EXPERIMENTAL DETERMINATION OF THE ELASTIC-PLASTIC MATERIAL BEHAVIOUR OF HYDROSTATIC EXTRUDED AZ31 AND AlSi1MgMn AS A FUNCTION OF TEMPERATURE

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Abstract: *For predicting the forming behaviour of Al-Mg-compounds and changes in the interface strength during further processing it is essential to accurate determine the occurring state of stress on the interface. For this purpose precise material properties of the compound are needed. Tensile tests with hydrostatic extruded AZ31 and AlSi1MgMn revealed flow curves with strong dependencies on temperature, strain rate and thermal treatment. During dwell times the tr ue stress relaxes significant under high temperatures.*

Key words: *magnesium-aluminium compounds, hydrostatic extrusion, material behaviour, tensile tests*

1. Introduction

In recent years lightweight materials have arisen into the focus of attention due to the necessity of saving energy and resources. Recent in vestigations [1-3] concentrated on the production of hydrostatic extruded Al-Mg-compounds (rotationally symmetric, aluminium-sheathed magnesium rods) and the ir interface strength and fracture mechanical properties.

The use of hydrostatic extruded Al-Mg-compounds as semi-finished product for subsequent processes like die forging requires beside investigations concerning the formability the determination of the mechanical properties of the c ompound, especially the interface, after the deformation.

Changes in the strength of the interface are expected in regions with a high degree of deformation. The determination of such regions will be performed by numerical investigations. In addition the stresses, which remain in the compound after the subsequent process, have to be taken in account for the experimental determination of the modified interface strength. A correct numerical calculation of these residual stresses is also only possible with accurate material properties. Through the extrusion process the elasti c-plastic behaviour of the basic materials changes [4] and have to be investigated for the present compound in an extended temperature and strain rate range.

2. Experimental Setup

The material properties determination of hydrostatic extruded magnesium (AZ31)

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and aluminium (AlSi1MgMn) is initiall y performed by tensile tests, which are described in the present paper und will be supplemented by bending and compression tests in future investigations.

2.1. Generation of uniaxial tensile stress states

For the realisation of the tensile t ests a ZWICK-testing machine was available. Specifically designed equipment (Figure 1) enables tests in a wide temperature range due to a gas heater. The c eramic elements representing another characteristic are used for the force transmission and thermal isolation of t he loading device and their connecting components. Both the specimen and the clamping elements are located completely inside the chamber. Furthermore the experi mental setup has a viewing window to which different p anes can be inserted whereby optical and thermographically images are possible.
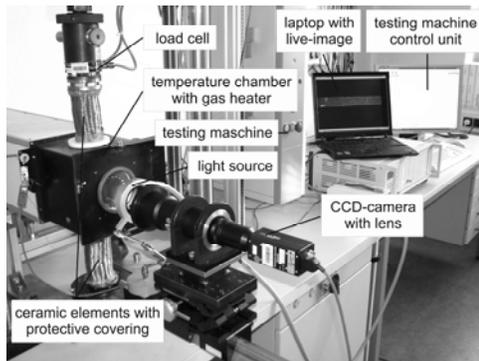

Fig. 1. *Experimental setup*

The geometry of the hydrostatic extruded compound with a strong curved sheath of 2.5mm thickness implies substantial limitations to the specimen geometry. The separation is performed lengthwise (Figure 2) by electrical discharge machining with a maximum thickness of 1.5mm. The remaining dimensions are
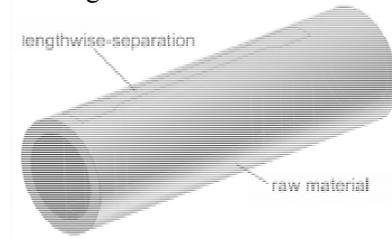
shown in Figure 3.

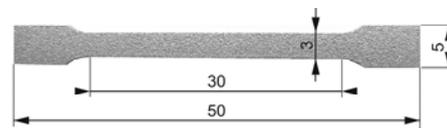Fig. 2. *Specimen separation*

Fig. 3. *Specimen geometry*

The generation of an uniaxial tensile stress state within the measuring range of the specimen requires a precise arrangement of the contact surfaces of the clamping elements. Bringing them closely together enables the accurate adjustment so that the twi st and horizontal offset c an be reduced to a minimum (Figure 4). In t his way the torsion and b ending involvement is kept low. For increasing the grip of the contact surfaces they were roughening.
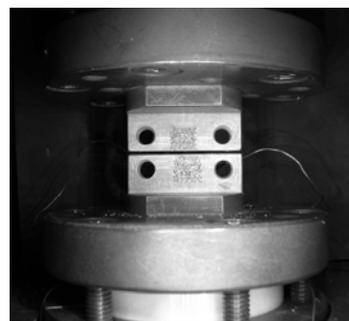

Fig. 4. *Justification of the contact surfaces inside the temperatur chamber*

2.2. Temperature field

The heating of the specimen in the temperature chamber is performed with the

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gas heater behind by absorbing and heating air from the surrounding. The specimen and the clamping elements are located completely inside the chamber. Even though low deviations from the ideal homogeneous temperature field are expected and determined by preliminary investigations.

