

Design Procedures for Multiaxial Stressing of Particulate MMC

Summary

This Measurement Note is concerned with the procedure required to incorporate multiaxial stress state situations into design calculations for the use of particulate metal matrix composites (MMC). The approach taken is to determine the stress state law most applicable to the material in question through analysis of data obtained by tensile straining of notched test bars.

It has been found that for designs based upon yield criteria a Von Mises effective stress criterion is applicable to both monolithic and particulate reinforced aluminium alloys. However, if fracture is the design criterion the monolithic alloy maintains Von Mises behaviour while the MMC becomes susceptible to maximum principal stress considerations.

Background

Many of the test data generated in the laboratory refer to simple loading conditions: either uniaxial tension, compression or flexure. In practice, components are subjected to complex, often triaxial, stress states and designers require procedures that enable them to deal with the stress distributions encountered.

Various laws have been formulated to characterise multiaxial stress state behaviour in engineering alloys. The most common approaches are based upon:

- maximum principal stress
- maximum principal strain
- Von Mises equivalent stress
- Tresca
- principal grain boundary facet stress (creep situations only).

Each of these methods has applicability for certain materials but there is no simple predictive tool that allows the designer to decide *a priori* which approach to use for his particular material and application.

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Nomenclature

- a radius of testpiece at notch plane
- b radius of parallel portion of testpiece
- R notch root radius
- σ_e Von Mises effective stress
- σ mean (hydrostatic) stress
- σ_{net} net section stress

σ_1 maximum principal stress

Notched Bar Testing

Notched bar testing provides, in principle, a relatively simple method of controlling the stress state in a testpiece by selection of an appropriate notch geometry. In addition the test can be performed in a normal uniaxial tensile machine thereby restricting testing costs.

During the test the non-uniform stress distribution across the notch throat evolves until a characteristic state is reached. The initial and final stress distributions are sensitive to the specific properties of the test material and a detailed knowledge of the stress distribution at any specific time or strain requires complex numerical analysis. Fortunately, a simplified analysis is available; examination of many computed solutions have shown the existence of a point (or more precisely a small volume) close to the notch root, where the triaxial stress state remains approximately constant with strain increment and is independent of the elastic, plastic and creep properties of the test material. Analysis of the behaviour of this point allows the response of materials to triaxial stress states to be evaluated without the need for extensive computations.

Several notch geometries have been examined and the ratio of maximum principal stress, the Von Mises equivalent stress and the hydrostatic stress to the net section stress have been calculated for the skeletal point (see [Table 1](#)). Analysis of notched bar test data using this approach gives a simple measure of which multiaxial stress criterion is applicable to the material under investigation.

Table 1 Stress analysis for the skeletal point for various geometries

Notch acuity ratio a/R	σ_1/σ_{net} (Principal)	σ_e/σ_{net} (Von Mises)	σ^*/σ_{net} (Hydrostatic)
0.5	1.01	0.87	0.41
1.0	1.02	0.79	0.47
1.5	1.03	0.73	0.51
2.41	1.04	0.68	0.55
5.0	1.06	0.64	0.65
10.0	1.09	0.61	0.75
17.5	1.10	0.60	0.84
25.0	1.11	0.60	0.87

Results

Tests with several notch geometries have been performed on BP217 material (2124 Al matrix, 17% SiC particles) where testpieces have been machined from 14 mm thick plate. The testpieces were taken from the same orientation within the plate and machined such that the centre of the testpiece coincided with the middle of the plate thickness. The results are summarised in Table 2.

Table 2 Summary of notch tensile data, based on net section stresses, for HP material (data are mean of four tests)

Notch Acuity a/R	0.2% Proof Stress, MPa	Ultimate Tensile Stress, MPa	Reduction in Area, %
Plain	446.3	597.0	7.5
0.5	571.9	730.2	8.1
1.5	651.2	714.8	4.2
2.4	698.0	704.2	3.1
5.0	590.2	662.0	2

The data are presented in [Figure 1](#) after normalisation with respect to the values for plain bars. It can be seen that

the 0.2% proof stress values are consistent with Von Mises equivalent stress behaviour, whereas the ultimate tensile stress values show a trend similar to that expected from maximum principal stress controlled behaviour, although the absolute values are higher than expected. This behaviour has been observed in many other materials, particularly where failure is controlled by cavitation.

