FLOW STRESS BEHAVIOUR OF AlZnMg ALLOYS AT TEMPERATURES CLOSE TO THE SOLIDUS TEMPERATURE

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ABSTRACT Through hot torsion tests it is shown that a constitutive equation, relating flow stress to strain rate, temperature and chemical composition at temperatures well below the solidus, also applies as the temperature approaches the solidus temperature. However, at 0 – 13°C below the solidus temperature of the material there is a sudden drop in the flow stress and the torsion specimen fractures in a brittle and intercrystalline manner. The difference between the solidus temperature and the critical temperature for fracture seems to increase as the solidus temperature decreases. The solidus temperatures of the alloys were measured by use of differential scanning calorimetry. Eight AlZnMg-alloys, containing 4.5 – 7.5 wt% Zn and 0.8 – 1.8 wt% Mg, were investigated.

Keywords: *AlZnMg-alloys, hot torsion, fracture temperature, solidus temperature*

1. INTRODUCTION

During extrusion of aluminium alloys, the outlet temperature of the profile is often close to the solidus temperature. If the outlet temperature exceeds a critical value, defects like tearing or spalling may occur on the surface of the extruded profile. Local melting of Mg_2Si-particles + α-matrix may cause tearing of the profile at eutectic temperatures [1,2]. In an alloy containing no low melting phases the critical temperature is usually associated with the solidus temperature [3] or with temperatures slightly below the solidus temperature [4]. It is not completely established if the surface defects that occur close to the solidus temperature are due to incipient melting of the matrix or if the mechanical strength of the material becomes too low to withstand the stresses in the extrusion die as the temperature approaches the solidus temperature.

The goal of this work is twofold:

1) Investigation of the mechanical properties of different AlZnMg-alloys as the temperature approaches the solidus temperature. A constitutive equation (Eq. 1) that relates steady state flow stress to strain rate, temperature and chemical composition is derived from hot torsion tests performed at temperatures well below the solidus temperature [5]. By conducting torsion tests at temperatures up to the solidus temperature and comparing the experimental flow stress with the predicted flow stress from the constitutive equation, it should be possible to detect any abnormal mechanical behaviour.

$$\sigma = \frac{1}{\alpha} \arcsin h \left[\left(\frac{Z}{A} \right)^{1/n'} \right] \qquad (1)$$

where

$$Z = \dot{\varepsilon} \cdot \exp\left(\frac{Q}{RT} \right)$$

$$\alpha = 0.0395 \cdot [Mg]^{-0.328}$$

$$n' = 0.863 \cdot [Mg]^{-0.560} - 0.103 \cdot [Zn] + 3.68$$

$$Q = 167.7 \text{ kJ/mole and } A = e^{24.9}/s$$

2) Determination of temperatures where fracture of specimen occurs. These temperatures are compared with the solidus temperatures.

2. EXPERIMENTAL

2.1 The material

Aluminium ingots of commercial purity with relatively low iron and silicon concentration, 0.07 wt% and 0.04 wt%, respectively, were melted in an induction furnace. Pure zinc and magnesium were added to the melt. Eight ternary AlZnMg-alloys with zinc concentration in the range 4.5 – 7.5 wt% and magnesium concentration in the range 0.8 – 1.8 wt% were DC-cast using the spout and float technology. The chemical composition and designation of the alloys are shown in Table I. The homogenisation was performed by holding the material at 490°C for 6 hours. The heating rate to holding temperature was approximately 150°C/h and after holding the material was quenched in water to room temperature.

Table I Designation* and chemical composition of the material

Design.	[Zn] [wt%]	[Mg] [wt%]	Design.	[Zn] [wt%]	[Mg] [wt%]	Design.	[Zn] [wt%]	[Mg] [wt%]
-	-	-	5508	5.45	0.79	7508	7.40	0.72
4512	4.58	1.18	5512	5.48	1.17	7512	7.55	1.18
4518	4.60	1.80	5518	5.55	1.71	7518	7.65	1.55

* *It should be emphasised that the designation used here is not in accordance with the Aluminium Association (AA) designation system. The numbers above simply indicate the concentration of zinc and magnesium. For example, "5508" means 5.5 wt% zinc and 0.8 wt% Mg.*

2.2 Differential scanning calorimetry

Differential scanning calorimetry (DSC) was performed in order to determine the solidus temperatures of the alloys. Small samples, 14-22 mg, were cut from the shoulders of the hot torsion specimens. Each sample was placed in a small Al_2O_3-cup inside a silver crucible of a Seiko SSC/5200 DCS-instrument. There were two cups inside the silver crucible. One contained the specimen and the other, which was empty, served as a reference. The temperature differences between a reference position in the silver crucible and positions close to the reference cup and the sample cup, respectively, were measured. From the measured values of $\Delta T_{ref.}$ and ΔT_{sample} the difference in heat flow (mW) between the sample and the reference was calculated by the instrument.

