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THE DEVELOPMENT OF A NEW MANUFACTURING ROUTE FOR SUPERPLASTIC MAGNESIUM ALLOY SHEET EXPLOITING TWIN ROLL CASTING

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Abstract

Because of their propensity to dynamically recrystallise, superplastic behaviour can be obtained from magnesium alloys considerably more easily than from comparable aluminium alloys. In some cases even as cast magnesium alloys can exhibit reasonable superplasticity and there appears no need for the special alloying additions or complex thermomechanical treatments required by aluminium alloys such as AA2004 or AA7475. The paper describes the superplastic behaviour (in uniaxial tension) and microstructure of sheet processed from strip cast magnesium alloys. The material was tested in the as-cast condition and after warm rolling to a number of gauges. Industrially useful superplastic capability was demonstrated in the strip cast alloys. Furthermore good superplastic capability was also demonstrated in sheet subsequently rolled from the cast metal and the ductilities obtained were not significantly influenced by rolling strain. Results are also included on the superplastic behaviour of die cast AZ31 and AZ91 in both as-cast and cast and rolled conditions. Despite both alloys demonstrating superplastic behaviour there were significant differences in their deformation characteristics as defined by their respective strain rate sensitivities. Some preliminary results obtained from twin roll cast AZ91 that had been subjected to severe shearing immediately prior to casting will be presented.

Keywords :

Magnesium based alloys, superplastic forming, twin roll casting

1 INTRODUCTION

Although production of primary magnesium has risen dramatically over the last five years and although manufacture of magnesium alloy die castings has also spectacularly increased, production of magnesium alloy sheet remains at a very low level. Much of the growth in die casting output is accounted for by increased utilisation in motor cars as the vehicle manufacturers try to counter the “weight creep” that has been occurring over the last two decades. There has been no comparable growth in the utilisation of sheet magnesium alloys in motor vehicles. Presumably this is because it is a widely held perception that rolled sheet will, regardless of volumes, always be expensive. Undoubtedly the limited room temperature formability of magnesium contributes to this. Not only does this make magnesium difficult to cold roll but also imposes severe limitations on forming the sheet into panels. Because of this perception vehicle manufacturers historically have considered the cost to be prohibitive. For magnesium sheet forming to be taken up by the automotive manufacturers two key issues have to be addressed. Ideally a process needs to be identified that avoids the need for a complex sheet hot/warm rolling procedure. Furthermore an alternative method to matched die pressing for panel forming is required. This paper describes a potential solution to both problems in which twin roll casting is employed to produce close to gauge sheet which, after limited rolling, is superplastically formed.

While no industrial roll casting capability exists, several experimental units have been reported [1-4]. Furthermore POSCO [4] have the capability to produce 600 mm wide sheet in continuous runs of up to 24 hours. It should be noted that significant quantities of aluminium alloys are produced commercially via roll casting and that there are no significant differences in the technology used for both metals. Recent work at Brunel University has shown that liquid treatment prior to the casting operation can lead to significantly improved microstructures in as-cast magnesium alloys [5]. The experimental results have confirmed that the introduction of severe shearing of the melt, at just above the liquidus temperature, leads to an order of magnitude of microstructural refinement and the elimination of the usual central line segregation observed in as-cast magnesium alloy strip. This has led to the successful development of the melt conditioned twin roll casting (MC-TRC) process [6]. Both of these features should be of considerable benefit in the development of superplastic behaviour.

The situation with superplastic forming of magnesium alloys for automotive components is somewhat different from that of aluminium alloys. Since magnesium alloys can exhibit remarkably good die casting behaviour, it is this that superplastic magnesium alloys are in competition with rather than, as in the case of aluminium alloys, other methods of sheet forming. However, the current indications are that optimisation of the superplastic process for magnesium alloys is relatively straightforward, whereas merely developing the tools for a fairly simple die casting can be prohibitively expensive.

