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SOME CONTRIBUTIONS TO THE PROBLEMS OF COLD FORMING OF MAGNESIUM ALLOYS

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ABSTRACT

Since the trend of using lighter alloys for many purposes is increasing nowadays, the production engineers have to study the workability of such new materials. Magnesium is one of the future materials, due to its vast nature resources. Its perfect strength to weight ratio gives the possibility of using it in many different applications. Its point of weakness is its bad cold formability which is not very much known till now. Almost only warm forming of magnesium is discussed in the technical literature. There are some possibilities of cold forming of magnesium presented in this paper, some experimental results and comparison between the mechanical properties before and after cold forming.

1. INTRODUCTION

The use of magnesium and its alloys is becoming more and more important in the production of various components in the lightweight industry [1]. The magnesium alloys can be find as a housing material for mobile phones, hand tools and for assembling parts for high performance internal combustion engines.

From the technological point of view the magnesium is appropriate only for die casting and hot extrusion applications [2, 3, 4]. The reason for this is the crystal structure (hexagonal lattice) which is low on the number of slide planes in the cold state. When increasing the temperature the number of activated slide planes increases thus improving the forming properties (extrusion of different shapes). Due to the high affinity with oxygen and the risk of self-ignition of the magnesium particles, the cold forming would be far more appropriate. Some research work in the field of improving the cold formability of magnesium alloys and the possibilities of improving the mechanical properties has been done.

Table 1: Chemical composition and major mechanical properties of magnesium alloy AZ91 and ZK30

	ZK 30	AZ 91
Chemical composition	3,5 - 4,5 % Zn 0,45 % Zr 0,3 % other	8,3 - 9,7 % Al 0,13 - 0,5 % Mn 0,35 - 1,0 % Zn < 0,5 % Si < 0,1 % Cu < 0,03 % Ni
R_m	304 N/mm^2	111 N/mm^2
$R_{p\,0.2}$	255 N/mm^2	96 N/mm^2
Poisson c.	0,35	0,35
Young m.	45 000 N/mm^2	25 000 N/mm^2
Density	1,83 g/cm^3	1,81 g/cm^3

Chemical composition and major mechanical properties of the refereed material are presented in the table1. The conventional cold forming processes of magnesium alloys are normally finished at the 7% deformation which is relatively low. At the cold upsetting test the cracks occur in the planes of highest shear stresses, which also showed the preliminary tests. It was stated as well by other author in the field [5, 6, 7, 8, 9, 10, 11]

Fig. 1: Upsetting of the magnesium cylinders

2. THE USE OF STEEL RING

The idea was to prevent the material from flowing radial outwards and thus increasing the hydrostatic pressure inside the magnesium core. Increasing the hydrostatic pressure would lead to the increasing of material formability (fig. 2).

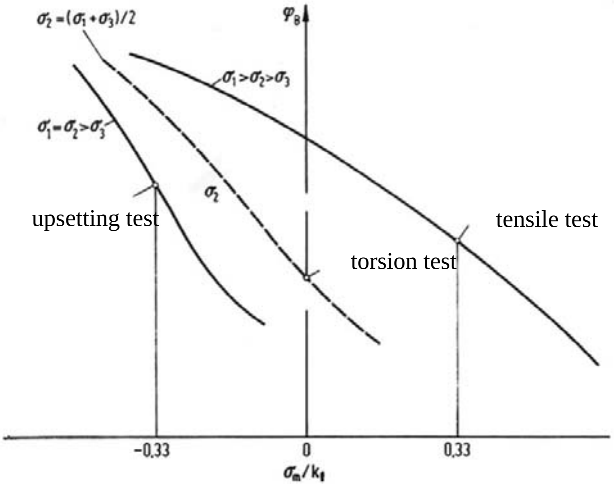

Fig. 2: *The influence of the stress state on the formability [12]*

The experiments showed no significant improvement and the cracks occur even though the ring was used (fig.3). Apart from this, it is possible to influence on the development of hydrostatic pressure by the varying of the friction coefficient using different lubricants [13, 14]. Though the lubricant with relatively high friction coefficient was used $k_{fr} = 0.08$ the formability of magnesium was not improved.

