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Dynamic Properties of Aluminium Alloys
Literature Review

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OFFICE OF RAIL REGULATION

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EXECUTIVE SUMMARY

Following the rail accident at Ladbroke Grove in 1999, concern has been expressed by HSE about the performance of the welded aluminium vehicles involved in this incident. In particular, weaknesses have been identified in the understanding of the behaviour of welded aluminium alloys under high strain rate impact loading.

A literature review has been carried out to evaluate the extent of available information on the behaviour of aluminium alloys and, particularly, aluminium alloy welds subjected to high strain rate or impact loading.

MAIN FINDINGS

Aluminium alloys are generally regarded as being insensitive to strain rate in the range of strain rates commonly encountered and, to date, mechanical properties determined from testing at quasi-static strain rates have been used in calculations of the crashworthiness performance of aluminium alloy structures.

At very high strain rates (greater than ~$10^3 s^{-1}$), significant strain rate sensitivity of mechanical properties has been reported although it is unlikely that strain rates of this level would be encountered in a typical crash situation.

Some variations have been observed in mechanical properties as a function of strain rate for several aluminium alloy systems at lower strain rates in the range $10^{-2} s^{-1}$-$10^2 s^{-1}$. These variations depend on alloy composition and temper.

Little systematic data was found on the performance of aluminium alloy welds under high strain rate loading. It is felt that the high strain rate behaviour of aluminium alloy welds will depend strongly on the individual alloy systems involved and on the strength mismatch between the weld and parent metal.

1 INTRODUCTION

Welded aluminium alloy structures are increasingly used in the construction of railway vehicles. In addition to the material requirements such as strength, stiffness and fatigue resistance expected in normal service, railway vehicles must be designed with sufficient crashworthiness to maximise passenger protection in the event of a collision. Modelling of the crashworthiness of modern railway vehicles is carried out based on the available mechanical properties of the materials used in the vehicle. To date, the mechanical properties of aluminium alloys used in this modelling have been based on results obtained from mechanical testing at quasi-static strain rates.

Following the accident at Ladbroke Grove in 1999, concern has been expressed by HSE about the performance of the welded aluminium vehicles involved in this incident. In particular, weaknesses have been identified in the understanding of the behaviour of welded aluminium alloys under high strain rate impact loading. Concern has also been expressed as to whether the crashworthiness modelling carried out on the new Class 390 “Pendolino” has taken sufficient account of possible strain rate effects in the aluminium alloys used in its construction.

A literature review has been carried out to determine the current level of knowledge concerning the properties of aluminium alloys and aluminium alloy welds under high strain rate loading. A further objective was to identify areas of future research which may be of benefit to the design of aluminium railway vehicles for improved crashworthiness.

An initial comprehensive search of the ‘Aluminium’, ‘Compendex’ and ‘Weldasearch’ databases identified approximately six hundred papers. These papers were reviewed on the basic of title and abstract and the full texts of the most promising papers were obtained. Review of these papers provided additional referenced links and a further set of papers were obtained. In total, approximately fifty papers were reviewed in detail.

2 SUMMARY OF DESIGNATION SYSTEMS OF ALUMINIUM ALLOYS

This section contains a brief summary of the Aluminium Association (AA) designation systems for identifying the composition and temper of wrought aluminium alloys. A four digit code identifies the alloy composition, with the first digit indicating the main alloying elements as follows:

- AA1xxx: Essentially pure Al with the remaining digits indicating impurity levels.
- AA2xxx: Al-Cu High strength heat-treatable alloys.
- AA3xxx: Al-Mn Low/medium strength alloys with good formability.
- AA4xxx: Al-Si Non heat-treatable alloys with a low melting point and good solidification characteristics.
- AA5xxx: Al-Mg Non heat-treatable alloys with medium/high strength, good weldability and good corrosion resistance.
- AA6xxx: Al-Mg-Si Heat-treatable alloys with medium/high strength, good formability (particularly in the O temper) and excellent extrusion characteristics.
- AA7xxx: Al-Zn-Mg (-Cu) High strength heat treatable alloys but with generally poor corrosion performance and weldability.
- AA8xxx: Other alloys including Al-Li and Al-Fe. Generally not very commonly used.

In the 2xxx – 8xxx alloys, the final two digits have no special significance other than to identify a specific alloy. Zero as the second digit indicates the original alloy, while numbers 1-9 as the second digit indicate modifications to the original alloy. Hence, alloy AA2219 is the 2nd recorded modification of alloy AA2019.

