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THE DEVELOPMENT OF 8090 AND 8091 ALLOY EXTRUSIONS

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ABSTRACT

This paper focuses attention on the manufacturing, mechanical properties, and microstructural aspects of 8090 and 8091 alloys in the extruded form. The paper draws upon the experience of commercially extruding the alloys at Alcan High Duty Extrusions and upon the results of extrusion trials carried out by Alcan International. These trials dealt with specific aspects of extrusions, in particular to show the interplay between the various process parameters involved in fabricating extruded product suitable for aerospace application. The paper will show how such factors as extrusion conditions (preheat temperature and extrusion speed, extrusion ratio, aspect ratio) and final thermomechanical treatments (stretching and ageing) influence the alloy's microstructure. The variation in mechanical properties, in particular strength and fracture toughness, will be discussed in terms of the microstructures observed. Emphasis is placed on examining the similarities and differences between the behaviour of thin (2 mm) and thick (25 mm) extrusions.

INTRODUCTION

The background to the development of the Al-Li-Cu-Mg-Zr alloys, designated 8090 and 8091 has been reported previously^(1,2) and initial data has been presented to show the properties which can be obtained^(1,2,3). This paper deals with the properties of extrusions. The extrusion of 8090 and 8091 alloys has been found to be readily achieved in commercial practice, except for rectification, where the high modulus can lead to difficulties in maintaining the high tolerances required for aerospace applications. The work reported herein concerns both the effect of extrusion conditions and post extrusion heat treatment on microstructure and mechanical properties.

Parson et al^(4,5) have shown that extrusion conditions affect the microstructure and properties of Al-Li-Cu-Mg alloys but have not studied the compositions developed by Alcan. Microstructural features of importance to both the strength and fracture toughness of these alloys which are determined by changes in the extrusion conditions are sub-grain structure and the degree of recrystallisation.

Extrusion trials were carried out under a wide range of processing conditions to produce material with variations in microstructure. The extrusion conditions were chosen to cover the range of variables encountered in commercial practice. The effect of these variables on microstructure and mechanical properties is detailed in this paper.

Data is also presented from commercially produced extrusions. Material from this source has been used to show how aspect ratio, section thickness, and post extrusion heat treatment influence mechanical properties. Particular attention is given to

the Final Thermo Mechanical Treatment (FTMT) and it will be shown how these factors (stretching and ageing conditions) can dramatically alter the balance of strength and toughness.

The billet employed was all machined from rectangular section slab cast in the Al-Li casting centre at Alcan Plate, Birmingham.

EXPERIMENTAL PROCEDURE

Extrusion trials were carried out on commercial extrusion presses. Two section sizes were used, namely 100 mm x 25 mm and 20 mm x 2 mm. For the larger section 8090 billets of 210 mm diameter were used (see Table 1 for composition). These billets were homogenised 24 h at 555°C before being preheated to the required extrusion temperature using a gas-fired oven. The container temperature was set at 380°C and a 90 mm long discard was used. Extrusion preheat temperature was varied from 355°C to 485°C and extrusion speed ranged from 1.6 m/min to 8.0 m/min. The extruded sections were solution treated for 1 hr at 525°C, cold water quenched, and stretched 2.5%. Extruding 100 mm x 25 mm flat bar from 210 mm diameter billet give an extrusion ratio of 14:1.

The smaller section, 20 mm x 2 mm, was extruded from 66 mm diameter billets (extrusion ratio 85:1). Both 8090 and 8091 billets were extruded (see Table 1 for compositions). The billets were induction preheated to the required temperature. The container temperature was set at 440°C and a 10 mm discard used. Extrusion preheat temperature was varied from 400°C to 500°C and extrusion speed ranged from 2 m/min to 20 m/min. The extrudate was solution treated for 15 mins at 540°C, cold water quenched and stretched 2%.

Selected extrusions were also examined which had been produced under commercial extrusion conditions in British Alcan. This particularly applies to the data on thick 8091.

Tensile and fracture toughness testing was carried out on the extruded sections. In the case of the 100 mm x 25 mm section fracture toughness was determined using compact tension specimens in accordance with ASTM E399 whereas for the 20 mm x 2 mm section Navy Tear tests were used. The extrudate microstructure was assessed using standard metallographic techniques.

