.,: *Consolidation of Al particles through forward extrusion-equal channel angular pressing (FE-ECAP)*. Materials Letters, vol. 62, 2008, pp. 3266–3268.

[16] NAGASEKHAR A. V., YOON S. C., YOO J. H., KANG S.-Y., BAIK S. C., EL AAL M. I. A., KIM H. S.: *Plastic Flow and Strain Homogeneity of an Equal Channel Angular Pressing Process Enhanced through Forward Extrusion*. Materials Transactions, vol. 51, no. 5, 2010, pp. 977–981.