The four digit designation is followed by a letter indicating the basic temper condition and a series of numbers indicating subdivisions of the temper. Basic temper designations are:

- F: As-fabricated – alloy formed to required shape with no attempt to control the mechanical properties.
- W: Solution treated – applied only to 7xxx alloys.
- O: Annealed – wrought products heat treated to reduce the mechanical properties to their minimum levels.
- H: Strain hardened – products strengthened through deformation processing. The H is followed by two or more digits to indicate the exact condition.
- T: Thermally treated – products which have had their mechanical properties controlled by a heat treatment other than those covered by the above tempers. The T is followed by one or more digits to indicate the exact condition.

Within the context of this report, the following specific tempers are of interest:

- T3: Solution treated, cold worked and naturally aged (room temperature) to a stable condition.
- T4: Solution treated and naturally aged (room temperature) to a stable condition.
- T6: Solution heat treated and artificially aged.

3 HIGH STRAIN-RATE PROPERTIES OF ALUMINIUM ALLOYS

As may be expected, more data exists in the literature on the behaviour of un-welded aluminium alloys during high strain rate deformation than welded alloys. However, most studies have not investigated the effect of alloying elements, temper or microstructure in a systematic manner. This is compounded by the fact that flow stresses are reported variously as 0.2% proof stress, stress at 2% strain and stress at 5% strain, making comparisons between work by different authors difficult.

At quasi-static strain rates, aluminium alloys are generally regarded as strain rate insensitive and significant changes in mechanical properties have only been observed at strain rates in excess of $10^3 s^{-1}$. However, subtle differences have been reported in the behaviour of different alloy systems at lower strain rates.

3.1 MECHANICAL PROPERTIES OF 5XXX ALLOYS

Mukai *et al* (1995) investigated the tensile properties of a mechanically alloyed Al-Mg-Li alloy as a function of strain rate and compared the observed behaviour with that reported by several earlier authors. This behaviour is illustrated in Fig 1 in a graph reproduced from the paper by

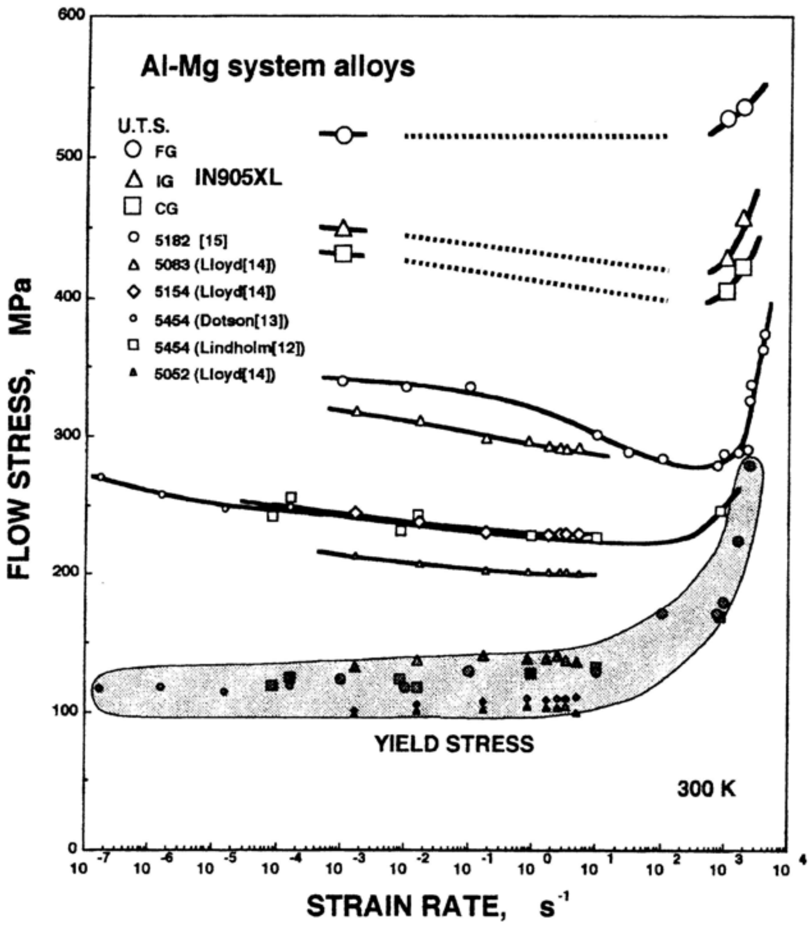

Figure 1: Summary of strain rate dependence of mechanical properties of AA5xxx series Al-Mg alloys. From Mukai *et al* (1995)