RESULTS

Extrusion Conditions

Figure 1 shows the influence of extrusion conditions on the 0.2% proof stress of the 100 mm x 25 mm section after ageing 16 hrs at 190°C. The extrusion conditions are expressed as $\ln(Z)$ where Z is the temperature compensated strain rate defined as;

$$Z = e^* \text{Exp} (\Delta H/RT)$$

where e^* = mean equivalent strain rate
 ΔH = activation energy of deformation
 R = Universal Gas Constant
 T = Temperature of extrudate (°K)

The results in Figure 1 are from the $\frac{1}{2}$ width, $\frac{1}{2}$ thickness test position. The 0.2% P.S. increases linearly with $\ln(Z)$ exhibiting a range of about 30-40 MPa depending on test direction. This observation is in agreement with the work of Parson et al.⁽⁵⁾ and is attributed to increases in the material substructural strengthening component with increasing $\ln(Z)$. The extrusions all showed an essentially unrecrystallised grain structure, typical of that shown in Figure 5(a).

For the high (85:1) extrusion ratio 8090 20 mm x 2 mm section there is a smaller change in strength with extrusion conditions, as shown in Figure 2. This is because the extrusion is essentially recrystallised, as shown in Figure 3 and hence sub

structure cannot play a role in developing the material's strength. The 8091 alloy showed the same pattern of results but the range of strength with $\ln(Z)$ was nearly double (i.e. 20 MPa).

Figure 4 shows the effect of extrusion conditions on the fracture toughness of the 8090 100 mm x 25 mm section. For a wide range of preheat temperature and extrusion speeds the fracture toughness does not vary significantly with processing conditions. Only the sample extruded at high speed (5 m/min) from a high preheat temperature (485°C) showed a significant loss in toughness. This loss only occurred at the extrusion backend which would have experienced the highest temperature due to frictional heating effects. (It is of interest to note that this sample was at the limit of viable extrusion conditions since hot tearing occurred if the speed was further increased). Figure 5 shows the structure of this extrusion at the front and back ends. A significant degree of recrystallisation has occurred at the back end which probably explains the lower fracture toughness measured in this position.

Figure 6 shows the results of Navy Tear tests on the 20 mm x 2 mm section. Little or no change in fracture toughness is found with change in extrusion conditions. This is attributed to the fact that the section was fully recrystallised. The 8090 alloy exhibited higher toughness and less scatter than the 8091 material.

Commercial Extrusions

The typical longitudinal tensile properties of commercially extruded 8090 100 mm x 25 mm flat bar aged 16 h at 190°C are shown in Figure 7. The data is based on eight lots and 28 individual results for each position. The increase in strength from the front to the back is due to the change in $\ln(Z)$ during extrusion which results in an increase in substructure strengthening. The variation in properties across the width of the section is due to increased deformation in the outer regions of the extrudate which results in a highly textured more fibrous grain structure in the outer regions, as illustrated in Figure 8. The very fine substructure associated with the edge of the material can produce a large increase in tensile properties, sometimes as much as 100 MPa over adjacent regions. This is in contrast to alloys such as 2014 which exhibit a coarse recrystallised outer band of lower strength. A similar pattern of results is shown in Figure 9 for commercially extruded 8091.

Effect of Ageing

Fracture toughness in the T-L direction, as shown in Figures 7 and 9 is low in material aged 16 h at 190°C. Ageing at lower temperatures results in less grain boundary precipitation⁽⁶⁾, and this appears to offer the opportunity to use lower ageing temperatures (150°C or 170°C) to obtain an improved balance of tensile strength and fracture toughness in both 8090 and 8091 extruded sections. Figure 10 shows the effect of varying ageing temperature on the strength/toughness relationship for both 8090 and 8091 100 mm x 25 mm section bar. The use of such lower ageing temperatures not only gives the opportunity for high toughness and acceptable strength in high strength tempers but also to obtain a damage-tolerant temper. Figure 11 shows 8090 in a lightly aged temper in comparison to 2024 T3511 data from MIL-HANDBOOK V. In-plane toughness exceeds that obtained in 2024 at higher strength levels while through-thickness toughness is similar. Fatigue crack growth rate data on plate indicates⁽⁷⁾ that these lightly aged tempers do have a complete balance of damage tolerant characteristics.