Fig. 3: Cracks in the cylinder when using the steel ring

3. THE APPLICATION OF HYDROSTATIC PRESSURE BEFORE THE INITIATION OF MATERIAL FLOW

The infirmity of the above presented experiments was above all the fact that the hydrostatic tensile stress state began to develop after the initiation of material flow. The fact is that in the critical stage of forming, the hydrostatic pressure is not high enough to influence the forming process significantly. The assembly cylinder-ring needed to be redesigned such that the hydrostatic press develop before the initiation of the material flow. The numerical simulations using software package ABAQUS were of a great help at determining the hydrostatic stresses. The reliability of the forecasting of the hydrostatic press development is limited only at the beginning of the process, since the reology is not yet known. The simulation gave some preliminary results used for the conical ring design (fig. 4).

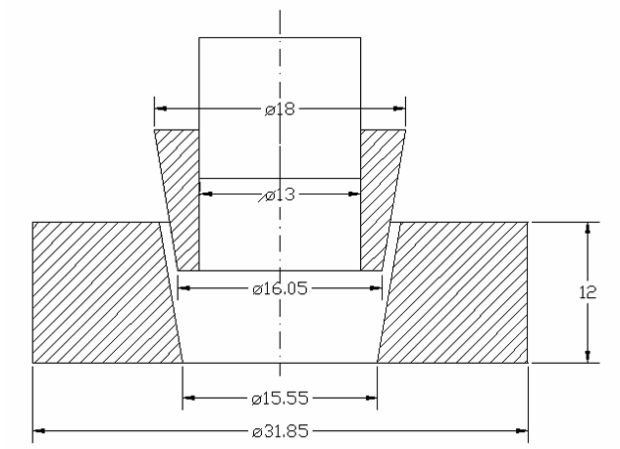

Fig. 4: The dimensions of the conical rings

The cone on the inner and outer ring causes the development of radial stresses in the cylinder before upsetting. The superposition of axial stress after the flow initiation causes the development of higher hydrostatic pressure as without the cone.

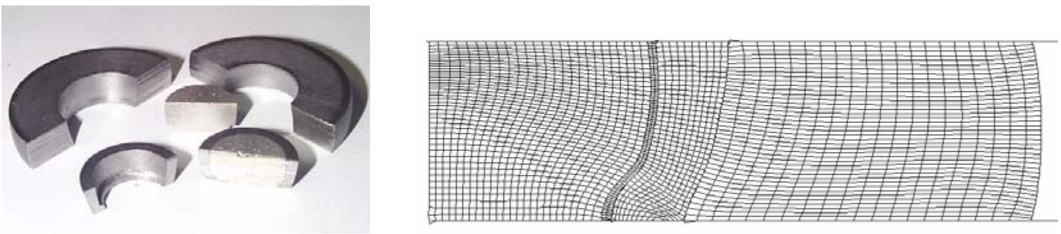

Fig. 5: Comparison between the experiment and simulation

The experiment showed a significant improvement of the formability of magnesium alloy, however some small cracks occur at the end of deformation. It is obvious that some shape correction will be necessary in order to further improve the formability.

4. COLD FORWARD EXTRUSION

Some research work in the field of cold forward extrusion was made as well. Based on the experiments at cold upsetting the geometry for cold forward extrusion was designed. Apart from assuring the proper geometry for hydrostatic stress state, the final geometry of core material has also been considered.

Fig. 6: Extruded specimens (magnesium core and aluminium cage)

The tensile tests were carried out after extrusion therefore the core diameter and core length have to be large enough. The cage material was aluminum alloy 6082 with well known forming properties, which absorb the shear stresses due to the friction in the die, thus preventing it to spread into the core.

Parameter	Before def.	After def.	diff. %
$R_{p\ 0.2}$ [N/mm^2]	255	385	+ 51
R_m [N/mm^2]	304	414	+ 36
A [%]	17	8,2	- 52
HV	55	88	+ 47

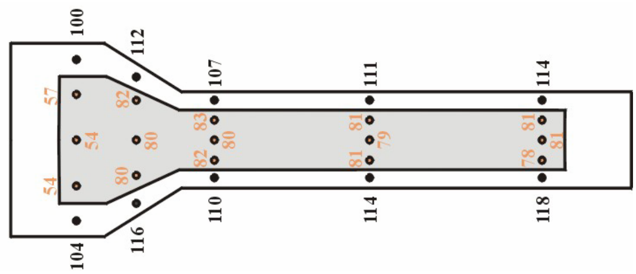

Fig. 7: Comparison of the mechanical properties of magnesium alloy (ZK 30)

The stress state in the magnesium cylinder is thus homogeneous. Apart from that, such kind of experiments replace the unknown tribologic-system magnesium - lubricant - tool and replaces it with the well known system aluminum - lubricant - tool. The experimental results were much better as upsetting tests. Alloy ZK30 has been cold formed without any problems, apart from that the improvements in mechanical properties of the alloy is significant (fig. 7).

