STUDY OF THE HOT EXTRUSION PROCESS IN A COMMERCIAL PURITY ALUMINIUM

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Abstract

Commercial purity aluminium with 0.22% Fe and 0.14% Si content was deformed by laboratory direct and indirect extrusion. The high temperature flow stress determined at strain rate of 1-2 s^{-1} was found to be independent of the reduction ratio and the mode of extrusion within the experimental error. To determine the strain rate dependence of the stress high temperature tensile test was also performed at lower strain rates. It was shown that the kinetics of the hot deformation process can be described by power law creep. Above 350°C a stress exponent of n=7 and an activation energy of 200 kJ/mol was found. Below this temperature the stress exponent increased up to 12 and the activation energy approached that of the grain boundary diffusion. The measured high n and Q values are explained by the presence of the AlFe particles inherited from cast state and of the stable fine subgrain structure formed in the early stage of deformation.

Introduction

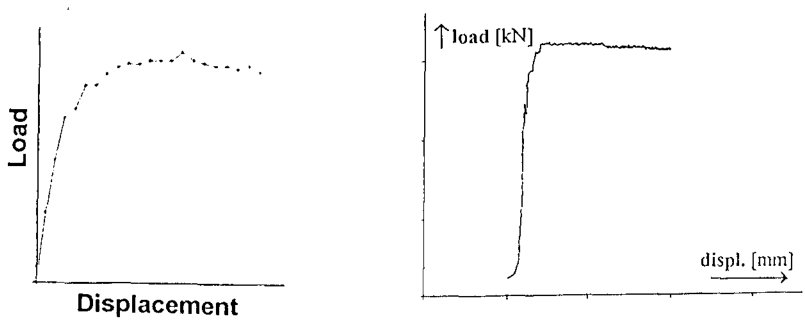
It is generally accepted that the dynamic recovery is the main softening process during high temperature deformation of aluminium and it is controlled by lattice diffusion [1-3]. However, a significantly larger activation energy of the high temperature deformation was obtained in some dispersoid containing aluminium alloys such as AlFe alloys [4, 5]. There are data on much higher activation energies found in composite materials [6], which are explained by the presence of hard particles [7]. The deformation process taking place at intermediate temperatures can be characterized by a lower activation energy in pure aluminium and in some alloys and is explained by diffusion along dislocations [8].

Together with the activation energy the stress exponent shows also a wide variety [9], although there may be problems with its determination [10, 11]. There are only limited information concerning the experimental investigations on the same samples by different methods [9, 12]. In case of extrusion the strain rate-stress relationship could be described by hyperbolic function [13] or by power function [11]. The thorough experimental and theoretical research of the extrusion process and the microstructure of extrudate was performed mostly on alloys [13-15].

The aim of this work was to study the hot deformation processes on a commercial purity aluminium applying laboratory direct and indirect extrusion supplemented by tensile tests at the same temperatures.

Experimental

Commercial purity aluminium containing 0.22% Fe and 0.14% Si was investigated. The billets of 56 mm in diameter were produced by semicontinuous casting at 210 mm/min rate without grain refiner. After homogenization at 610°C for 3 hours the samples were furnace cooled. Laboratory direct extrusion on a vertical hydraulic press of 1 MN with a 41 mm diameter container and indirect extrusion on a similar equipment of 650 kN power with 34 mm diameter of container and 50 mm in height were applied between 200 and 550°C. The experiments were conducted on homogenized billets using circular dies of different diameter at nearly constant, about 1mm/s ram speed. The data of the extrusion process were stored and the load-displacement curves were plotted (Fig. 1.a. b.)



a b

Fig. 1. Typical extrusion load - displacement curve, a. direct, b. indirect extrusion