Mukai *et al* (1995). Fig 1 shows that little effect of strain rate on yield stress has been observed in 5xxx series alloys between quasi-static strain rates and a strain rate of ~$10^3 s^{-1}$, but a significant increase in strain rate sensitivity has been reported above $10^3 s^{-1}$. However, both Mukai *et al* (1995) and earlier authors (Lindholm *et al* (1971), Dotson (1974), Lloyd (1980) and Higashi *et al* (1991)) have reported a negative strain rate sensitivity of flow stress or UTS in the strain rate range $10^{-7} s^{-1} – 10^2 s^{-1}$. Similar effects have also been noted more recently by Masuda *et al* (2000) in alloys AA5052-H112, AA5083-H112 and AA5154-O. This decrease in flow stress/UTS combined with an unchanged yield stress is also evidence of a decreasing work hardening capacity as strain rate increases. In addition, Lloyd (1980) reported a significant positive strain rate sensitivity of elongation to failure. However, no increase was observed in the uniform elongation and the overall increase in ductility was attributed to more diffuse necking at high strain rates.

3.2 MECHANICAL PROPERTIES OF 6XXX ALLOYS

A significant amount of work has been carried out by various authors on the strain rate dependence of mechanical properties in 6xxx alloys, and particularly in AA6061 (Al-1%Mg-0.6%Si-Cu-Cr). The properties of AA6061-T6 have been investigated at a variety of strain rates, and using a variety of experimental techniques, by Carden *et al* (1980), Lee *et al* (2000), Masuda *et al* (2000), Morita *et al* (1998), Ogawa (2001) and Wada *et al* (1998). A sample of the data from the above studies is plotted in Figure 2. Similar trends were also reported in the

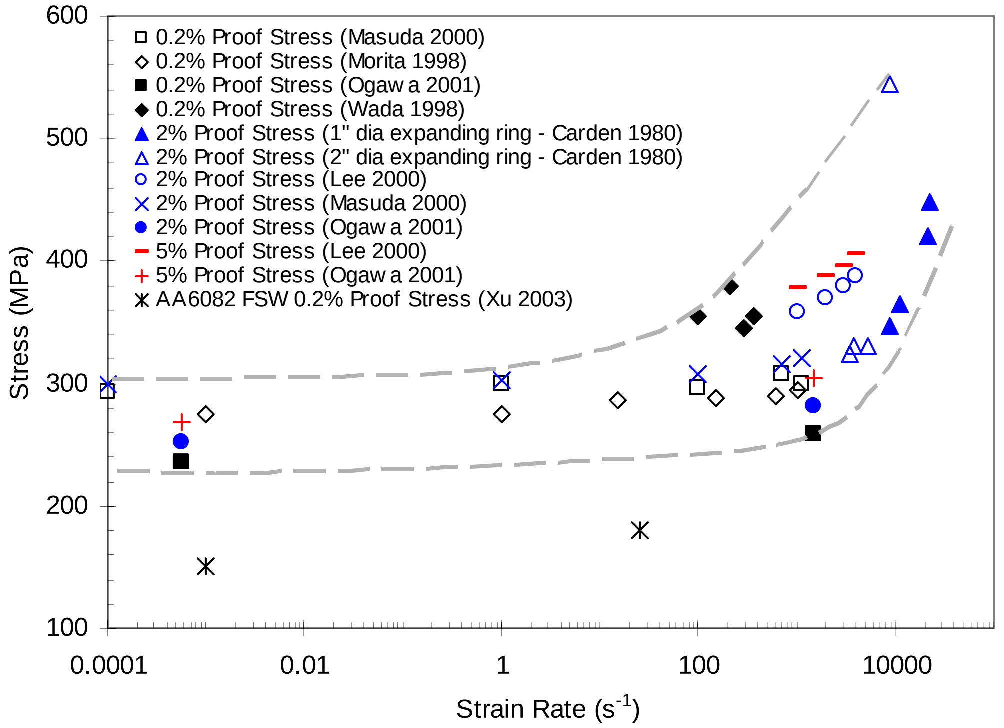

Figure 2: Flow stress properties of AA6061-T6 obtained by several authors as a function of strain rate. Also shown are the properties obtained by Xu and Gittos (2003) for alloy AA6082 after friction stir welding, showing an increased strain rate effect compared to the T6 treated alloys.

