Microforming of Lightweight Metals in Warm Conditions

M. Arentoft[1], S. Bruschi[2], A. Ghiotti[3], N.A. Paldan[1], J.V. Holstein[1]

[1]IPU, Building 425, Produktionstorvet, DK-2800 Kgs. Lyngby, Denmark
URL: www.ipu.dk *e-mail: ma@ipu.dk, nap@ipu.dk*

[2]DIMS, University of Trento, Via Mesiano 77, 38050, Trento, Italy
URL: www.ing.unitn.it/dims *e-mail: stefania.bruschi@ing.unitn.it*

[3]DIMEG, University of Padova, Via Venezia 1, 35131, Padova, Italy
URL: www.dimeg.unipd.it *e-mail: andrea.ghiotti@unipd.it*

ABSTRACT: Within medical production there is a need for small size, high precision, low weight and high strength components. This work describes an alternative to the existing time and material consuming machining process of such components. A micro forming device with controlled heating up to 450°C and high precision guiding is developed. The magnesium alloy AZ31B is analysed by compression and the flow stress and formability are determined as function of strain, strain rate and temperature. A component for dental purposes is formed at varying temperature and the results in kind of load displacement curves and fracture are discussed with respect to the material tests carried out.

Key words: Microforming, Magnesium, Elevated Temperature

1 INTRODUCTION

Lightweight metals like titanium and magnesium alloys show excellent properties as regards strength to weight ratio and, due to biocompatibility (Ti) and ability to be absorbed by human body (Mg), they are often used for medical purposes. However, their intrinsic low formability when processed at room temperature reduces the number of feasible processes only to machining, even bulk forming operations could give higher strength and productivity, their limited formability reduces the industrial interest.
From literature it is well-known that titanium and magnesium alloys are characterised by higher formability already at 200°-250°C, even if thermal gradients can decrease the achievable precision. Elevated temperatures can activate in these alloys more slip planes that greatly enhance their formability when bulk processed [1-4].
When considering micro forming, some size effects need to be taken into account. Normally, the size effect is related to topography of tool and work piece and the grain size of the formed material [5]. In this work, the downscaling of the process involves size effects phenomena related to the thermal gradients and the precision of billet, tool and die system.
The objective of this work is to investigate the feasibility for warm forming of micro components devoted to medical purposed in brittle lightweight metals. To achieve this goal, accurate data about the material rheological behaviour and workability at different temperatures, strain and strain rates are needed. An experimental set-up for microforming at elevated temperature was designed, and an extensive experimental campaign was established taking into account the material charaterization results. The main elements in the newly developed device are a die heating unit enabling controlled temperature in the range from room temperature to 450°C, and a high precision guiding system which, no matter the temperature, can provide a positioning of the upper and lower die within few microns. The tool system is based on knowledge from existing systems and use the same kind of flexible modular based punched, containers and ejectors [6,7].
The component chosen for the study is for dental purposes. At figure 1, the geometry is shown. The outer diameter is 3.6 mm with and inner triangular 3 mm deep hole and a spherical bottom.
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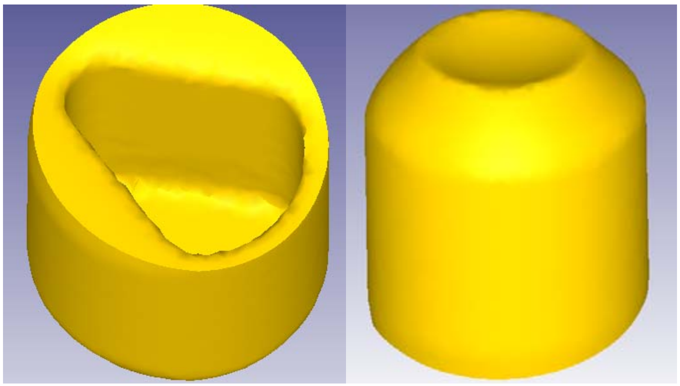

Fig. 1. Industrial demonstrator for dental purposes

2 MATERIAL CHARACTERIZATION

The investigated alloy is the AZ31B provided in round bars in the annealed state. To characterize the material, compression tests both at room temperature and elevated temperature were carried out on a Gleeble 3800™ machine. The experimental plan is reported in Table 1. All tests were conducted with graphite foils between specimens and punches to prevent friction. The aim of such tests was to determine the material flow strength in order to evaluate the sensitivity to strain, temperature and strain rate, as well as to identify those conditions leading to the specimen fracture.

Table 1. Experimental plan for compression tests

ε	T [°C]	$\dot{\varepsilon}[s^{-1}]$		
1	ambient	0.01	/	/
1	150	0.01	0.1	1
1	200	0.01	0.1	1
1	250	0.01	0.1	1
1	300	0.01	0.1	1
1	400	0.01	0.1	1

The analysis of the compressed specimens showed cracks on the outer surface for all testing conditions at room temperature and T=150°C. While a sound specimen was found at T=200°C only for the lowest strain rate. For all the other testing conditions no cracks were detected either on the surface or in the inner of the specimens. Figure 2 shows the material sensitivity to temperature at strain rate equal to 0.01 s^{-1}: temperature strongly influences both the material workability and resistance to deformation. Strain rate sensitivity is proposed in Figure 3 at T=300°C: its influence on material behaviour is opposite to that of temperature.