Effect of Stretching

An alternative way to improve the overall balance of mechanical properties is to modify the degree of cold work prior to ageing. This aspect is covered in detail in other Alcan papers in this conference^(6,7). Figure 12 shows the effect on tensile strength of various levels of stretch. As found for plate, high levels of stretch increase tensile strength. By corollary with the data on plate it would be expected that fracture toughness was essentially constant for all the levels of stretch (at the same ageing conditions). However, it must be recognised that high

levels of stretch cannot be applied to all extrusions because it may lead to problems of tolerance control on complex sections.

Aspect Ratio

Figure 13 shows how aspect ratio affects the tensile properties of 8090. This property variation is attributed to the effect of texture and has been discussed in detail elsewhere⁽⁹⁾.

Section Thickness Effects

Figure 14 shows the effect of section thickness on the tensile properties of 8090 extruded sections over the thickness range 1.5 mm to 52 mm. Lower properties are found as section thickness decreases, which is attributed to an increase in recrystallisation (see section 1 of this paper). Static recrystallisation occurs in thin extruded sections and a coarse recrystallised outer band may form if inappropriate extrusion conditions are used. The degree of recrystallisation can be changed by altering both the heating rate to the solution heat treatment temperature and the time of the solution heat treatment, as found previously for sheet⁽¹⁰⁾.

DISCUSSION

The degree to which extrusion conditions affect the tensile properties of both 8090 and 8091 depends on whether or not recrystallisation occurs. In thicker sections (typically > 5 mm) recrystallisation is difficult to achieve either during extrusion or in post-extrusion heat treatment. Extrusion conditions can be changed to maximise tensile properties and fracture toughness by controlling substructure development, as is well recognised for other aluminium alloys. However, extrusion conditions must be carefully controlled to avoid recrystallisation which adversely affects fracture toughness. Thin sections, which by their very nature are extruded with high extrusion ratios, tend to recrystallise and this produces slightly lower tensile properties. This effect is well recognised and currently issued material specifications reflect this⁽¹¹⁾.

Commercial aluminium-lithium base alloys contain zirconium which results in the development of strong textures and this gives rise to a variation in tensile properties within a single extrusion. It is perhaps fortunate that the lowest strength position coincides with the usually specified test position⁽¹²⁾.

Fracture toughness in the T-L orientation has been shown to be low in 8090 and 8091 extrusions when aged for 16 h at 190°C. This can be dramatically improved by using lower ageing temperatures. This both takes advantage of the reduced grain boundary precipitation to improve toughness and gives more control over the degree of ageing allowing material to be aged to just below peak properties. The effect of such ageing treatments on the stress-corrosion resistance of these alloys is documented elsewhere⁽¹³⁾. The use of increased stretching, which is considered beneficial for plate⁽¹⁴⁾, may only be applicable to simple extrusion sections.

The range over which 8090 and 8091 can be extruded to give acceptable tensile properties and the scope for post extrusion heat treatment, which can be used to maximise the fracture characteristics, is now well understood. Both alloys can be produced to compete with conventional alloys both in high strength and damage tolerant tempers.

CONCLUSIONS

1. Changes in extrusion conditions have more effect on tensile properties if the substructure is retained.
2. Fracture toughness can be improved by reducing the time and temperature of ageing while still obtaining a satisfactory level of tensile strength. Compensating for reduced tensile properties by increased levels of stretch is unlikely to be beneficial for all sections.

3. Fracture toughness is reduced if recrystallisation is allowed to occur.
4. 8090 has great potential in the lightly aged condition as a damage tolerant material comparable with 2024 T3511.
5. Thick sections exhibit higher tensile properties than thin sections due to substructure strengthening and the effect of recrystallisation.

ACKNOWLEDGEMENTS

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TABLE 1

Chemical composition of the billets used in the Alcan International trials

| Section Size | Alloy | Composition | | | |
|----------------|-------|-------------|------|------|------|
| | | %Li | %Cu | %Mg | %Zr |
| 100 mm x 25 mm | 8090 | 2.55 | 1.12 | 0.78 | 0.11 |
| 20 mm x 2 mm | 8090 | 2.56 | 1.02 | 0.74 | 0.13 |
| 20 mm x 2 mm | 8091 | 2.50 | 1.64 | 0.75 | 0.14 |