UTS values and the elongation to failure. Little significant strain rate sensitivity was observed at strain rates in the range $10^{-4} s^{-1} – 10^3 s^{-1}$, but a significant positive strain rate sensitivity of flow stress can be observed at strain rates in excess of $10^3 s^{-1}$. Therefore, the behaviour of alloy

AA6061-T6 at very high strain rates is similar to that reported for 5xxx alloys, but at lower strain rates no negative rate sensitivity of UTS is reported in AA6061-T6.

Ogawa (2001) also investigated the strain rate dependence of flow stress in AA6061-T6 as a function of temperature in the range 77K – 473K. A greater strain rate sensitivity, compared to that noted at ambient temperature, was observed at both elevated temperature and reduced temperature. These effects were also found to be a strong function of strain. Oosterkamp *et al* (2000) also reported an increased strain rate sensitivity at elevated temperature in alloy AA6082-T6 when tested at strain rates up to 3000s^{-1}.

Carden *et al* (1980) and Yokoyama (2003) compared the behaviour of alloy AA6061-T6 with the same alloy in the annealed O temper. Both authors reported an enhanced strain rate sensitivity in alloy AA6061-O, and this effect was more pronounced at the high strain rates (in excess of 3000s^{-1}) studied by Carden *et al* than at the lower rates (~1000s^{-1}) investigated by Yokoyama.

3.3 MECHANICAL PROPERTIES OF OTHER ALLOYS

Mausda *et al* (2000) published results of tensile tests at a variety of strain rates on ten different aluminium alloys. These included AA6061-T6, several 5xxx alloys, AA2024, AA7075 and an Al-Si alloy (~6.5%Si) designated as "AC4CH-T6" which is similar to a 4xxx alloy such as AA4008, used for filler wire in the welding of 6xxx series alloys. In all of these alloys, no significant strain rate effects were observed at strain rates lower then ~$10^3 s^{-1}$ other than a slight negative strain rate sensitivity of UTS in the 5xxx alloys, as mentioned above (§ 3.1). Similar results were also found by Wada *et al* (1998) in alloys AA2024-T6 and AA7075-T651, by Oosterkamp *et al* (2000) in alloy AA7108-T79 and Lee *et al* (2000a) in alloy 7075-T6

3.4 FRACTURE PROPERTIES

Tensile or compressive mechanical properties do not give the full picture when considering crashworthiness and the fracture initiation and propagation behaviours are also important. Little data was found in the literature on the effects of strain rate on the fracture toughness of aluminium alloys, and the data that has been found is somewhat inconclusive.

Yamamoto *et al* (2004) used a drop-weight arrangement to deform Charpy impact specimens of alloy AA6061-T651 at various loading rates. The absorbed energy was correlated with a quantification of the fracture surface appearance and variations in these properties as a function of loading rate were suggested. However, no evidence was provided that the variations lay outside of experimental variability, and judging from the data presented, no statistically significant variations in absorbed fracture energy were present. A similar experimental set-up was used by Tsukagoshi *et al* (1996) to investigate the static and dynamic fracture behaviour of alloy AA7075-T6. A 20% reduction in dynamic fracture toughness was reported with respect to the static fracture toughness, but, using the experimental procedure described, it is difficult to see how valid fracture toughness data was obtained and the results do not look particularly trustworthy.

Owen *et al* (1998) investigated the crack initiation and propagation behaviour in 2024-T3 thin sheet as a function of loading rate. The critical dynamic stress intensity factor and the dynamic crack propagation toughness were found to dramatically increase at high rates of loading and at high crack-tip speeds.

Itabashi and Fukuda (2001) investigated the tensile behaviour of 2219-T87 and 6061-T6 at strain rates of $10^{-3}s^{-1}$ and $10^{3}s^{-1}$ after degradation through pre-fatigue. A reduction in UTS was reported in the pre-fatigued AA2219 alloy at the higher strain rate, but this reduction was only to the same level as in the static tests. Data was not presented for the AA6061 alloy.

3.5 MECHANISMS

The strain rate sensitivity of aluminium alloys is controlled by various different mechanisms depending on the strain rate range and the alloy composition and temper. There is also some disagreement in the literature over the dominance of different mechanisms and the strain rate ranges over which they are valid.