The extrusion temperature was considered as constant and it was assumed to be the same as the initial temperature of the billet. This approximation can be applied because of the small sample mass as compared to the large mass of the equipment. The validity of this statement is supported by the constancy of the extrusion load showing the lack of deformational heating.
The flow stress, σ, during extrusion was determined from the steady state load, P according to the formula given by Sheppard and Raybould [13] :

$$\sigma = (P/A)(0.52 + 1.32\ln\lambda)^{-1}$$

where A and λ are the cross section of the extrudate and the extrusion ratio, respectively. The speed of extrusion was calculated by the Feltham formula [13]. To determine the stress-strain rate relationships tensile test was also performed using an Instron machine supplied by a resistance furnace. The constant cross head velocity caused a slight decrease of the speed of deformation during the test but it hardly exceeded the error of measurement. At temperatures lower than 350°C the steady state process, if it appears at all, was preceded by an intensive work hardening stage. In this case the maximum stress was considered to be the flow stress. Tensile test with 30 mm gauge length and 5 mm diameter was conducted on extruded rods after annealing at 400°C for 1 hour. After deformation the samples were air cooled. Samples for investigations were cut from the middle part of the extrudate length and cross section. Optical microscopy (OM), electron probe microanalysis (EPMA) and transmission electron microscopy (TEM) were applied. Samples cut perpendicularly to the axis of casting and extrusion. were investigated.

Results

The evolution of microstructure starting from the cast state can be seen in pictures of Fig. 2. taken by optical metallography. The cast billet contained twin boundaries and oriented intermetallic particles in high density (Fig. 2.a.). As a result of homogenization the structure of the ingot became fully recrystallized consisting of coarse polygonal grains and mostly oriented particles (Fig. 2.b.). In extruded state, depending on the temperature, the samples show deformed (Fig. 2.c.) or recrystallized structure because of the relatively slow cooling. The particles can well be seen in Figs 3.a, b, c representing EPMA pictures taken in cast, homogenized and extruded state, respectively.

The change of flow stress as a function deformation temperature at different forming rates can be seen in Fig 4. Above 400°C the stress values belonging to the same rate of deformation are situated along the same curve independently of the mode of deformation and of its degree. This finding shows that at high temperature the effect of friction and the change of flow stress with changing extrusion ratio can not be revealed. Below 300°C the friction can not be neglected in case of direct extrusion. The slight increase of strain rate arising from the higher degree of deformation has no measurable effect.

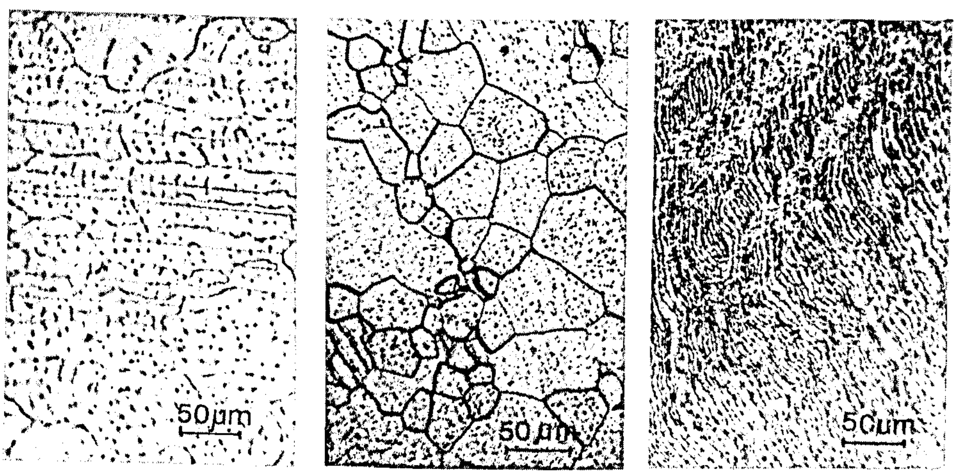


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Fig. 2. Optical micrograph of samples, a. cast, b. homogenized, c. direct extruded at 300°C, λ=21