Early in the development of superplastic materials it was reported [7] that a number of magnesium alloys could exhibit superplastic behaviour in sheet form in their "as manufactured" condition. However, in the following thirty, or so, years little effort appears to have been devoted to superplasticity of magnesium and it is only in the last ten years that interest in the topic has been rekindled, presumably because of the determination of the manufacturers to reduce the mass of their vehicles by the increased utilisation of low density materials. While superplastic forming of structures would greatly reduce the manufacturing difficulties compared with cold sheet pressing the high production cost of conventionally manufactured sheet would probably still result in a cost that would be too high for most vehicles.

Over the years since the possibility of employing superplastic forming as a serious manufacturing process was first mooted [8] it seems to have become fairly generally accepted that the production of good superplastic sheet is aided by employing large strains prior to a static or dynamic recrystallisation process to create a very fine grain structure. This belief culminated in the development of the Equal Channel Angular Extrusion (ECAE) process that has certainly demonstrated a capability of generating remarkably fine microstructures and concomitant excellent superplastic behaviour. While this view seems to be correct for aluminium alloys, there is ample evidence to demonstrate that superplastic behaviour can be produced relatively easily in a wide range of magnesium alloys without the imposition of very large strains. In some circumstances, superplastic behaviour that compares favourably with the performance of alloys in sheet form can be obtained from magnesium alloys (e.g. AZ31, AZ91 & Elektron 21) in the as-cast state [9]. In the latter case 1.5 mm samples cut from a 25 mm thick sand casting by electro-discharge machining gave tensile ductilities that were generally comparable with those from the two commercially produced sheet alloys. The grain structure was approximately halved during the superplastic deformation.

In this paper superplastic properties obtained from twin roll cast AZ31 and AZ91 in both the as-cast and the cast and rolled conditions will be presented. The behaviour of die cast material will be included together with preliminary results on AZ91 that had been subjected to shearing prior to twin roll casting.

2 EXPERIMENTAL PROCEDURE

The experimental materials were as follows:-

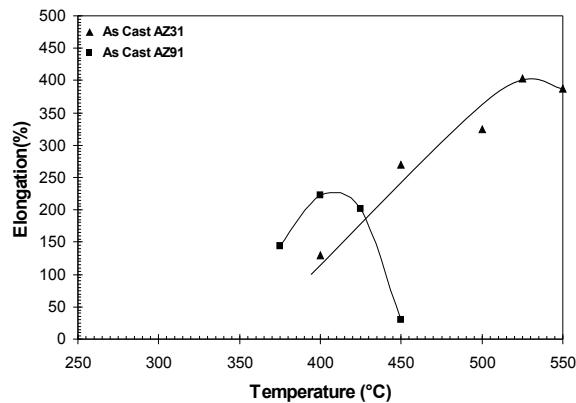
- 1) Twin roll cast AZ31; provided by Superform Aluminium in the form of 3.25 mm thick 300 mm wide sheet.
- 2) Twin roll cast AZ91; provided by BCAST in the form of 5 mm thick 150 mm wide sheet.
- 3) Twin roll cast AZ91 which had been subjected to severe shearing prior to casting; provided by BCAST in the form of 5mm thick 150 mm wide sheet.
- 4) Die cast AZ31 and AZ91; provided by TWI in the form of 5 mm thick 100 mm wide and 150 mm long plates.

The as cast material was then warm rolled at 370°C with 10 minute inter-pass reheats. Superplastic testing was conducted on test pieces with a 12.5 mm by 6.3 mm gauge length in a horizontal constant crosshead velocity machine. Limited tests were performed using a servo hydraulic machine at constant strain rate. A 'staircase' method was used to determine strain rate sensitivity at various strains. Samples for light microscopy were prepared using conventional metallographic techniques.