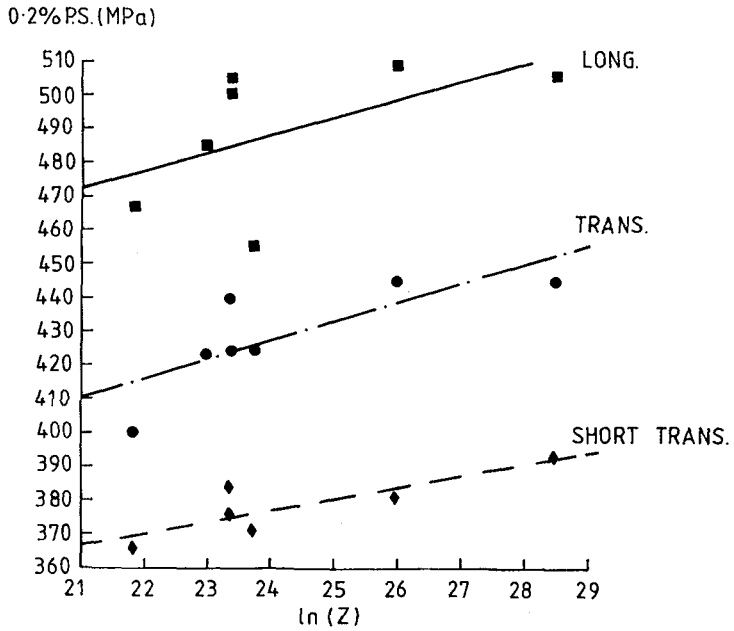


Figure 1 Influence of extrusion conditions on the back-end longitudinal 0.2% proof stress of 8090 100 mm x 25 mm flat bar, aged 16 h/190°C.

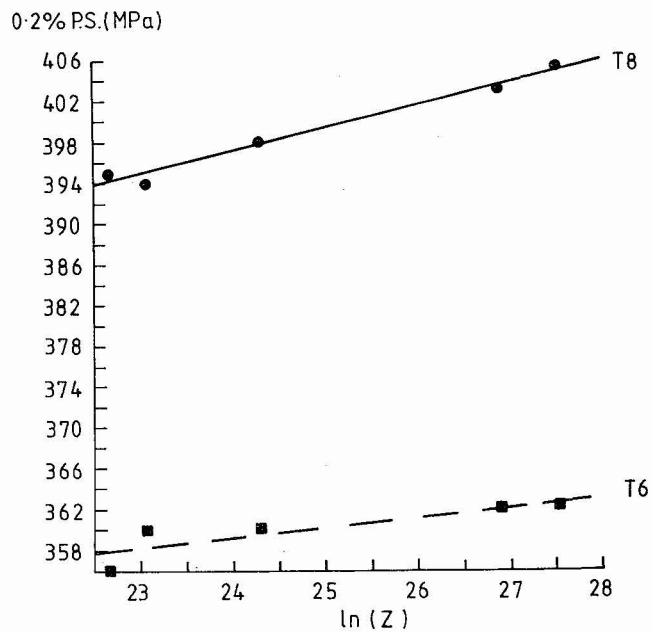


Figure 2 Influence of extrusion conditions on the longitudinal 0.2% proof stress of 8090 20 mm x 2 mm flat bar, aged 16 h/190°C.

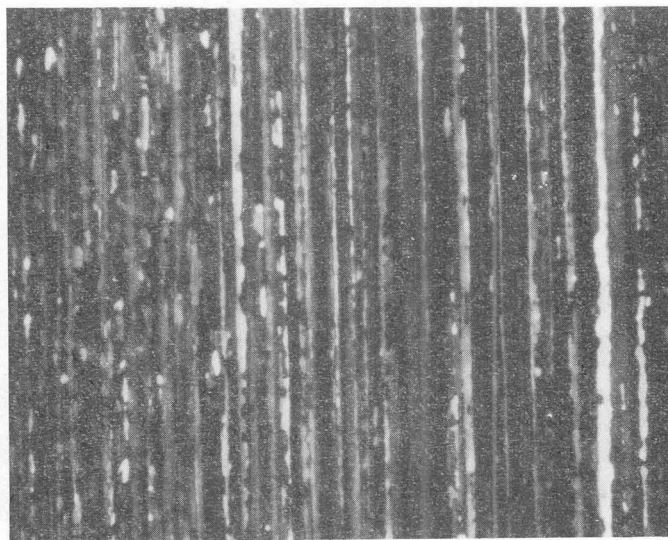


Figure 3 Grain structure of the 8090 20 mm x 2 mm flat bar.