Some cracks occur at the forming of AZ 91 alloy at the beginning stage, but later on they completely disappear. Using the counter punch for generating the axial press it will be possible to eliminate those small cracks too.

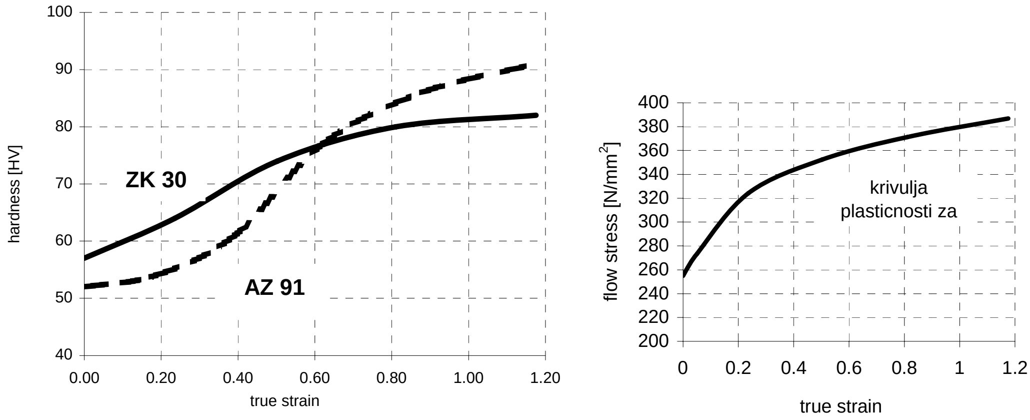

Fig. 8: Approximate flow curve for ZK30

Based on the measured hardness distribution in the forming zone, it is possible to calculate the approximate flow curve for magnesium alloy ZK 30 (fig. 8).

5. THE COMBINATION OF UPSETTING AND BACKWARD EXTRUSION

The experiments stated that cold forming of magnesium alloys is possible, considering special conditions. The development of the forming process exploiting the hydrostatic stress state was presented. In the field of cold upsetting there is e need of further improvement of the process and one of it is a combination of upsetting and backward extrusion.

The magnesium cylinder is being upset and the radial flow is prevented by backward extruded aluminum conical ring, which causes the hydrostatic stress development in the magnesium core. The numerical simulations were necessary at proper designing of the conical ring. The hydrostatic stress state should be as high as possible and the contact stress in the die should not exceed a certain limit. In spite of that the cracks occur in the magnesium cylinder.

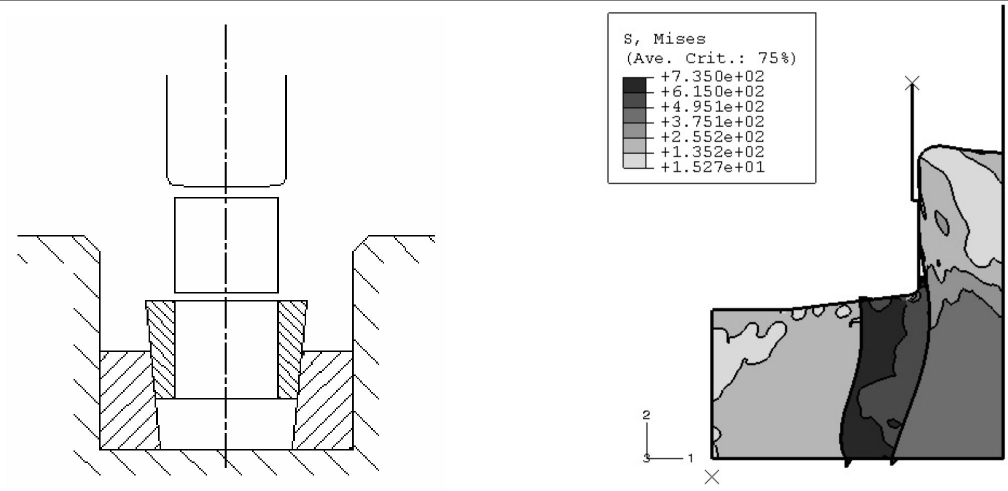

Fig. 9: The combination of forward and backward extrusion (simulation - experiment)

6. ANALYSIS AND FURTHER RESEARCH CONCEPTS

The forward extrusion experiment showed the possibility of cold forming of magnesium alloys and presents the way how to asses the flow curve of the magnesium alloy. It was approximately calculated from the hardness distribution in the forming zone.
Using different die geometry it is possibly to attain many different strains and many different mechanical properties of the formed material. Each one represents one point in the stress strain diagram.