The measurement of the temperature field inside the chamber is carried out with the thermographic system "VarioCam hr head" from Infratec and with a window pane consisting of zinc sulphide. The transmission coefficient amounts 0.68 and was determined by comparative measurements using a commercial AGEMA blackbody. The analysis took place by a temperature of 225°C.

With a maximum difference of 4K and a standard deviation of 0,4K the temperature field can be referred as nearly homogeneous (Figure 5). The maximum deviation from the average temperature occurs close to the lower fixing.

Beside the temperature measurement with the thermography system a thermocouple was used for the temperature control of the gas heater. Since the temperature monitoring using the thermography is not possible parallel to the deformation analysis with the digital image correlation (see 2.3.) due to the necessity of the different window panes.

The temperature measured by the thermocouple differs only by 3K from the average specimen temperature and therefore can be used as control unit for the test temperature.

2.3. Force and Strain measurement

The force measurement is performed with a 5kN load cell from GTM Gassmann Theiss-Messtechnik GmbH. The digital image correlation and the traverse offset are used for the strain measurement.

The digital image correlation belongs to the digital image processing methods and is performed with the commercial program "VEDDAC 4.0" from CWM GmbH. It compares two images of different object states and calculates the displacement field through a correlation procedure. The accuracy was verified by a tensile test using a clip-gage and the digital image correlation parallel for the strain measurement (Figure 6). The strain identified by the clip-gage is considered as correct due to a calibration test with a splitted specimen. A maximum deviation of 3% was detected for the digital image correlation.
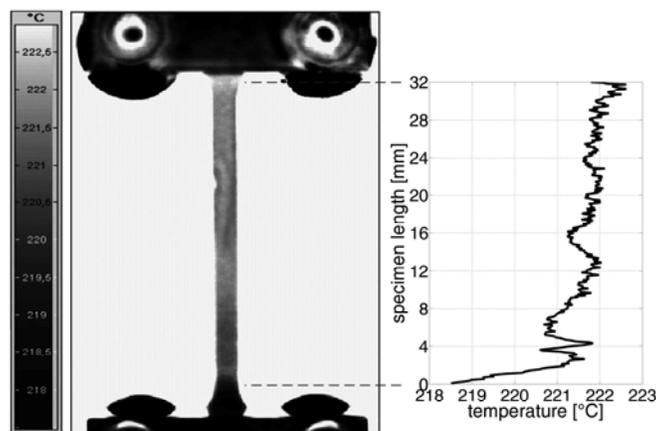

Fig. 5. *Thermography image of a tensile specimen, temperature distribution*

Fig. 6. *Strain measurement using digital image correlation and clip-gage*

true stress which are calcu lated by the formulas (1) and (2).
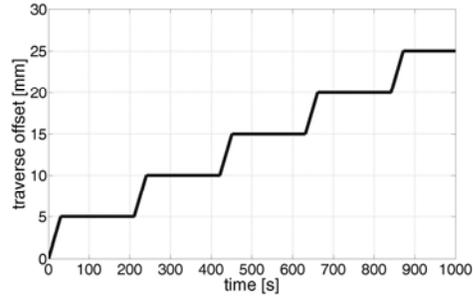
Fig. 7. *Traverse offset depending on time for a strain rate of* $5\cdot10^{-3}\ s^{-1}$

At higher temperatures a str ain measurement using the d igital image correlation was per formed for each test parameter combination (see 3.). As a result a ratio between the traverse offset and the strain is received and used for all strain measurements of the respective parameter combination. The transfer of the r atio seems to be feasi ble due to the iden tical experimental setup and free speci men length.

3. Results and Discussion

The program of s tudies is shown in Table 1. For each test parameter combination two experiments were performed. The maximum traverse offset amounts 25mm und is divided into five steps. After each step a dwell time of 180s follows whereby the traverse offset keeps constant. During the dwell times no relief takes place. The test p rocedure is exemplary shown in Figure 7 fo r a s train rate of $5\cdot10^{-3}\ s^{-1}$.

The evaluation of the tensil e tests is performed based on logarithmic strain and

$$\varphi = \ln\left(\frac{\Delta l}{l_0} + 1\right) \tag{1}$$

$$\sigma_W = \frac{F}{A_0}\left(\frac{\Delta l}{l_0} + 1\right) \tag{2}$$

3.1. AlSi1MgMn

The results are shown fo r the different temperatures and strain rates i n Figure 8 and 9. During the second step the specimen constricted and broke.

Strong dependencies of the yield stresses on temperature and strain rate are detected. Due to higher temperatures the strengthening behaviour at room temperature changes to a sligh t softening behaviour. The absence of an i mmediate constriction can be traced to the strain rate dependent behaviour of the al uminium. In sections of constriction the deform ation concentrates. As a resu lt the strain rate increases and leads to a stabilization of the specimen.

