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INFLUENCE OF EXTRUSION PROCESS PARAMETERS ON THE MECHANICAL PROPERTIES OF Al-Li-EXTRUSIONS

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ABSTRACT

The influence of the extrusion process parameters and TMT on the mechanical properties of different Lital A (8090)-extrusions was investigated. Strength was shown to be influenced less by extrusion temperature and ratio than by the extrusion aspect ratio (width/thickness) determining texture. With increasing extrusion aspect ratio the strength declines considerably. Depending on the homogeneity of slip distribution the strength decrease can be calculated with excellent accuracy by the SACHS- or the TAYLOR-model on the basis of a quantitative texture analysis.

1. INTRODUCTION

For the production of high quality Al-Li semiproducts ready for service it is essential to get knowledge of the influence of the production conditions on the properties of the semiproduct. As there are little publications especially for extrusions [1,2], the purpose of this investigation is to determine the influence of the extrusion process parameters on the tensile properties of differently shaped extrusions. As the strength of Al-Li sheet and plate material is known to have a stronger susceptibility towards texture [3-6], this topic is a point of special interest in this investigation.

2. EXPERIMENTAL PROCEDURE

The extrusion billets ($\emptyset$ 77 x 200 mm) were machined from rectangular DC cast bars (300 x 900 x 2500 mm). The chemical composition of the used Lital A-alloy (8090) is given in Tab.1.

Li	Cu	Mg	Zr	Si	Fe	Mn	Cr	Zn	Ti
2.45	1.08	0.73	0.1	0.03	0.04	0.001	0.001	0.02	0.02

Tab. 1: Chemical composition of the Lital A alloy investigated

The billets were homogenised for 24h at 550°C in air and directly extruded on a 3.15 MN-press with a 80 mm dia. container. Within 2 min. the billets were heated to the extrusion temperatures of 400°C or 450°C, which were always equal to those of the container. Circular rods ($\emptyset$ 16 mm), and different flat shapes were extruded (exit speed 2m/min.). All extrudates were solution treated for 30 min. at 535°C, quenched in water (20°C) and then stretched (2 %) immediately. After pre-aging (5d, 20°C) the extrusions were aged at 185°C. Additionally the circular rod was aged without preceding stretch. The tensile properties were determined in extrusion direction.

The texture measurements were carried out on a fully automatic and computer-controlled texture goniometer [7]. For each specimen four incomplete different pole figures {111}, {200}, {220}, {113} up to a maximum tilting angle of 85° were

measured, from which the three-dimensional orientation distribution functions (ODF) were calculated [8]. By the means of isotropic Gauß-type distribution functions the ODF were separated in the single components of texture and quantitatively evaluated [9].

3. RESULTS

3.1 Influence of Stretch on the Artificial Aging Behaviour

Fig. 1 shows the dependence of the mechanical properties of the circular rods from aging time at 185°C with and without stretch (extrusion temperature 450°C). At the beginning of aging the strength values without stretch are higher than those for the stretched condition. With increasing aging time the strength for the unstretched condition reaches a plateau followed by the peak strength. By stretching, however, the strength is continuously increasing to its peak. Maximum strength is achieved after an aging time of 30h for each treatment. The yield strength $R_{p0.2}$ is higher by 25 MPa and tensile strength R_m by 10 MPa due to stretching. At the beginning of aging the elongation values A_5 drop for both conditions. Then for the unstretched rod the elongation remains nearly constant and then increases with overaging. For the stretched condition the elongation exhibits a slight minimum and increases just before the aging peak. Stretching always results in slightly higher values of both strength and elongation. Therefore in the further investigation, all extrusions were stretched before aging.

Fig. 1: Age hardening curve (185°C) of the circular rod

3.2 Influence of Extrusion Parameters and Shape on the Tensile Properties

The strength of different shapes (circular and flat) extruded at 450°C and aged for 30h at 185°C does not systematically depend on the extrusion ratio R (Fig.2). For nearly equal extrusion ratios in the range from 1 : 22.3 to 1 : 25.8 e.g.