Within the quasi-static to $10^{3}s^{-1}$ strain rate range, the flow stress of many aluminium alloys has been reported to be proportional to the logarithm of the strain rate. This suggests that the dominant mechanism in this regime is one of thermally activated dislocation flow where the dislocation motion is governed by an activation energy required for the dislocation to overcome a barrier. For relatively small barriers to dislocation motion, thermal vibrations in the lattice may be sufficient to allow dislocations to overcome barriers at lower stress levels than would be required at very low temperatures. In this regime, a reduction in the strain rate increases the probability of a dislocation overcoming a barrier purely due to thermal vibrations and, hence, a reduction in the flow stress occurs.

For thermally activated dislocation flow, the strain rate $\dot{\varepsilon}$ can be related to the flow stress σ_f and a stress-dependent activation energy $H(\sigma_f)$ by an equation of the form [Lindholm *et al* (1971)]

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp\left(-\frac{H(\sigma_f)}{kT}\right)$$

where

$$H(\sigma_f) = H_0 - \nu(\sigma_f - \sigma_i)$$

H_0 is the total activation energy, ν is the activation volume and σ_i is an athermal back-stress opposing dislocation motion. This means that the effective stress controlling the activation process is $(\sigma_f - \sigma_i)$.

Lindholm *et al* (1971) plotted a normalised rate sensitivity parameter, $[1/\sigma_0](\partial\sigma_f/\partial\log\dot{\varepsilon})$, as a function of a mean stress level σ_0 (taken as the yield stress at a strain rate of $1s^{-1}$) for a variety of aluminium alloys. This graph is reproduced in Figure 3 and shows a definite decrease in strain rate sensitivity with increasing alloy strength. However, the solid curve shown in Figure 3 is proportional to $[1/\sigma_0]$ and hence represents a constant value of $(\partial\sigma_f/\partial\log\dot{\varepsilon})$. It was suggested that, as the experimental data lies close to this line, strengthening due to alloying additions results only in an increase in the athermal back-stress σ_i without any change in the rate-controlling mechanisms or the basic activation parameters.

On the basis of Figure 3, the concept of thermally activated flow appears to describe the strain rate behaviour of aluminium alloys reasonably well. However, there is significant scatter around the line of constant $\left(\partial \sigma_f / \partial \log \dot{\varepsilon}\right)$ in Figure 3, suggesting other mechanisms may also be operating.

Lindholm *et al* (1971), Dotson (1974) and Lloyd (1980) suggest that the negative strain rate sensitivity of flow stress in Al-Mg alloys is due to reduced solute-dislocation interaction at high strain rates and an inhibition of the Portevin-Le Chatelier effect of periodic locking-unlocking of mobile dislocations by diffusing solute atoms. This behaviour is, however, specific to Al-Mg alloys at certain strain rates where the velocity of gliding dislocations is very similar to the velocity of diffusion of Mg solute atoms.

Mukai *et al* (1995) suggested that thermal softening due to adiabatic temperature increases at high strain rates may be responsible for the negative strain rate sensitivity observed in Al-Mg alloys, but, although this may have a small influence on flow stress, it is difficult to see how this would only affect Al-Mg alloys. However, Lindholm (1974) and Lee *et al* (2000a) both reported microstructural evidence of adiabatic shear bands formed by temperature rises due to strain localisation in high strain rate torsion and compression tests, respectively. Lindholm (1974) reported that the formation of these shear bands accompanied a significant reduction in elongation to failure, but had little effect on the flow stress or UTS.

At very high strain rates ($>10^3 s^{-1}$) a significant increase in strain rate sensitivity has been observed in many alloy systems where the flow stress becomes proportional to the strain rate (as opposed to log strain rate). This effect is generally attributed to viscous drag acting on fast moving dislocations.