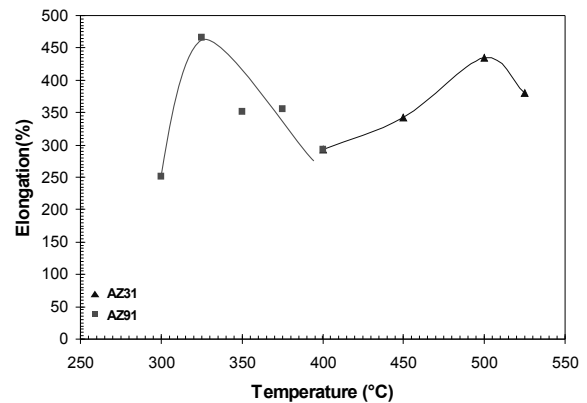
RESULTS AND DISCUSSION

3

The earlier observation of superplastic behaviour in as cast Elektron 21 led immediately to the possibility of employing twin roll casting as the precursor for the manufacture of superplastic magnesium alloy sheet. Thus samples of twin roll cast AZ31 and AZ91 were acquired and results of initial tests are summarised in Fig. 1. In the as-cast condition both alloys exhibited superplastic behaviour but the AZ31 was superior to the AZ91. After warm rolling both alloys presented similar ductilities. In both conditions the AZ31 gave the best behaviour at test temperatures significantly higher than that for AZ91. It is believed that this is a reflection of the difference in solidus temperatures for the two alloys; 605° and 470°C respectively.



a)



b)

Fig. 1, Superplastic ductility as a function of temperature at an initial strain rate of 0.0013 s⁻¹ for a) the as twin roll cast material, b) material warm rolled to a gauge of 2.5 mm.

The roll cast material combines a rapid solidification rate, as a consequence of the forced contact with the rolls, with a hot rolling reduction. It was therefore concluded that a study of material that was simply cast in the absence of any hot working should be undertaken to isolate the effect of the hot deformation. Die cast AZ31 and AZ91, of comparable thickness, were acquired. Light micrographs of the as die cast plates are shown in Fig. 2. The AZ31 displayed a fine grained (~11 μm) structure in contrast to the coarser dendritic

structure observed in the AZ91. Fig. 3 demonstrates the effect of warm rolling on the microstructure of die cast AZ91. Remarkably even after a small rolling reduction of 15% the microstructure appears to be fully recrystallised. Furthermore there was no obvious change in the grain structure with subsequent rolling passes. In all three conditions the grain size was measured to be in the order of 20 μm .