Fig. 2: Influence of extrusion ratio R on strength $R_{p0.2}$, R_m

Fig. 3: Strength $R_{p0.2}$, R_m vs. extrusion aspect ratio W/T

there are considerable differences in strength. The shapes also differ in the extrusion aspect ratio W/T of width W to thickness T . From the minimum W/T -ratio of 1 (axisymmetric shapes) (Fig. 3) the strength strongly drops and is still being reduced for W/T -ratios greater than 10. This reduction is approximately by two times greater for the yield than for the tensile strength. Yield strength differs most between the circular rod ($W/T = 1$) and the 65×3 mm flat shape ($W/T = 21.7$). In Fig. 3 the strength values of three shapes extruded at 400°C are given additionally. On a level 10-26 MPa higher than by extrusion at 450°C they show the same W/T -dependency. In order to verify the influence of the W/T -ratio at one extrusion the L-shape shown in Fig. 3 was extruded at 450°C . It can be divided in section A (thickness 12 mm, $W/T = 1$) and section B (thickness 2 mm, $W/T = 16$, if the entire width of the shape is considered). The strength values of the sections A and B fit very good to the dependency of Fig. 3. The elongation values (Fig. 4) are nearly independent from the W/T -ratio and do not differ significantly for the

Fig. 4: Elongation A_5 vs. extrusion aspect ratio W/T

Fig. 5: Age hardening curve of section A and B (L-shape)

two extrusion temperatures. The influence of the state of precipitation on the W/T -dependency was determined by the age hardening curves of the sections A and B (Fig. 5). As expected from the same W/T -ratio of 1, similar curves for strength and elongation are observed for section A and the circular rod (Fig. 1). In section B, however, the peak strength is reached 20h later and the strength is always lower. There are also considerable differences in the elongation curves.

Fig. 6: Strength difference between section A and B vs. aging time

Fig. 7: Grain structure of section A (a) and B (b)

At the begin of aging the elongation declines for the two sections. For section B it remains nearly constant up to the overaged condition. Section A exhibits lower elongation values with a minimum after 8h. Having reached its peak aged condition the elongation is even significantly greater than that of section B.

The difference of yield strength $\Delta R_{p0.2}$ and tensile strength ΔR_m between section A and B changes with aging time (Fig. 6). After quenching and in the overaged condition the $\Delta R_{p0.2}$ and ΔR_m -values are lowest. With the begin of aging $\Delta R_{p0.2}$ increases rapidly and reaches its maximum (125 MPa) after 7h in the underaged condition. The differences in tensile strength ΔR_m are approximately half of those in yield strength. Compared with the curve for $\Delta R_{p0.2}$ the maximum is less pronounced and is reached after a longer aging time (16h).

4.3 Influence of Microstructure

The microstructures of section A and B (30h 185°C) were examined by light and TEM microscopy in order to determine the reason for the strength differences. In the centre of section A and B (Fig. 7) there is an as-extruded microstructure with pancake-shaped grains in section B due to the greater W/T-ratio. At the original grain boundaries a fine recrystallisation has started with the recrystallised volume fraction slightly greater in section B. The results of the TEM-examination show the subgrains to be equal in structure and size. There are also no differences in the state of precipitation. The flatter grains in part B and the higher degree of recrystallisation are unlikely to cause the remarkable difference in strength.

4.4 Influence of Texture

The $\{111\}$ -pole figures taken from the centre of section A and B differ considerably (Fig. 8). According to its axisymmetric deformation section A shows a pronounced $\langle 111 \rangle + \langle 100 \rangle$ double fibre texture.