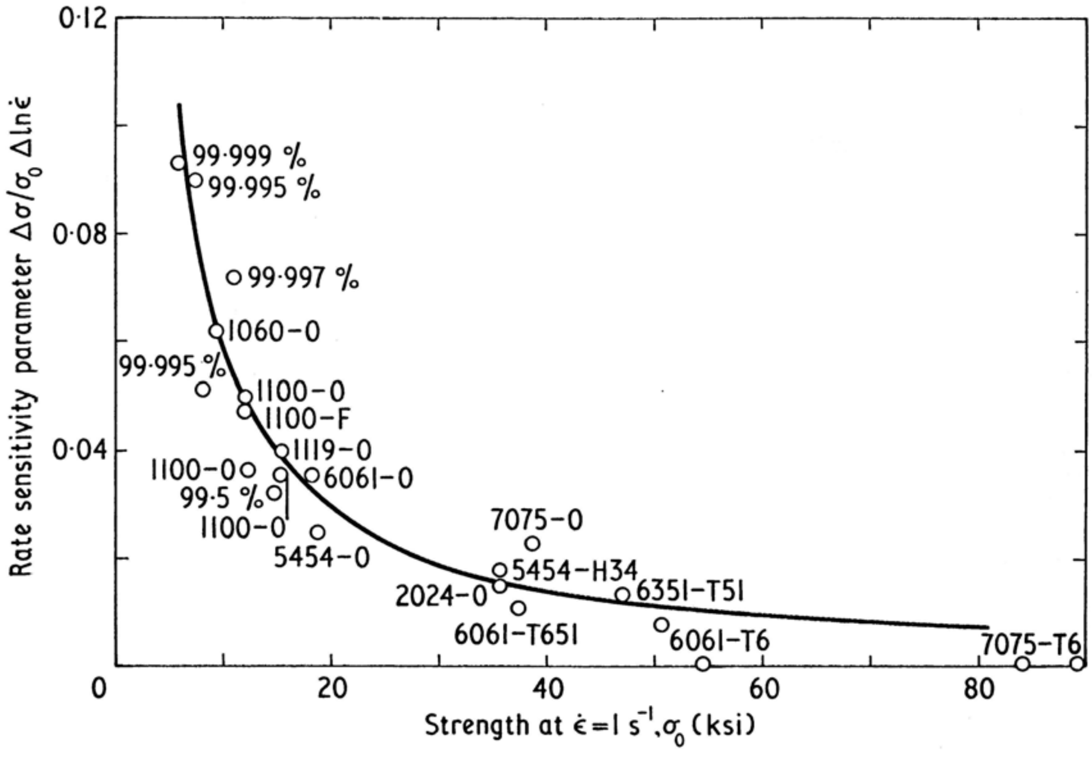

Figure 3: Variation in rate sensitivity parameter as a function of alloy strength. From Lindholm (1974).

4 HIGH STRAIN-RATE PROPERTIES OF WELDED ALUMINIUM ALLOYS

Little research has been carried out into the behaviour of welded aluminium alloys under high strain rate loading. Given the variety of alloys, welding processes and heat treatments available, it is difficult to draw firm conclusions from the available literature.

Huss *et al* (1996) investigated the behaviour of aluminium butt welds with a view to improving the design of crumple zones in rail carriages. Samples of annealed AA5754 H111 (approx Al-3%Mg) were tested under static and dynamic (strain rates of $170s^{-1}$ and $330s^{-1}$) conditions, along with identical samples containing a butt weld. AA5356 (approx Al-5%Mg) was used as the filler material, giving a weld strength greater than that of the parent material. Under both static and dynamic tensile loading, rupture occurred in the parent material with little change in yield stress or UTS as a function of strain rate. A reduction in elongation was observed in the welded sample (due to the extensometer encompassing both weld and parent metal – this change will depend on weld width and extensometer gauge length), and in both cases elongation increased with increasing strain rate. Dynamic compression tests were also performed on parent plate and weld metal samples in the strain rate range $850s^{-1}$ to $2700s^{-1}$. A significant positive strain rate sensitivity of flow stress was observed in this range.

Xu and Gittos (2003) carried out a variety of tests on alloy AA6082-T6 parent metal, and after either friction stir welding or MIG welding using AA4043 (Al-5%Si) filler wire. In both welding conditions, the strength of the weld significantly undermatched the strength of the parent plate. For the friction stir welded samples, tensile tests were carried out at quasi-static and dynamic (of the order of $10s^{-1}$) strain rates. At the higher strain rate, the 0.2% proof stress was ~180MPa, compared to ~150MPa for the quasi-static tests. These points are compared to the properties of AA6061-T6 on Fig 2 and show a slightly greater strain rate sensitivity than reported for AA6061-T6. This is consistent with the results of Yokoyama (2003) (see below) and also the observations of Lindholm (1971 and 1974) suggesting that the strain rate sensitivity of an alloy decreases as the strength increases. The MIG welded samples investigated by Xu and Gittos (2003) were only deformed at quasi-static strain rates, although they expected to investigate the effects of strain rate and welding parameters on these samples at a later date.