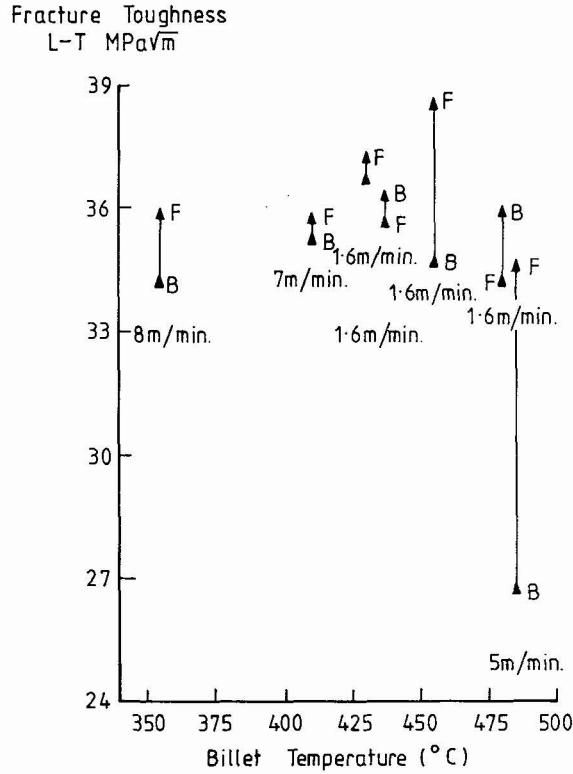


Figure 4 Effect of extrusion conditions on the fracture toughness of 8090 100 mm x 25 mm flat bar aged 16 h/190°C.

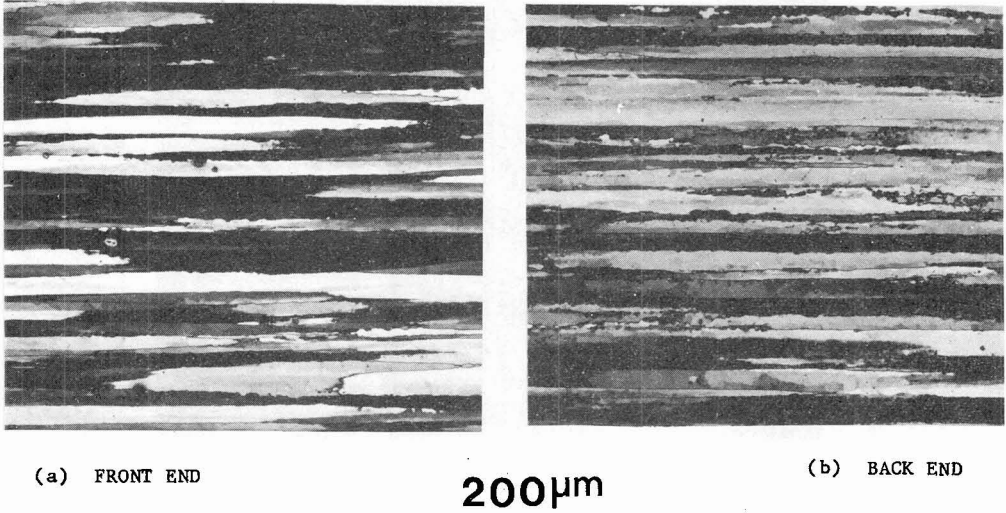


Figure 5 Grain structure of the 100 mm x 25 mm 8090 flat bar extruded at 5 m/min from a preheat temperature of 485°C.