Fig. 8: $\{111\}$ -pole figures of section A (a) and B (b)

Due to the predominantly plane deformation the texture of section B is similar to that achieved by rolling. The volume fractions of each texture component and the background were determined from the ODF's (Tab. 2). The double fibre texture (section A) is composed of 75 % in $\langle 111 \rangle$ direction and of 22 % in $\langle 100 \rangle$ direction. Irrespective of slight deviations from the given ideal orientation, in section B the three typical rolling textures S, Bs and Cu predominate with a total amount of 65.9 %. For each texture component the orientation factors Ms and Mt resp. were calculated, which relate yield stress σ_y and critical resolved shear stress τ_c :

$$\sigma_y = M_{s,t} \cdot \tau_c \quad (1)$$

Ms is the factor for the SACHS-model (inverse SCHMID-factor 1/m) and Mt the TAYLOR-factor. According to the SACHS-model [10] plastic deformation occurs as single slip in the {111} <110> slip system with the minimum factor Ms, i.e. the maximum SCHMID-factor m. The TAYLOR- model [11], however, is valid for multi-slip in at least five independent {111} <110> slip systems. In Tab. 2 the factors Ms

<uvw>	Section A			Section B			Mi%	Mt	Ms
	Mi%	Mt	Ms	Component	{hkl} <uvw>				
<111>	75	3.67	3.67	S	{123} <634>	33	3.19	2.48	
<100>	22	2.45	2.45	Bs	{011} <211>	18.7	3.07	2.45	
Background	3	3.07	2.24	Cu	{112} <111>	14.2	3.62	3.05	
				Goss/Bs	{011} <511>	5.4	2.34	2.21	
				-	{138} <751>	3.3	2.55	2.12	
				-	{111} <112>	2.9	3.18	2.54	
				Cube _{RD}	{025} <100>	2.1	2.45	2.45	
				Background		20.4	3.07	2.24	
Mean Value									
Mt, Ms		3.38	3.36					3.12	2.48

Tab. 2: Volume fraction Mi, TAYLOR-factors Mt and SACHS-factors Ms for the texture components.

and Mt are given for loading in extrusion direction <uvw>. Except for the <111> and <100> orientations the Mt-factors are greater than the Ms-factors, because in the case of multi-slip less favoured slip systems must be active to maintain compatibility at the grain boundaries. The Mt and Ms factors are equal for the <111> and <100> orientations, because 6 and 8 slip systems resp. have the same Ms-factor, thus sufficient equivalent slip systems being active for the validity of the TAYLOR-model. The mean orientation factors Ms and Mt -balanced with the volume fraction- are nearly equal for section A. In section B Ms and Mt differ considerably and they are lower than in section A, especially for the SACHS-model. The higher Mt and Ms values of section A are due to the high volume fraction (75 %) of <111> orientations with the highest Mt and Ms factors at all. For the same critical resolved shear stress in both sections the difference of the yield strength $\Delta R_{p0.2}$ related to the yield strength of section A [$R_{p0.2}$ (A)] can be

Fig. 9: Strength difference related to "A" vs. aging time

Fig. 10: Slip distribution (a) and precipitation (b) of section B (2h 185°C)

calculated from $\bar{M}_s$ and $\bar{M}_t$ with eqn. (1):

$$\text{SACHS: } \Delta R_{p0.2}/R_{p0.2} (A) = 26.2 \%$$

$$\text{TAYLOR: } \Delta R_{p0.2}/R_{p0.2} (A) = 7.7 \%$$

These models describe extreme conditions with the SACHS-model as the upper and the TAYLOR-model as the lower limit for the relative difference in yield strength. Principally the relative strength difference (Fig. 9) shows the same dependency from aging time as the mere strength difference $\Delta R_{p0.2}$.

In the underaged condition (2h aging time) the maximum of 27 % is achieved. After quenching or overaging the values are lowest (12 %, 15 % resp.).

Fig. 11: Slip distribution (a) and precipitation (b) of section B (150h 185°C)

Fig. 12.: Slip distribution of section B (solution treated)

5. DISCUSSION

The applicability of either the SACHS- or the TAYLOR-model depends on the predominant slip-mode, which was determined by TEM-analysis of deformed and not deformed sections of the failed tensile specimens (section B).