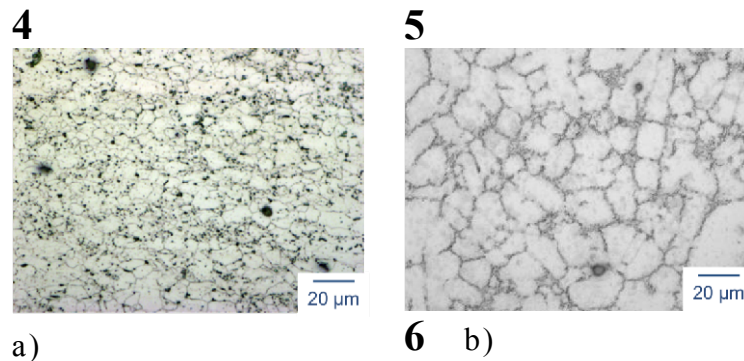


Fig. 2, Light micrographs of as die cast a)AZ31 and b)AZ91

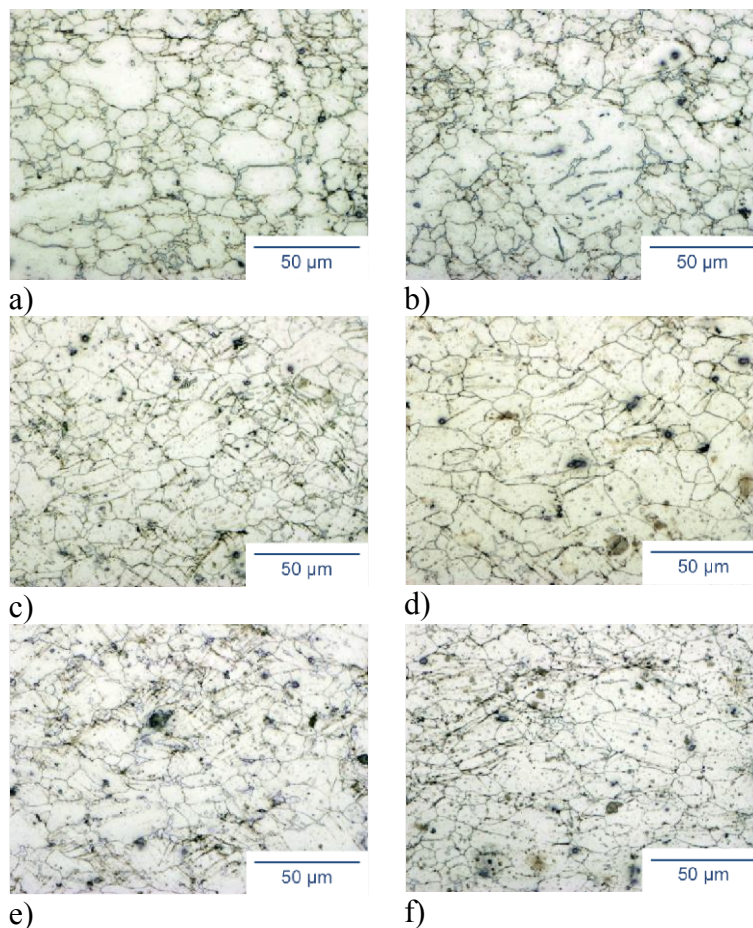


Fig. 3, Effect of warm rolling on the microstructure of AZ91. 15% reduction a) surface, b) centre. 30% reduction c) surface, d) centre. 45% reduction e) surface, f) centre.

The superplastic behaviour of the die cast AZ31 (Fig. 4) is reasonably consistent with that observed in the roll cast materials. It is interesting to note that the material exhibited good superplastic behaviour over a wide temperature range and that the warm rolling had only a marginal effect.

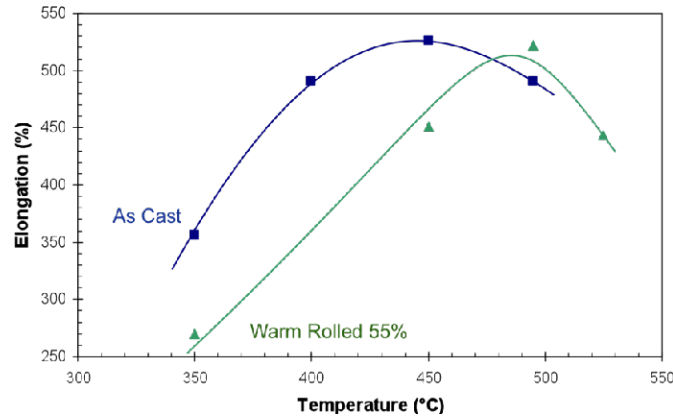


Fig.4, Superplastic ductilities obtained from die cast AZ31 in the as-cast condition and after 55% warm reduction. Tested using an initial strain rate of $8 \times 10^{-4} \text{ s}^{-1}$.