Labur and Ishchenko (1991) carried out work on the failure resistance of three Russian alloys; AMg6 NPP (uncertain composition, but probably a 5xxx alloy with ~6%Mg), 1201 (an Al-Li alloy of uncertain composition) and 1420 (Al-5.5%Mg-2.25%Li-0.12%Zr – no real equivalent in the Aluminium Association designation system). No information was given as to the temper or thermomechanical processing history of the alloys. Notched, pre-cracked, flat specimens were deformed under three-point bending and offset tensile loading at a variety of loading rates and with the pre-crack in the parent, HAZ and weld. In the alloys used, the fracture resistance of the welded joints was greater than that of the parent metal and this was attributed to "structural changes during the thermal welding cycle". This suggests that the parent metal is not in the fully annealed state. Increasing the loading rate from 2mm/min to 360mm/min was found to reduce the fracture resistance by 1.5-2 times, with the greatest reduction observed in the fusion zone.

Chao *et al* (2001) carried out compression tests at a variety of strain rates on the parent metal and weld zone of friction stir welded AA2024-T3 and AA7075-T7351. The 0.2% proof stress values obtained from the parent and weld metal regions are plotted in Figure 4 as a function of strain rate. Also shown in Figure 4 is the dynamic compression data obtained by Huss *et al*

(1996) for alloy AA5754. The limited data published by Chao *et al* (2001) shows a decrease in proof stress due to the welding process, but also suggests a reduction in strain rate sensitivity of the AA7075 weld metal compared to the parent. There is insufficient data to evaluate whether this result is statistically significant, but it illustrates that welding may have an effect on the strain rate sensitivity.

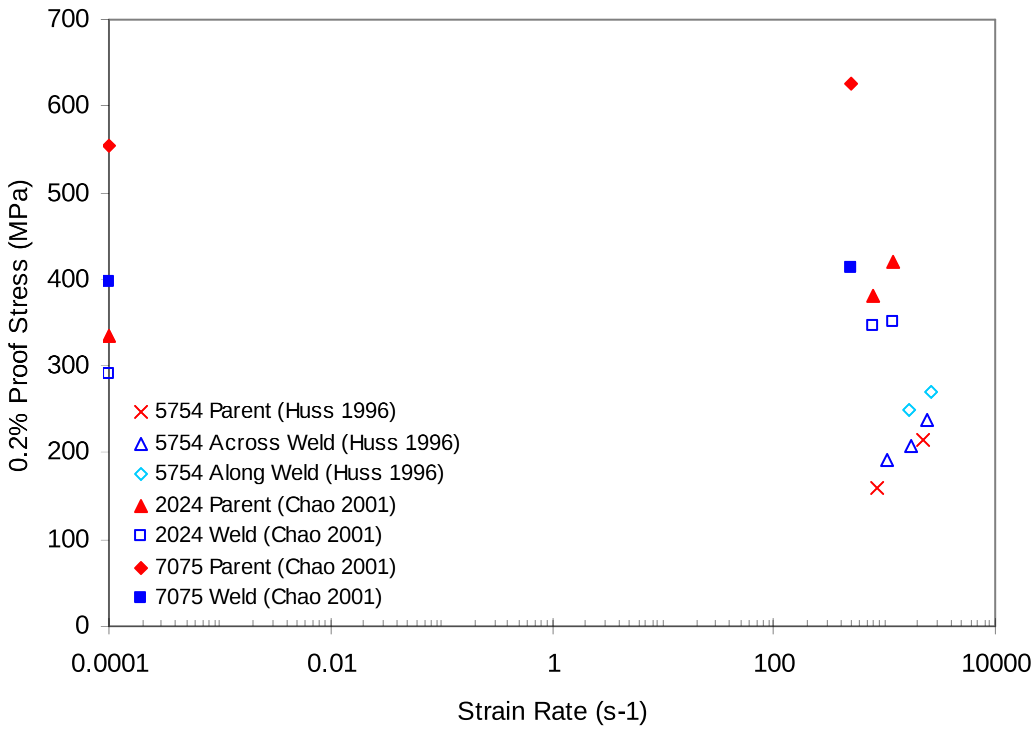

Figure 4: 0.2% Proof stress data for aluminium alloy welds and parent materials as a function of strain rate.