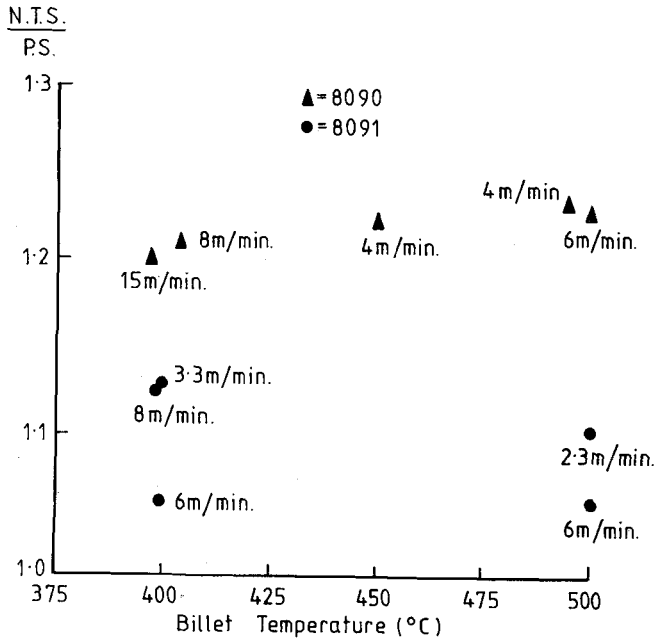


Figure 6 Navy tear test results obtained on the 8090 and 8091 20 mm x 2 mm section after ageing for 16 h/190°C.

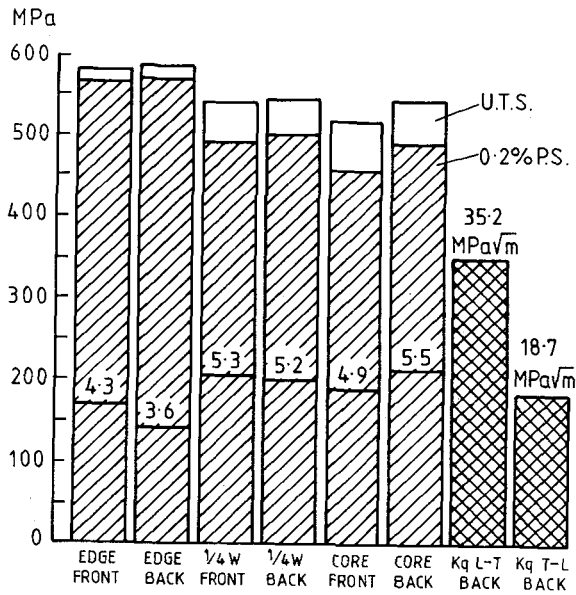
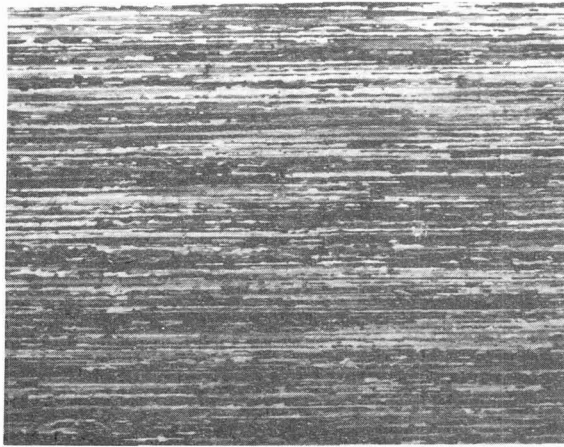
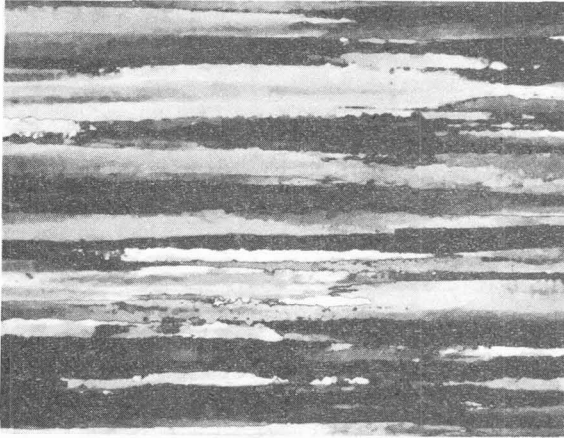


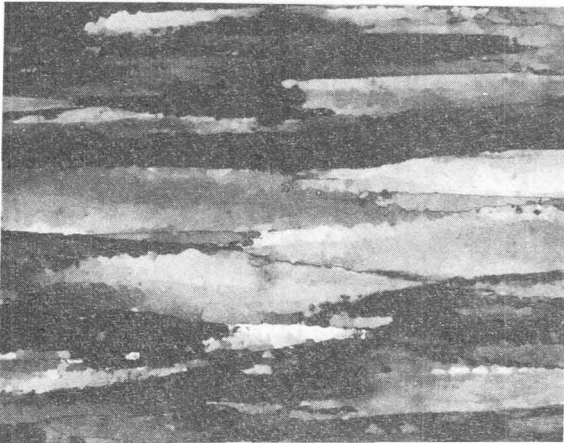
Figure 7 Typical longitudinal tensile properties of commercially produced 8090 100 mm x 25 mm flat bar aged 16 h/190°C.