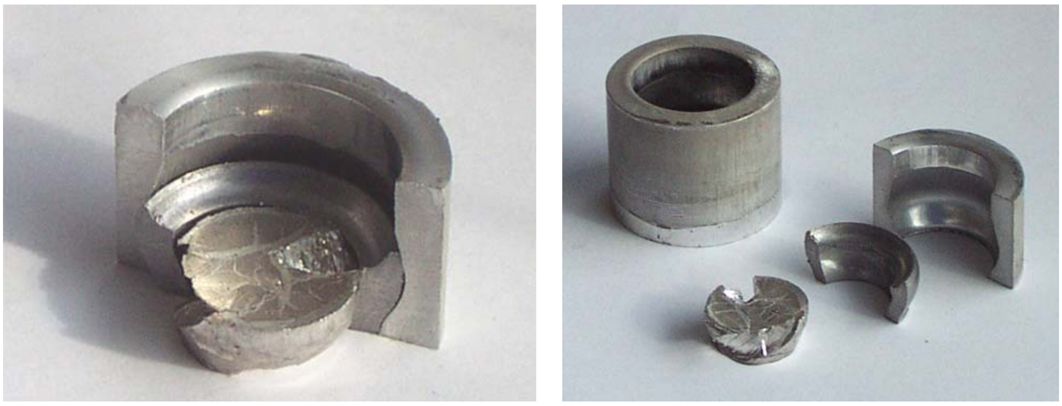

Fig. 10: Cold upsetting of the magnesium alloy using an aluminum cage

The research work can be applied in the industrial environment. It will be possible with appropriate tool geometry to induce hydrostatic pressure, which is high enough to form the magnesium alloys. The improved material properties after cold forward extrusion is very welcome in special applications where the need of low weight and high strength are needed. Though the experiments have quite sophisticated geometry at the moment (magnesium core, aluminum cage) the results are useful and quite promising.

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PRILOG ISTRAŽIVANJU PROCESA HLADNE OBRADE MAGNEZIJUMSKIH LEGURA

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REZIME

Korišćenje lakih legura za različite namene je sve više rašireno u domenu proizvodnje metalnih delova. Zbog toga je veoma važno da se problemu obradivosti takvih legura posveti posebna pažnja. Magnezijum je jedan od materijala pred kojim je značajna budićnost, obzirom na velike prirodne resurse. Veoma povoljan odnos jačina/težina pruža mogućnost primene ovog materijala u različitim oblastima. Negativna strana ovog materijala je njegova slaba obradivost u hladnom stanju. Ta problemska celina nije dovoljno istražena do sada. U literaturi se – do sada – sreće isključivo toplo deformisanje magnezijuma.

U ovom radu prikazane su neke mogućnosti deformisanja magnezijuma u hladnom stanju. Dati su određeni eksperimentalni tezultati kao i komparacija mehaničkih osobina pre i nakon hladne obrade. Dve legure magnezijuma su ispitane: AZ91 (8,3-9,7%Al, 0,13 - 0,5 % Mn, 0,35 - 1,0 % Zn, < 0,5 % Si, < 0,1 % Cu, < 0,03 % Ni) i ZK30 (3,5 - 4,5 % Zn, 0,45 % Zr, 0,3 %). Korišćen je model sabijanja cilindra sa čeličnim prstenom, istovremeno istiskivanje, kao i kombinacija procesa sabijanja i suprotnosmernog istiskivanja.

Istraživanja daju rezultate koji se mogu primeniti u industriji. Pomoću specijalnih konstrukcija alata moguće je modelu saopštiti hidrostatički pritisak koji obezbeđuje zadovoljavajuću obradivost. Poboljšanja mehanička svojstva materijala nakon obrade čini ovu obradu veoma zanimljivu za različite konkretne primene.