Program of studies Table 1

Temperature [°C]	20	250	300	350
Logarithmic strain rate in s^{-1}	$5\cdot10^{-3}$	$5\cdot10^{-3}$	$5\cdot10^{-5}$; $5\cdot10^{-3}$; $5\cdot10^{-2}$	$5\cdot10^{-3}$

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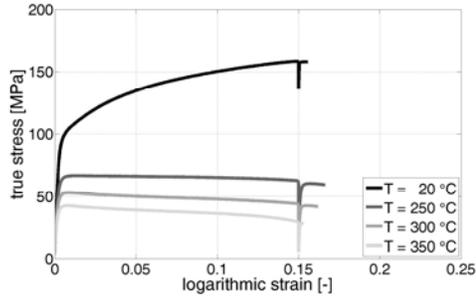

Fig. 8. *Yield stress-strain curves (5·10⁻³s⁻¹)
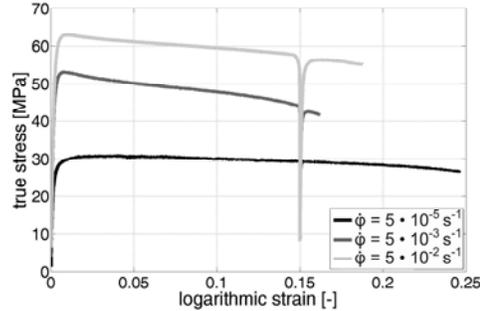for AlSi1MgMn at different temperature*

Fig. 9. *Yield stress-strain curves (300°C)
for AlSi1MgMn at different strain rates*

During the dwell time (30-220s) an extreme stress drop can be observed. The force-time-curves which are exemplary shown in Figure 10 for room temperature and 300°C present typical relaxation curves.
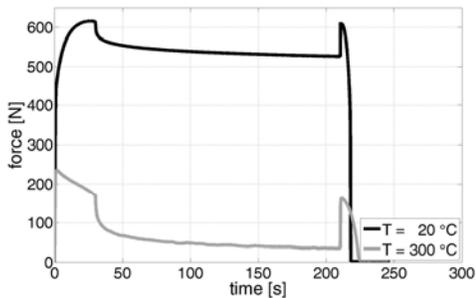

Fig. 10. *Force-time-curves for AlSi1MgMn
at a strain rate of 5·10⁻³ s⁻¹*

3.2. AZ31

The results are shown fo r the different temperatures and s train rates in Figure 11 and 12. Due to strengthening behaviour logarithmic strains up to 0.59 could be reached without constrictions. The flow behaviour also depends strongly from temperature and strain rate.
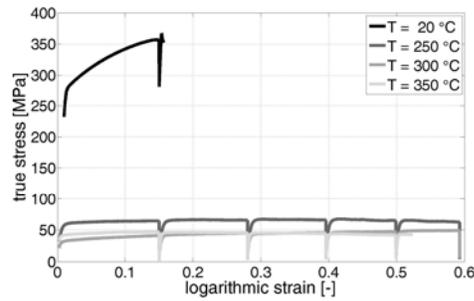

Fig. 11. *Yield stress-strain curves (5·10⁻³s⁻¹)
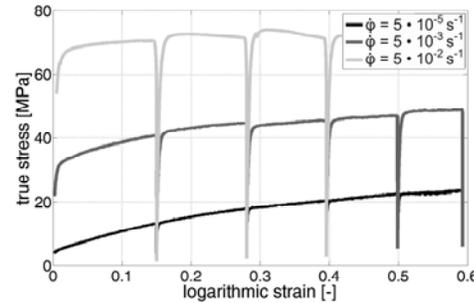for AZ31 at different temperatures*

Fig. 12. *Yield stress-strain curves (300°C)
for AZ31 at different strain rates*

In Figure 11 the yield stress of 350°C lies above 300°C. Time and temperature depending processes in the specimen are suspected to increase the strength. Verifying this hypothesis further tensile tests at 3 00°C and a strain rate of 5·10⁻³ s⁻¹ are performed with different thermal treatments of the specimen (Figure 13). In consequence of 60min at 300°C the directly afterwards executed tensile t est released a significant strength increase.

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Heating up the specimen to 350°C for 15min and a slow cooling down to the test temperature of 300°C even doubles the tensile strength.
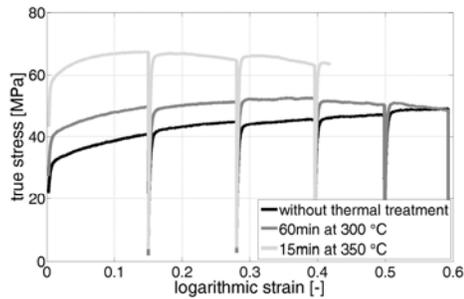

Fig. 13. *Yield stress-strain curves (300°C) for AZ31 depending on thermal treatment*

4. Conclusion

The results of th e material study reveal a significant dependency of the yield stress curves on temperature and strain rate. Specimens with a ther mal treatment indicate tensile strength enhancements.

Acknowledgements

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