Nitrogen was introduced into the silver crucible with a flow rate equal to 30 ml/min in order to prevent oxidation. The specimens were heated relatively quickly from room temperature to approximately 530°C. From this temperature and up to the pre-set end temperature, the heating rate was 5°C/minute. All specimens were heated to temperatures above the liquidus temperature. The DSC-curve was calibrated against the melting point of pure aluminium.

2.3 Hot torsion testing

Torsion specimens with a gauge length equal to 10 mm and a gauge diameter equal to 10 mm were mounted in water-cooled grips in a torsion machine. An induction coil enveloped the gauge section of the specimen and heated the specimen. The heating rate was approximately 1°C/s. A thermocouple was situated in the shoulder of the specimen, with the hot junction 1 mm away from the gauge section. The deformation of the specimens started approximately 15°C below the expected temperature for fracture. The heating of the specimens continued with the same heating rate during the deformation. The specimens were deformed with an equivalent strain rate, $\dot{\varepsilon} = 0.1/s$. During the deformation the specimens would eventually fracture when a critical temperature was reached. Torque, angle of twist and temperature were recorded by a computer.

Due to the heating system and the water-cooled grips, there was always a temperature gradient in the specimens. The warmest part was close to the surface of the gauge section. Since the thermocouple was situated some distance from this surface, the temperature measured by the thermocouple was always lower than the maximum temperature. It is assumed that the maximum temperature in the specimen will determine when the fracture occurs. The temperature difference between the hot junction of the thermocouple and the specimen surface was measured to be approximately 11 – 12°C. The thermocouples that were used were calibrated to an accuracy of +/- 1.5°C.

3. RESULTS AND DISCUSSION

3.1 Differential scanning calorimetry

In Figure 1 the DSC-signal and its derivative with respect to time is plotted versus temperature for alloy 5508 and 7512. The point were deviation from the base line of the DSC-signal occurs is defined as the temperature where melting of the matrix starts. For alloy 5508 and 7512 this temperature is 616°C and 596°C, respectively. The solidus temperature from the present study is found to be approximately 7-11°C below the solidus temperatures taken from Phillips [6]. This difference may be attributed to a difference in impurity level.

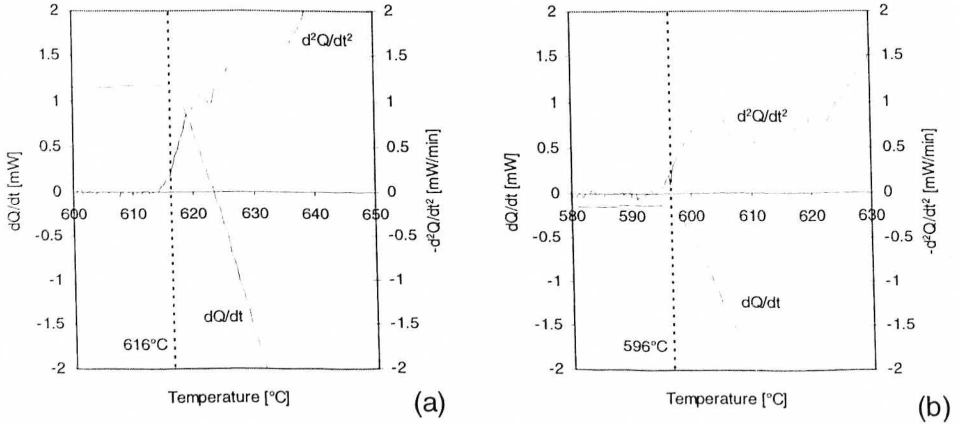

Fig. 1 DSC curves and their derivatives for a) alloy 5508 and b) alloy 7512

3.2 Hot torsion tests

Experimental equivalent flow stress and temperature is in Figure 2 plotted as a function of equivalent strain for alloy 5508 and 7512. Equivalent flow stress calculated by means of the constitutive equation (Eq.1) is also shown. From the figure it can be seen that the experimentally determined flow stress follows the calculated flow stress quite closely up to a critical temperature, where the flow stress drops rapidly. As the flow stress drops the specimen fractures. The critical temperature is not easily defined, but it is taken at the point where the difference between the calculated and experimental flow stress suddenly increases rapidly with increasing strain. This is shown in Figure 3. The corresponding points on the flow stress curve and the temperature curve are in Figure 2 marked with crosses. The solidus temperatures determined by the DSC-measurement are also indicated in the figure.