In an attempt to identify the deformation mechanism during superplastic deformation of these alloys in the as-cast condition some strain rate sensitivity tests were conducted. Examples of the results obtained for AZ91 and AZ31 are shown in Fig. 5 and Fig. 6 respectively. It should be noted that the tests shown were conducted close to the optimum temperature for the particular alloy as determined by constant crosshead velocity testing. As a result the AZ91 was tested at 350°C and the AZ31 at 400°C. A 'staircase' methodology was employed to determine the strain rate sensitivity (m). Once plastic flow had been established the strain rate was dropped by an order of magnitude but then progressively raised back to the starting strain rate in three steps. The time taken for this procedure was deliberately kept short to minimise any microstructural modifications. This appears to have been successful as demonstrated by the good coincidence of the step change and constant strain rate tests. The procedure was repeated at various strains to establish the effect of deformation on the strain rate sensitivity. Interestingly AZ91 and AZ31 exhibited very different behaviours. The flow behaviour of AZ91 was dominated by flow softening with the m value apparently increasing with increasing strain. It is believed that this was due to continuous dynamic recrystallisation resulting in a gradual reduction in grain size and hence flow stress. In contrast flow hardening dominated the AZ31 behaviour with the strain rate sensitivity decreasing significantly with increasing strain. It is postulated that the initial deformation was taking place by grain boundary sliding and that progressive grain coarsening resulted in the observed flow hardening. It is possible that the difference in the initial grain sizes of the two materials and test temperatures contribute to these differences. The finer grain size displayed by the AZ31 could lead to a larger initial strain rate sensitivity, while the high temperature (and lower second phase content) would promote grain coarsening. Further micro-examination, particularly by electron backscatter diffraction is clearly required to clarify these issues.

Work at BCAST (Brunel University) has demonstrated that it is possible to refine the cast microstructure by the imposition of severe shearing of the liquid metal just above the liquidus temperature and immediately before casting. Conventional wisdom would suggest that this structural refinement would be beneficial for a superplastic material and limited exploratory tests have been conducted on twin roll stir cast AZ91. Fig. 7a shows the uniform refined microstructure observed in the as-roll cast material. Fig. 7b shows the same material having simply been uniaxially tested (350°C and $8 \times 10^{-4} \text{ s}^{-1}$) to failure with an elongation of 260%. A remarkable transformation in grain structure has resulted simply from the imposition of a modest uniaxial tensile strain and seems further to strengthen the argument that continuous dynamic recrystallisation readily occurs in AZ91. To date the best superplastic ductility that has been observed in this material is 320%. Whilst this is

superior to any ductility observed in the non stir cast variant insufficient testing has been conducted to make any overall conclusion.

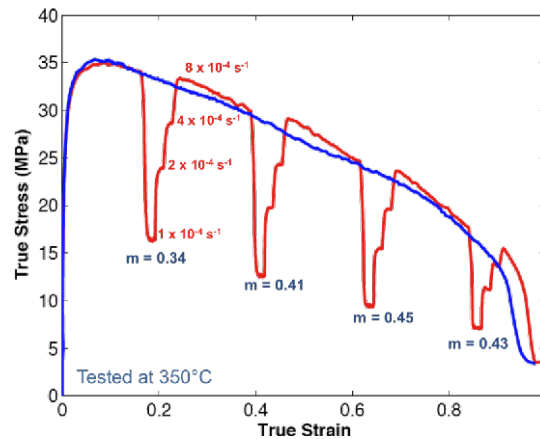


Fig. 5, Stress strain curve obtained during the constant strain rate testing of as twin roll stir cast AZ91 at 350°C with a superimposed strain rate sensitivity test.

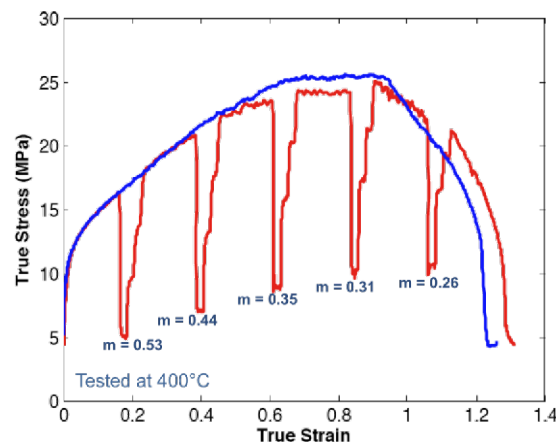


Fig. 6, Stress strain curve obtained during the constant strain rate testing of as die cast AZ31 at 400°C with a superimposed strain rate sensitivity test.

