REVIEW

of the PhD dissertation by Ing. Stanislav Tylšar entitled "Development of SPD process terms of increased effectiveness ECAP" submitted to the Mechanical Department of the VSB Technical University of Ostrava

The subject of the thesis is well chosen since in the recent years there is an increasing interest in severe plastic deformation of metals and alloys due to tendency of decreasing weight of constructions, what require a new low weight materials with increased strength and plasticity. One of important ways of improving these properties of alloys is a decrease of grain size up to nanocrystalline range. It allows to increase simultaneously strength and plasticity of metals and alloys. Among important methods of severe plastic deformation of metals is Equal Channel Angular Pressing (ECAP) method modified in the present thesis.

In the first part of the thesis author describes the task of the dissertation which is development of a new geometry of tool for Equal Channel Angular Pressing in order to obtain the effect of back pressure and consequently a better grain refinement of chosen aluminum and magnesium alloys and therefore to optimize their mechanical properties. The experimental work was done in cooperation with industrial partners like VUHZ Dobra and COMTES FHT Dobrany and with some universities from Slovakia and Poland. It allowed to increase the range of research methods for those applied abroad and to consult the developed methods with the industrial needs.

In the next chapter author describes the effect of changing grain size in the nano-range on the mechanism of deformation and properties of nanomaterials. At the end of this chapter author summarizes recent knowledge related to the deformation of nanomaterials and differences in relation to conventional materials. In my opinion however more attention should be given to dedicated materials like aluminum and magnesium due to a high stacking fault energy of aluminum as compared to such materials like copper or stainless steels. Also, the hexagonal structure like that of magnesium has a specific influence on deformation mechanism and it should be discussed. This subject is continued in the next chapter, where different methods of severe plastic deformation are described and compared. Most attention was given to the ECAP method what is logical since it was the main author interest. Author describes various ECAP modifications including back pressure, ultrasound systems, twist extrusion and increased temperature effect. Next chapter includes characteristics of magnesium alloys used for casting and plastic deformation and describes their properties and possible applications. In Chapter 5 of the dissertation author characterizes magnesium alloys as from AZ and EZ series, describes their chemical compositions, mechanical properties and used thermal treatment. Furthermore author characterizes experimental
conditions, like sample shape type of press, ECAP pressing tool with 10° and 30° screw output, heating attachment. The stress during pressing was measured for all passes what is rather unique during ECAP processing and indicate a very good experimental setup. The structure of alloy AlMn1Cu is shown in Fig.47, however they should be shown at the same magnification since otherwise comparison is more difficult.

The characterization of experimental material author starts with optical microstructures from the alloy AZ31 are shown in Fig 51 after different heat treatment and after 1-3 ECAP passes (Fig.52 and 53). It can be clearly seen that with increasing number of passes the structure becomes more refined and homogeneous. The other investigated alloys AZ61, AZ80 are also characterized in the initial state (VS) and after quenching in water and cooling in the air. The ECAP temperature was given as between 250-280°C what seems to be too broad temperature range, considering that in the upper range the recrystallization processes can be considerably faster. The comparison of ECAP pressing stress after 4 passes for the investigated alloys shows interesting results, namely in the alloy AZ31 it is not changing much, however for the alloys AZ80 and AZ61 it increases significantly with the number of passes for all applied heat treatment. It has its influence on the hardness of alloys which increases with a number of passes, however not so much as the pressing stress. The optical microstructures of the alloy AZ31 are different than those of AZ61 and AZ80. As one can see in the optical microstructures of the alloy AZ31 (Figs71-74) the grain size decreases with a number of passes, however the difference is not large (decrease from 4.7 to 2 μm). The optical microstructures from the alloy AZ61 show clearly the effects of nonhomogeneous deformation after all types of heat treatments and no grain size can be distinguished. With increasing number of passes the deformed area shows higher fraction, what explains the increase of hardness and the increase of the pressing stress due to higher deformation resistance. This aspect of structure changes was described based on the well prepared microstructures. Since the microstructures particularly of alloys AZ61 and AZ80 were deformed and heterogeneous it was important to characterize the structure using electron microscopy. As one can see from the transmission electron microscopy investigations presented in Figures 83-84 for the alloy AZ31 and85-86 from the alloy AZ61 obtained results support optical microscope investigations. The TEM microstructures of alloy AZ31 before ECAP in the VS state shows also deformed microstructure, however with larger grain size. After ECAP clearly formed subgrain boundaries can be seen resulting from the recovery and recrystallization processes. The dislocation density is rather low what explains why grain size could be clearly determined using only optical microscopy. On the contrary TEM microstructures from the alloy AZ61 show a high dislocation density and small particles being intermetallic phases precipitating in Mg-Zn-Al system. Their presence increases most probably recrystallization temperature and the alloy hardens what increases the ECAP pressing stress. A high dislocation density after the first and third ECAP pass confirms this observation. Indeed rather low angle subgrain boundaries can be seen due to weak recovery effects. This observation is supported in further microstructures obtained using EBSD technique presented in Fig.87 which is particularly important for severely deformed structures. It
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confirms a high fraction of a low angle grain boundaries in AZ61 alloy due to early stage of recovery processes.