EDGE



$\frac{1}{2}$ WIDTH



CORE

200 μ m

Figure 8 Variation in grain structure across a commercially extruded 100 mm x 25 mm flat bar.

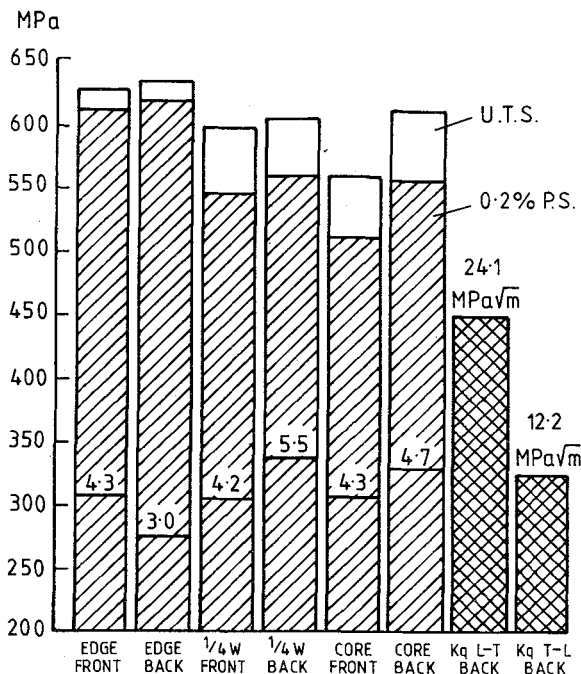


Figure 9 Longitudinal tensile properties of commercially extruded 8090 100 mm x 25 mm flat bar aged 16 h/190°C.

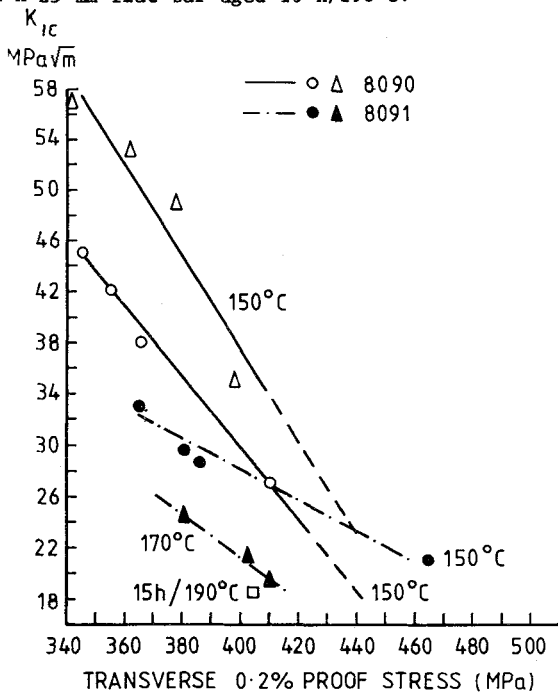


Figure 10 Effect of ageing at 150°C and 170°C on the 0.2% proof stress/T-L fracture toughness relationship for 8090 and 8091 100 mm x 25 mm flat bar.

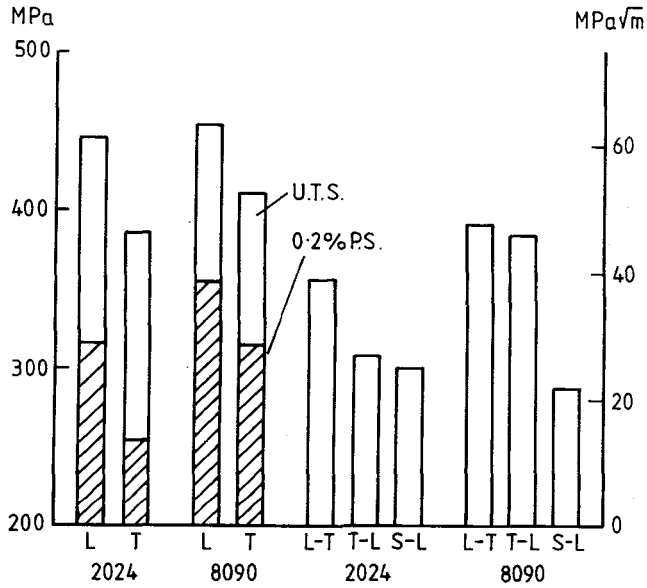


Figure 11 Comparison of lightly aged 8090 tensile and fracture toughness properties with 2024 T3511 data from MIL.HANDBOOK V in the thickness range 19-37 mm.