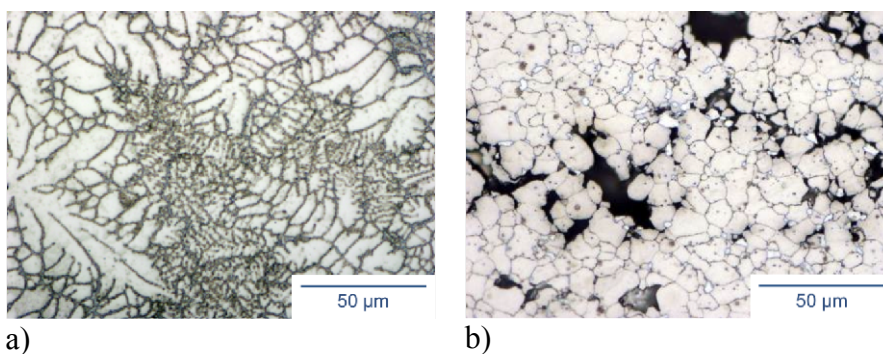


Fig. 7, Light micrographs of twin roll stir cast AZ91 a) in the as cast condition, b) superplastically deformed (350°C and $8 \times 10^{-4} \text{ s}^{-1}$) to failure (260%)

7 CONCLUSIONS

This programme has shown that twin roll casting can be utilised to produce magnesium alloy sheet that is capable of being superplastically formed without the need for further working. Industrially useful superplastic capability was demonstrated by both AZ31 and

AZ91 in the roll cast, die cast, or cast and rolled conditions. All the tests emphasise the key role of dynamic recrystallisation thus offering the potential for further grain refinement simultaneously with any rolling. Strain rate sensitivity analysis implies different behaviour between the AZ31 and the AZ91. During superplastic deformation the m value of AZ31 decreases (suggesting grain coarsening) while for AZ91 m increases (suggesting grain refinement). Nevertheless, in practical terms, AZ31 seems to exhibit superior superplastic performance.

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9 REFERENCES

- [1]H. Watari, K. Davey, T.M. Rasgado, T. Haga and S. Izawa, *Semi-solid manufacturing process of magnesium alloys by twin-roll casting*, Journal of Materials Processing Technology, 2004, 155–156, p. 1662–1667
- [2] Z. Bian, et al, Mater. Sci. Tech., 2008 in press.
- [3]D. Liang and C.B. Cowley *The twin-roll strip casting of magnesium* JOM, 2004, 56, p. 26-28
- [4]I. Jung, W. Bang, I.J Kim, H. Sung, W. Park, D. Choo and S. Ahn, *Mg Coil Production via Strip Casting and Coil Rolling Technologies* Magnesium Technology 2007, ed. Beals et al, TMS p85-88
- S.M. Zhang, Z. Fan and Z. Zhen *Direct chill rheocasting (DCRC) of AZ31Mg alloy* Materials Science and Technology, 2006, 22, p. 1489 - 1498
- Z. Fan and G. Liu, *Solidification behaviour of AZ91D under intensive forced convection in the RDC process* Acta Mater, 2005, 53, p. 4345-4357.
- W.A. Backofen, F.J. Azzarto, G.S. Murty and S.W. Zehr *Superplasticity* Ductility, 1968, ASM, Metals Park, Ohio, p. 279-310
- W.A. Backofen, I.R. Turner and D.H. Avery, *Superplasticity in an Al-Zn alloy*, Transactions of the American Society of Materials, 1964, 57, p. 980-990
- R. Grimes, R.J. Dashwood, A. Dorban, M. Jackson, S. Katsas, I. Pong and G. Todd, *Development of Superplastic Properties in Quasi Single Phase Alloys*, Materials Science Forum, 2007, 551-552, 357-364