Important is also the following chapter where simulation of ECAP processing is shown for the alloy AlMn1Cu after 1-5 ECAP passes. As written in this chapter it was done jointly with the author of the next thesis, Ing. Jan Kedroń using program Simufact.forming. It allowed to determine effectiveness of the screw exit canal changing from 10° to 30°. Simulation confirmed a higher effectiveness of the screw canal with 30° of the exit screw.

The description and discussion of the experimental work is summarized in pages 99-103. Author summarizes and tries to interpret the results. In this part it is missing comparison of the obtained results with those from the literature, since as results from the presented references there are several papers on severe plastic deformation of magnesium alloys. Particularly important would be comparison of the ECAP with a screw exit canal with a traditional one.

After reading of the thesis some critical remarks are raised, which should be particularly considered for future publications:

1. In the section 5 where characteristics of magnesium alloys is presented more attention should be given to previous works where severe plastic deformation was applied this should be combined with explanation of the research target of the present work.
2. The grain size change after ECAP passes was evaluated only in alloy AZ31, where it can be clearly seen, but not in alloys AZ61 and AZ80. The etching methods should be modified to visualize the grain boundaries and to see the grain size. This experiments should be performed, however the grain size was determined using EBSD method, but only after 3 passes.
3. Electron microscopy studies should be also used to characterize the effect of precipitates on the structure after ECAP processing as compared to the initial state. The grain refinement should be accompanied by refinement of the precipitates what could be determined using TEM and scanning electron microscope studies.
4. The discussion is missing of results obtained with those obtained for similar alloys by other authors.

The above critical remarks do not affect my entirely positive opinion about the thesis, which was performed using modern materials i.e. magnesium alloys which become recently more extensively used in the industrial practice. The experiments brought interesting results and the most important results from the dissertation are:

- Verification of suitability of the ECAP method and forming tool with helix 30° for a production of ultrafine grain materials, which was proved by achieved results by TEM and SADP methods and also by own increasing of use property of magnesium alloys, which can consequently be used in practise of mechanical engineering, automotive, military and pharmaceutical industry.
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- Determination that four is an optimum number of ECAP passes to increase the mechanical properties of all studied Mg alloys AZ31, AZ61 and AZ80. The parameters of the ultimate strength and the yield values rise at the expense of elongation, which is undesirable due to application in industry. Based on the stress simulations a modification of geometry a forming tool was proposed in order to achieve a higher degree of deformation of the material.

- Demonstration of a real possibility of application new technologies for refining the material structure and thus an increase of mechanical properties of metallic materials, what allows to propose forming equipment integrated into production lines. Future commercial outputs are semi-finished products of a high strength and reduced weight, replacing the currently used materials.

Considering above mentioned new and important results concerning a new tool design, improvement of material properties after forming and elaboration of technology of DRECE processing for of all studied Mg alloys AZ31, AZ61 and AZ80, with a good perspective of application in the industry, my opinion about the dissertation of Ing. Stanislav Tyšar is entirely positive, since it meets all the requirements concerning PhD thesis in technical sciences and in my opinion the Dissertation meets the conditions set out in paragraph 47 of the Universities Act no. 11/98 Coll.

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