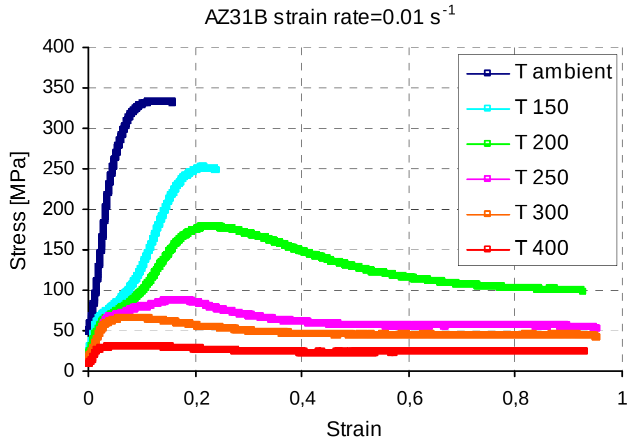

Fig. 2. AZ31B sensitivity to temperature at 0.01 s^{-1}

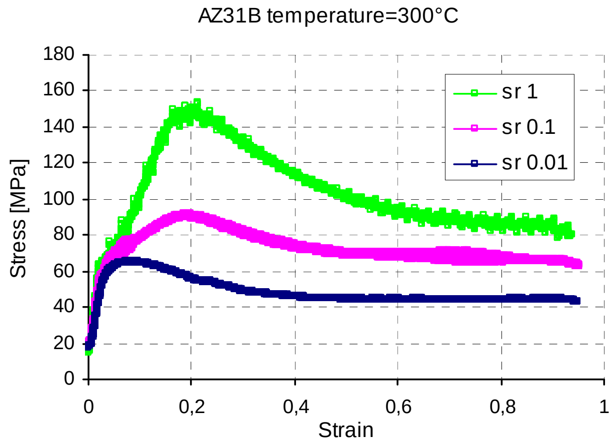

Fig. 3. AZ31B sensitivity to strain rate at 300°C

3 DESIGN OF EXPERIMENTAL SETUP

The industrial component is supposed to be formed by a backward can extrusion using a triangular punch and a spherical ejector positioned at the right height of the container. The problem in such process is to control the temperature of the billet in the range between 20-450°C, to position the punch in the centre of the container, and to design the tool to resist pressures in the size of 2500 MPa found from numerical simulations.

3.1 Thermal system

In conventional warm forming processes, the billet is heated before inserted in the die. However, when micro forming, the heat capacity of the billet is too low compared to the cooling caused by surrounding air and dies; therefore, an indirect heating is proposed by heating the dies. To obtain an easily adjustable and flexible thermal system, the heated parts should be as few and small as possible and the heating source should be as close as possible to the billet.

A system with resistance heating on the outside of the container and punch has been analysed by numerical methods. Due to the high internal pressure in the container, a stress ring is needed. To keep the flexibility, the stress ring is mounted in an adapter with an outer diameter of 50 mm, which fit to the inner diameter of a 400W commercial resistance heater. The punch is mounted in a punch holder with an outer diameter of 50 mm on which the upper 400W heater is mounted. To control the temperature, thermocouples are welded to the free surface of the punch holder and the adapter. From numerical simulations it is found that the temperature of the supporting plates only reach 40°C if operating the system at laboratory conditions. Since the system is designed for later industrial implementation, the plates are prepared for cooling systems which is needed for industrial production of more than 2 hours. In figure 4, the tool system is shown with red-heaters and 2 blue isolation plates.

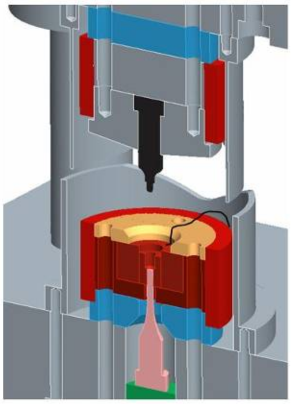

Fig. 4 Thermal system for a warm forming micro tool-set

3.2 *Guiding system*

From experience with micro forming tool systems, it is known that positioning the punch in the centre of the container is one of the most challenging problems [6,7]. The best way for processes like rod extrusion is found to let the guiding surface be the contact surface between punch and container, but such surface does not exist for a can extrusion process. The tool set is produced with a "floating punch", which can be fixed. During the assembly a high precision insert is mounted in the gab between punch and container. In this position, the punch is fixed ensuring a fully alignment of the upper and lower tool part.

A completely clearance free guiding system is designed as a sub-press in which the upper and lower tool part is mounted. However, heating the guiding system to more than 400°C will cause unacceptable inaccuracies. A thermal isolation between the heated tool parts and the guiding system is therefore needed. A concept combining isolating materials and reflecting shiny surfaces has been designed. By mounting ceramic plates in the contact surface between the sub-press and the heated upper and lower tool parts, the heat flow into the sub-press is reduced. At 450°C the heat transported by radiation is a considerable parameter. The guiding surfaces are therefore protected with a thermal shield of shiny stainless steel surfaces around the heated tool parts.