For the underaged condition (2h 185°C) slip occurs on single, very pronounced slip bands (Fig. 10a). This inhomogeneous slip distribution is attributed to the spherical, ordered and coherent δ' (Al_3Li)-precipitates (Fig. 10b) easily shearable by dislocations. Once slip in the system with the lowest SACHS-factor has started and cut δ' -precipitates, this primary slip plane is weakened and further slip is being concentrated on it leading to the observed formation of slip bands [12]. Therefore the relative strength difference in this condition must be calculated by SACHS, which is clearly confirmed by the experiment. After overaging (150h 185°C) the slip distribution is completely homogeneous (Fig. 11a) due to the partly coherent $S'(Al_2CuMg)$ laths besides δ' -precipitates acting as obstacles to dislocation movement (Fig. 11b). They are bypassed on other (secondary) slip systems with the necessity of multi-slip [4,13].

After quenching slip is also homogeneous (Fig. 12), as the δ' -precipitates are too small to be detected and to cause inhomogeneous slip [14]. The homogeneous slip is obviously caused by multi-slip. For the quenched and the overaged condition the low relative difference in strength therefore agrees well with the calculation according to the TAYLOR-model.

6. CONCLUSIONS

Compared with extrusion temperature and ratio the strength of Lital A-shapes strongly depends on the extrusion aspect ratio (width/thickness) W/T which

- changes texture
- reduces strength with shapes getting flatter (increasing W/T)
- brings about a strength difference between axisymmetric and flat shapes, which is great at the begin of aging and low after quenching and in the overaged condition.

As the texture-strength relationship is described by the SACHS-model for single slip and by TAYLOR for multi-slip, the strength difference can be calculated on the basis of a quantitative texture analysis with good agreement

- by SACHS for the inhomogeneous slip distribution at the begin of aging
- by TAYLOR for the homogeneous slip distribution after quenching and in the overaged condition.

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REFERENCES

- [1] N.C. Parson and T. Sheppard in: "Aluminium-Lithium Alloys II", ed.: T.H. Sanders, Jr. and E.A. Starke, TMS-AIME, Warrendale, PA (1984) 53.
- [2] N.C. Parson and T. Sheppard in: "Aluminium-Lithium Alloys III", ed.: C.Baker et al., The Institute of Metals, London (1986) 222.
- [3] M. Peters, K. Welpman and T.H. Sanders, Jr., Proc. 3rd Conf. of E-MRS on Advanced Materials R & D for Transport, ed.: R.J.H. Wanhill et al., Les éditions de physique, Les Ulis (1986) 63.
- [4] P.J. Gregson and H.M. Flower, Acta Metall, 33 (1985) 527.
- [5] M. Peters, J. Eschweiler and K. Welpmann, Scripta Met., 20 (1986) 259.
- [6] S. Fox, D.S. Mc Darmaid and H.M. Flower, Conf. Aluminium Technology 1986, The Institute of Metals, London (1986) 72.1.
- [7] J. Hirsch, G. Burmeister, L. Hoenen and K. Lücke in: "Experimental Techniques of Texture Analysis", ed.: H.J. Bunge, DGM-Verlag (1986) 63.
- [8] H.J. Bunge "Mathematische Methoden der Texturanalyse" Akademie Verlag Berlin (1969).
- [9] J. Hirsch and K. Lücke in: "Theoretical Techniques of Texture Analysis", ed.: H.J. Bunge, DGM-Verlag (1987).
- [10] E. Sachs, Z. Verein Deutsch. Ing. 72 (1928) 734.
- [11] G.I. Taylor, J. Inst. Met. 62 (1938) 307.
- [12] K. Welpmann, M. Peters, T.H. Sanders, Jr., Aluminium 60 (1984) 735 and 846.
- [13] W.S. Miller, M.P. Thomas, D.J. Lloyd and D. Creber, Mater. Sci. and Techn. 2 (1986) 1210.
- [14] K. V.-Jata and E.A. Starke, Jr., Metall. Trans. A. 17A (1986) 1011.