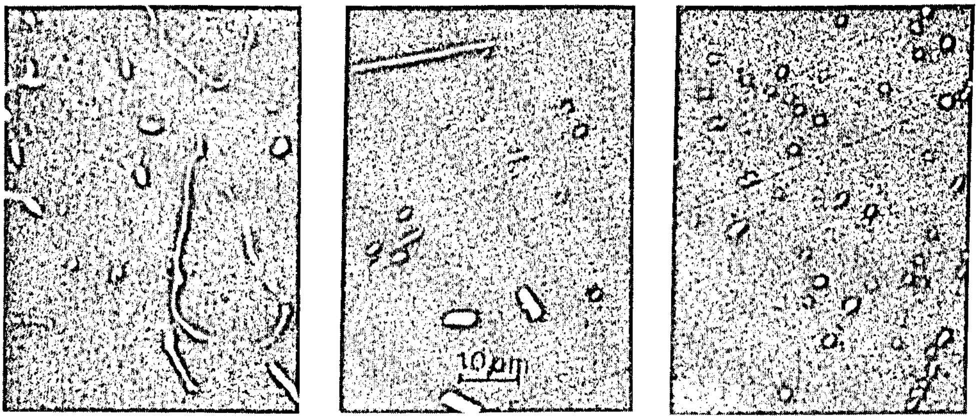

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Fig. 3. EPMA micrographs on the same samples as in Fig. 2.

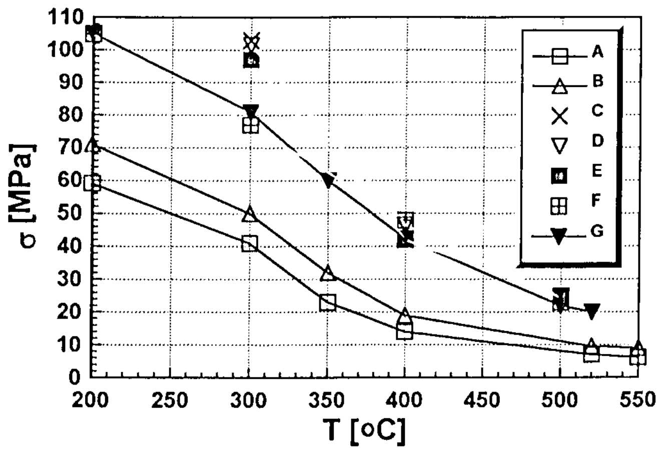

Table of denotations to Fig. 4.

Mark	Method	Rate (s^{-1})	λ
A	tensile test	0.001	
B	tensile test	0.01	
C	direct extrusion	1	7
D	direct extrusion	1	21
E	direct extrusion	1	110
F	indirect extrusion	1	12
G	indirect extrusion	1	32

Fig 4. Flow stress as a function temperature

Fig. 5. shows the lnσ-lnε̇ function obtained at different temperatures. It can be seen that a linear connection exists between these parameters. The measured values at lower strain rates were obtained by tensile test, while the stresses belonging to the maximum rate of strain were the average values obtained from extrusion experiments. It was found that above 350°C the slope of the straight lines is constant and its value is about 7 but it increases with decreasing temperature. The determination of the activation energy was carried out on the basis of Fig. 6.