More unusual welding processes were investigated by Debbouz and Navai (1997), Chen and Huang (1999) and Yokoyama (2003). Debbouz and Navai (1997) investigated the tensile behaviour of diffusion w elded joints in 2017-T4 at a strain rate of ~$10^3 s^{-1}$. With optimisation of the welding parameters, weld strengths approaching that of the base metal (after similar thermal processing) were achieved. However, tensile elongation and failure energy of the welded joint remained poor, and this was exacerbated by high strain rate loading. The performance of electron beam welded 8090 plates of various thickness, and with various welding parameters, was studied by Chen and Huang (1999). Samples were tested in Charpy impact tests and under low and high strain rate bending. Irrespective of welding parameters, significant reductions in the flexural strength and absorbed fracture energy were observed in the welded samples compared to the base metal. This was the case both in the as-welded condition and following a post-weld T6 heat treatment. Yokoyama (2003) reported on the properties of a weld between dissimilar metals under impact loading. Friction welds between 6061-T6 and a stainless steel were loaded at strain rates ranging from quasi-static to ~$800 s^{-1}$. Fracture occurred either in a brittle manner at the weld interface, or in a more ductile manner in the thermally softened HAZ region of the Al alloy. Performance was found to depend on the welding parameters as well as loading rate. With increased loading rate, an increase in tensile strength of the joint was observed and this was attributed to a greater strain rate sensitivity of the 6061 after thermal softening in the welding cycle compared to the original T6 temper.

5 HIGH STRAIN-RATE PROPERTIES OF ALUMINIUM ALLOY STRUCTURES

A number of papers were found dealing with the deformation behaviour of aluminium structures, particularly thin-walled tubes, subjected to dynamic loading. A paper by Barbat *et al* (1997) described the crashworthiness design approach adopted by Ford in its "Aluminum Intensive Vehicle" (AIV). In addition to conventional mechanical property assessments, static and dynamic axial crush tests were carried out on resistance spot welded "hat-section" columns of a 5xxx series alloy. The energy absorption in the dynamic tests was found to be 10%-30% greater than that in the static tests. This "dynamic factor" increased to 64% when the entire AIV sub-system was tested. However, in the design process of the AIV structure, the effect of strain rate on the mechanical properties of the aluminium alloys used was judged to be insignificant. Hence, strain rate effects were not accounted for and no testing was conducted.

The dynamic and static axial crush behaviour of thin-walled aluminium alloy tubes was investigated by Langseth *et al* (1999), while the quasi-static deformation of thin-walled aluminium tubes containing circular crush initiators was studied by Arnold and Altenhof (2004). Langseth *et al* (1999) studied alloy AA6060 in the T4 and T6 tempers and Arnold and Altenhof (2004) studied alloy AA6061, also in the T4 and T6 tempers. The buckling behaviour was also modelled by Langseth *et al* (1999) and good agreement was found between the model and the experimental results. In this model, alloy AA6060 was regarded to be effectively strain rate insensitive in the strain rate range $10^{-4}s^{-1}$-$10^{3}s^{-1}$ and static mechanical properties were deemed to be sufficient as model input parameters.

In addition to the work on the dynamic properties of welded AA5754-H111 (detailed in §4), Huss *et al* (1996) also performed axial dynamic crush tests on square section tubes of the same alloy with rounded corners and longitudinal welds present on the side walls. The performance of the tubes during these tests was described as good, with no cracking observed in either the base metal or weld. However, in these tests, the weld strength significantly overmatched that of the base material and different results may be obtained using undermatched welds.

6 CONCLUSIONS

A number of research papers have been found concerning the effect of strain rate on the mechanical properties of aluminium alloys. However, few studies deal systematically with the effects of alloy composition, temper or microstructure on the observed mechanical behaviour. Very little work appears to have been published on the strain rate sensitivity of welded aluminium alloy joints, and what work there is generally does not include a systematic study of the many variables involved in welding aluminium alloys. Still less work has been published on the dynamic fracture properties of aluminium alloy welds.

1. Aluminium alloys are generally regarded as being insensitive to strain rate in the range of strain rates commonly encountered ($10^{-3}s^{-1}$–$10^{2}s^{-1}$) and, to date, mechanical properties determined from testing at quasi-static strain rates have been used in calculations of the crashworthiness performance of aluminium alloy structures.

2. At very high strain rates (greater than ~$10^{3}s^{-1}$), significant strain rate sensitivity of mechanical properties has been reported (proportional to strain rate). Although it is unlikely that macroscopic strain rates of this level would be encountered in a typical crash situation, it is possible that strain localisation, for example in undermatched-strength welds, may result in locally very high strain rates.

3. Some variations have been observed in mechanical properties as a function of strain rate for several aluminium alloy systems at lower strain rates in the range $10^{-2}s^{-1}$-$10^{2}s^{-1}$. These variations depend on alloy composition and temper.

4. Little systematic data was found on the performance of aluminium alloy welds under high strain rate loading. It is felt that the high strain rate behaviour of aluminium alloy welds will depend strongly on the individual alloy systems involved and on any strength mismatch between the weld and parent metal.

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