The tool-set is mounted in a new mini-press developed at IPU with a nominal load of 5 tonnes. At figure 5, the outline of the tool-set is shown.

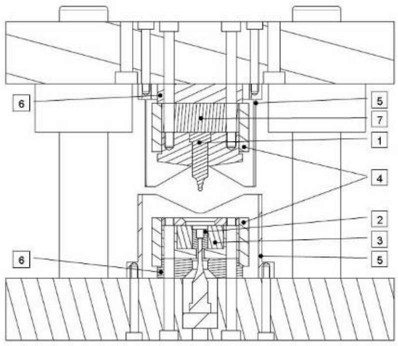

Fig. 5 The tool-set for micro warm forming. 1) Punch 2) Die insert 3) Stress ring 4) Heaters 5) Thermal shield 6) Thermal isolation 7) Load distributor

4 EXPERIMENTAL WORK AND RESULTS

4.1 *Experimental plan*

From material analysis, it is found that the formability and flow stress vary significantly in the range from 20°C to 400°C. To keep the conditions iso-thermal, the punch speed is kept very low (1mm/minute). The billets are machined to an outer diameter of 3.58 mm with a height of 1,72 mm. The billet, punch and container are lubricated with a high temperature graphite based molykote D-321R. The billet is kept in the closed tool-set until a stable temperature is obtained, which take less than 10 seconds. After forming, the component is manually ejected. The temperature of the parts outside the thermal shield is only hand hot and therefore easy to handle

The stroke and load are measured by a strain gauge 15kN load cell positioned above the tool set and a displacement transducer measuring between the upper and lower tool plate. At figure 6, the experimental set-up is shown.

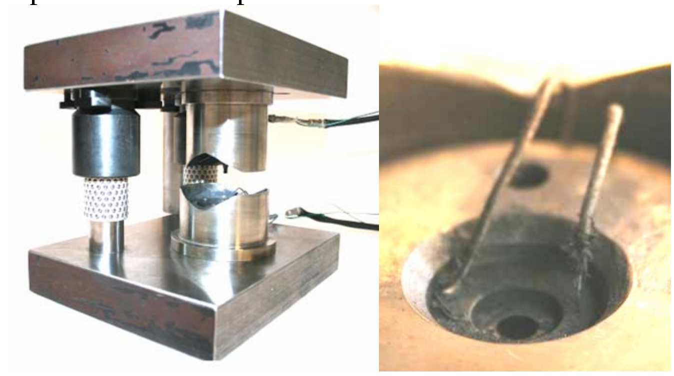

Fig. 6 Experimental setup. Left:Guided tool-set. Right: Die and punch with thermo couples and heaters

The Mg is formed at 7 temperatures: 20, 100, 150, 200, 250, 300 and 400°C. In all cases an apparent successful component is achieved. A closer inspection of the ones formed at room temperature shows some cracks at the skirt of the backward can, as shown in figure 7. At figure 8, the load-displacement curves for the experiments are shown.

Fig. 7 Left: Formed component at 20°C with cracks in the skirt Right: Billet and formed component at 400°C

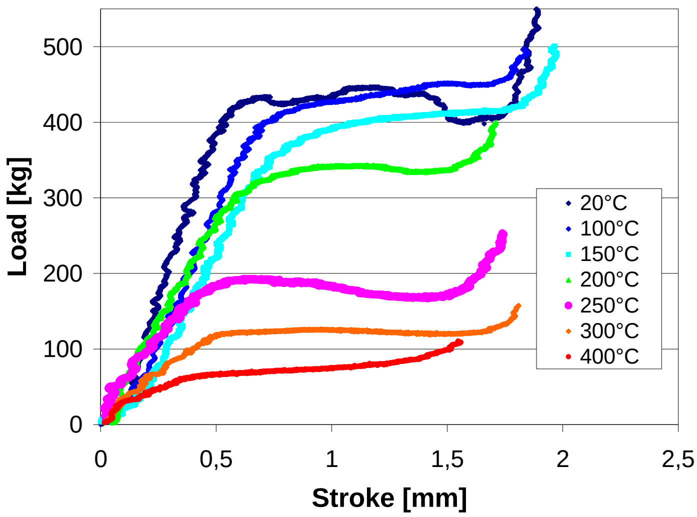

Fig. 8 Load-displacement curves for forming the Mg component at varying temperature

5 CONCLUSIONS

From figure 8, it is clearly seen that the forming load can be severely reduced by heating the work piece material. In this case, the load is reduced from more than 400 kg to less than 100 kg. From figure 2 it is known, that the formability is increased when heating is applied but reduced when the strain rate is increased (fig. 3). To obtain a sound component, is therefore a balance between the forming speed and applied temperature. In this case, where the forming is carried out at very low punch speed (1mm/min) and the process is characterized with compressive stresses, a sound component can be obtained at only 100°C.

Based on the results obtained, it seems more appropriate to carry out the process at 300°C, where the AZ31B has high formability and the forming forces are low and the tool materials still preserve its strength.

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