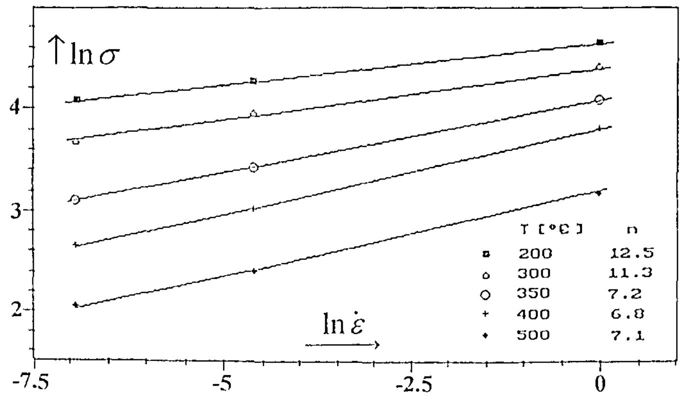

Fig. 5. Strain rate dependence of the flow stress

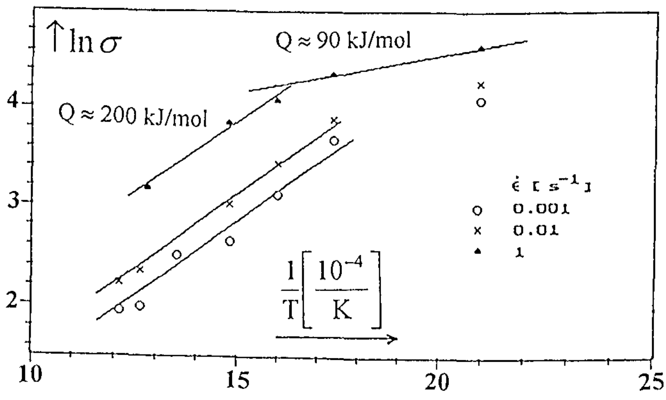

Fig 6. To the calculation of the activation energy

At temperatures higher than 350°C about 200 kJ/mol, while below 300°C a lower activation energy of about 9O kJ/mol was estimated on the base of tensile and indirect extrusion data. The microstructure of an extruded sample taken by TEM can be seen in Fig.7. [16],

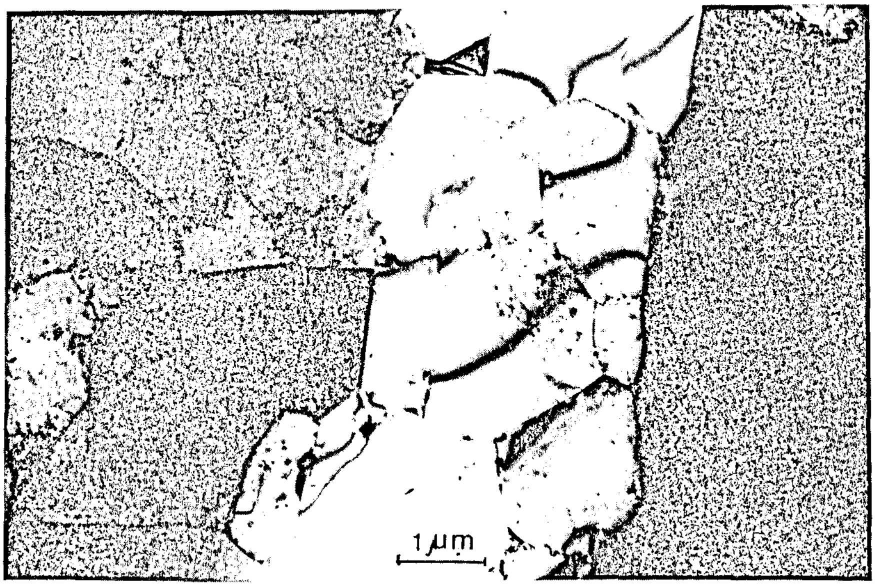

Fig. 7. Typical TEM micrograph taken after direct extrusion at 300 °C λ=21

Discussion

The results concerning the same flow stress determined from direct and indirect extrusion show that the friction can strongly be decreased above 400°C because of the proper lubrication between the die and container and the small length of billets. The fact that the flow stress at a given temperature proved to be the same independently of the reduction ratio, λ, shows further the lack of deformational heating. The results obtained at different temperatures are comparable with that of obtained by high temperature tensile test at lower strain rates. In addition, it was proved earlier that the tensile data do give the same results as the impression creep experiments performed at much lower strain rates [17]. This findings also support the conclusion that the deformation process produced by either creep or hot forming operation can be described by the same kinetics.