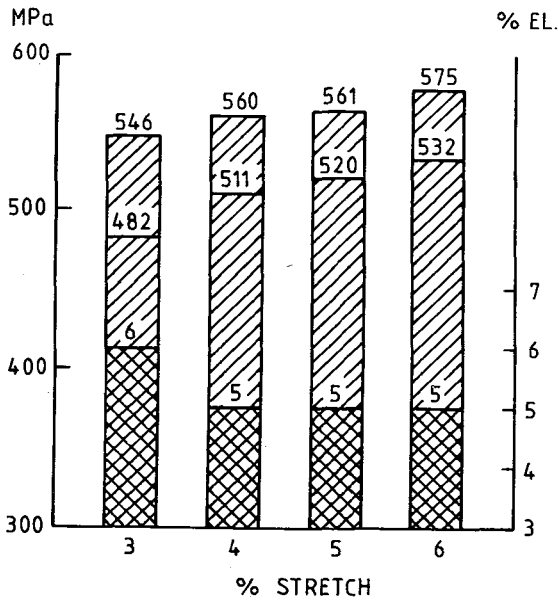


Figure 12 Shows the effect of stretching on the longitudinal tensile properties of 100 mm x 25 mm 8090 flat bar aged 16 h/190°C.

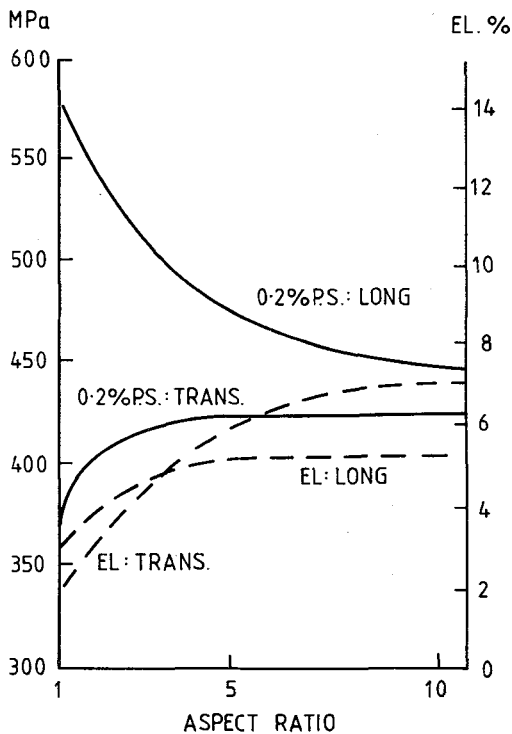


Figure 13 Effect of aspect ratio on 8090 peak aged tensile properties.

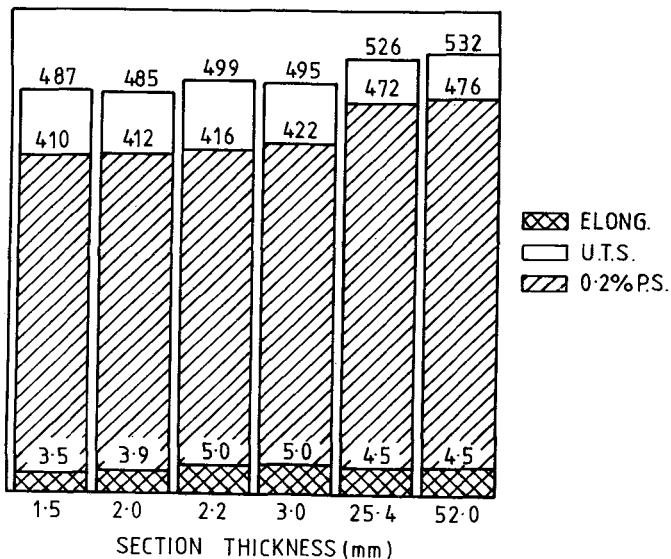


Figure 14 Effect of section thickness on tensile properties of 8090 T8511 extruded section.