The measured critical temperature for drop in flow stress is lower than the solidus temperature. This is clearly seen in Figure 4 where the difference between the solidus temperature and critical temperature, $T_{solidus} - T_{crit.}$, is plotted versus the solidus temperature measured on the DSC-instrument. The difference in temperature seems to decrease with increasing solidus temperature. For the alloys with a low content of alloying elements there is a very small difference between the solidus temperature and the critical temperature. For the alloy containing 7.5 wt% Zn and 1.55 wt% Mg the difference between measured solidus temperature and critical temperature is approximately 13°C.

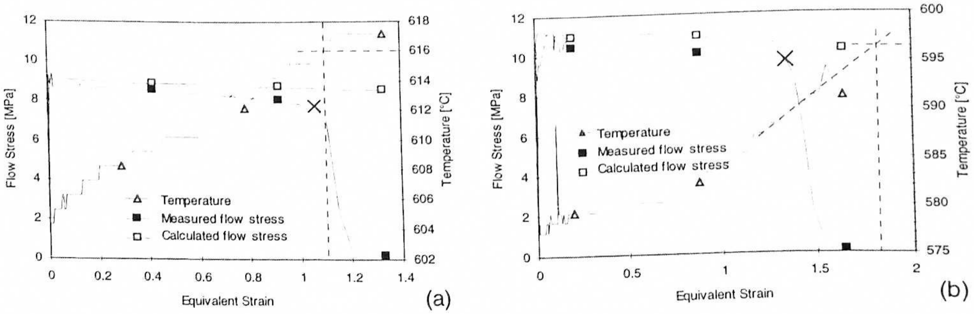

Fig. 2 Experimental and calculated flow stress for (a) alloy 5508 and (b) alloy 7512. The solidus temperatures are shown as dotted lines.

Inspection of the fracture surface showed that the fracture was brittle and intercrystalline. This indicates that the grain boundary regions are weaker than the interior of the grains. This may be attributed to the more open atomic structure at the grain boundaries or a different local chemical concentration at the grain boundaries than in the interior of the grains. An increased concentration of for example magnesium and zinc at the grain boundaries would lead to a local decrease in the solidus temperature. However, microprobe analysis across grain boundaries showed no gradients of magnesium and zinc in the homogenised material.

Another explanation on the difference between the measured solidus temperature and the measured critical temperature could be errors in the measurement of the temperature. If, for example, the intimate contact between the hot junction of the thermocouple and the material in the specimen is lost, then the thermocouple would measure a too low temperature. Tests are now being performed in order to eliminate this uncertainty.

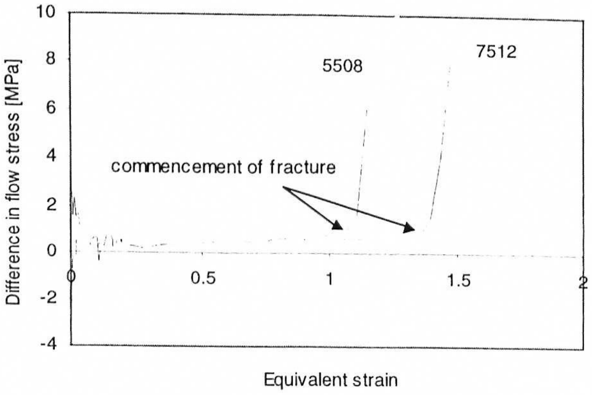

Fig. 3 Difference between calculated and experimental flow stress.

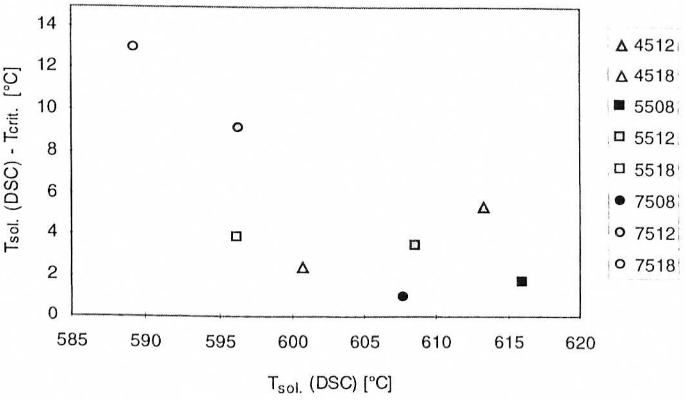

Fig. 4 Difference between solidus temperature measured by DSC and critical temperature for fracture measured in torsion as a function of solidus temperature.

4. CONCLUSIONS

Steady state flow stress determined by hot torsion at temperatures close to the solidus temperatures can be predicted by a constitutive equation derived at temperatures well below the solidus temperature. This is true until a critical temperature is reached where the experimental flow stress drops suddenly and the specimen fractures. This critical temperature is measured to be 0 – 13°C below the solidus temperature. The reason for this difference is still uncertain.

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