The relationship between stress and strain rate follows power law:

$$\dot{\varepsilon} = A.\sigma^{n}$$

where A depends on the temperature. The parameter, n differs in the high and the intermediate temperature range.

To explain the results the microstructure of samples can be considered. It was mentioned that the initial state of samples was a coarse recrystallized structure. During deformation subgrains are formed in the early stage of the process and their polygonal shape and size change hardly with increasing reduction. The size of subgrains was increased from 1 to 2 μm when the deformation temperature increased from 200 to 300°C. Another feature of structure was the appearance of deformation bands. Similar finding was obtained on AlMg alloys [15]. The bands are formed at low temperature and at small reduction ratio. Their narrowing with increasing deformation could be observed [16].

The high stress exponent may also be the consequence of the stable substructure. Namely, it was pointed out by Sherby et al. [10] that if the stress dependence of the subgrain diameter has been taken into account then a corrected stress exponent of about n=8 can be obtained. In our experiments the stress dependence of the subgrain size is less than in other cases therefore the situation approaches this "corrected" case. Concerning the high activation energy an analogy with the behaviour of composite materials can exist, although there are not sufficient data on the size and distribution of particles to calculate their effect.

Summary

It was stated that above 400 °C the flow stress was independent of the mode and degree of extrusion. The same power function describes the hot forming process in case of direct and indirect extrusion and tensile deformation. Above 350°C a stress exponent of n=7 was obtained. Below this temperature the stress exponent increased up to 12. The activation energy of the high temperature process was found to be 200 kJ/mol which is much higher than the lattice diffusion activation energy. The microstructure of samples before and after deformation contained many iron containing particles which can stabilize the subgrain structure formed in the initial state of forming. The high activation energy may also be connected with these particles because similar values were found in AlFe alloys [4, 5].

Acknowledgment

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References

1. H. Luthy, A. K. Miller and O. D. Sherby, Acta Metall. 28. (1980), 169.
2. F. R. Castro-Fernandez, C. M. Sellars and J. A. Witeman, Mat. Sci. and Techn. 6. (1990), 453
3. H. J. Mc Queen, E. Evangelista and M. E. Kassner, Z. Metallkde. 82. (1991), 336.
4. H. J. Mc Queen and P. Sakaris, The 3rd Intern. Conf. on Aluminium Alloys, eds. L. Arlberg, O. Lohne, E. Nes and N. Ryum, 1992. Vol. 1. p. 179.
5. Y. C. Yoo et al., Ibid p. 215.
6. M. V. Gurjar, G. S. Murty and G. S. Upadhyaya, J. Mater. Sci. 28. (1993), 5654.
7. J. Rösler and E. Arzt, Acta Metall. 38. (1989) 671.
8. M. S. Soliman, Scripta Metall. 29. (1993), 987.
9. P. Olla and P. F. Virdis, Metall. Trans. 18A. (1987) 293.
10. O. D. Sherby, R. H. Klundt and A. K. Miller, Metall. Trans. 8A (1977) 843.
11. J. J. Urcola and C. M. Sellars, Acta Metall. 35. (1987) 2637.

12. A. K. Mukhopadhyay, H. M. Flower and T. Sheppard, Mater. Sci. and Techn. 6. (1990), 461.
13. T. Sheppard and D. Raybould, J. Inst. Met. 101. (1973), 74.
14. T. Sheppard, Metals Techn. 1981. p. 130.
15.T. Sheppard, 8. Leichtmetalltagung, Leoben-Wien 1987, p. 301.
16. A. Cziráki and E. Kovács-Csetényi, Multinat. Conrress on Electron Microscopy, Parma, 1993. p.53.
17. E. Kovács-Csetényi, N. Q. Chinh, Proc. on Intern. Conf. on Plasticity and its Current Application, ed. A. S. Khan, 1994. In press.