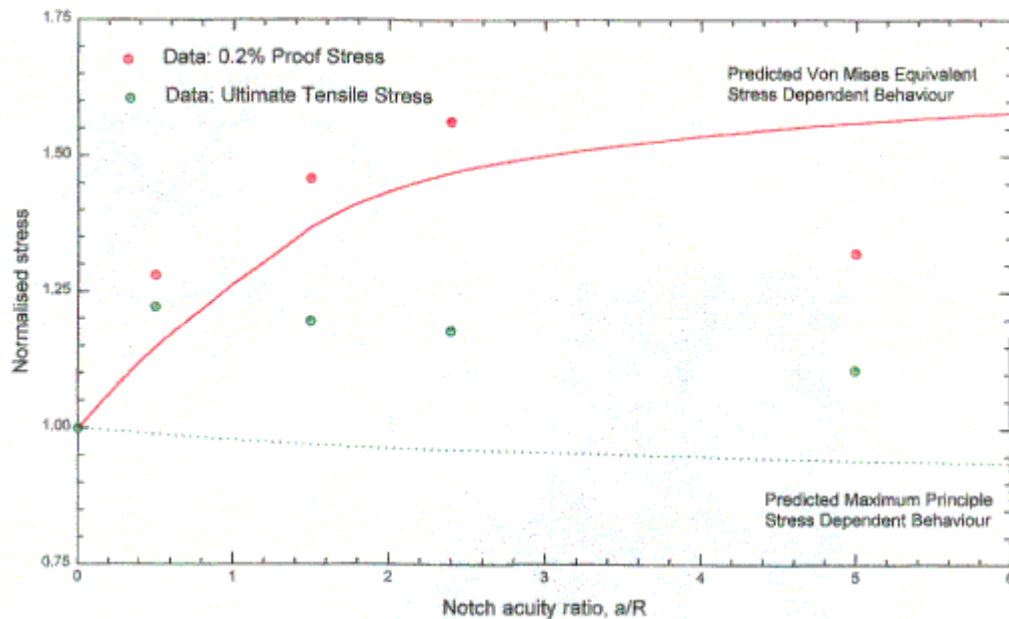


Figure 1 Comparison of notched tensile data with predictions using skeletal stress concept

Failure ductility, as measured by reduction in area, decreases significantly as the notch acuity rises. The main reason for this behaviour is probably a transition from generalised damage to a single crack as the final failure mechanism, although more work will be required to confirm this hypothesis.

Comparison With Monolithic Al Alloys

Previously published work [2] on the notched-bar tensile behaviour of monolithic Al alloys is reanalysed using the skeletal stress approach in Figure 2 where it can be seen that both the 0.2% proof stress and the ultimate tensile stress show good correlation with Von Mises behaviour.

The most probable reason for the difference in behaviour between the monolithic alloy and the MMC is the failure initiation site. In the monolithic alloy failure is associated with ductile tearing within the grains, whereas in the MMC failure is initiated at the interface between the strengthening carbides and the matrix.

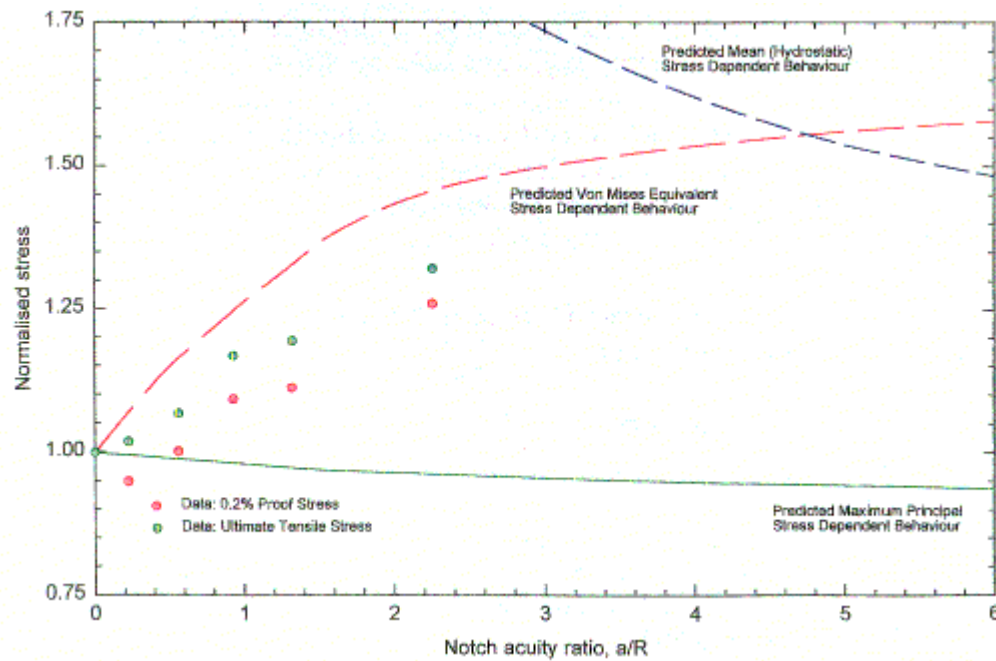


Figure 2 Comparison of notched tensile data with multiaxial stress-state laws for a monolithic 7075 aluminium alloy

This latter observation is confirmed by [Figure 3](#), which shows damage at a carbide/matrix interface in the region within the throat of the notch, close to the final fracture path. This result is consistent with the observations of Derby who observed similar features after uniaxial straining of an Al-6061 alloy strengthened with SiC particles.

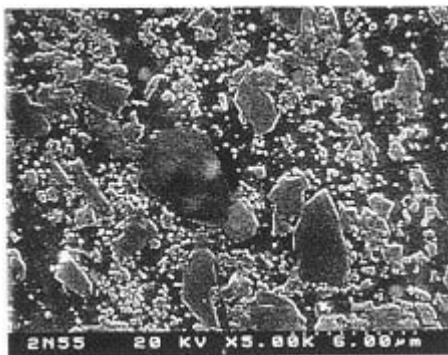


Figure 3 Failure initiation at carbide/matrix interface for specimen with notch acuity ratio, $a/R = 2.4$

Acknowledgements

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References

1. G A Webster, B J Cane, B F Dyson and M S Loveday. A Code of Practice for Notched Bar Creep Rupture Testing: Procedures and Interpretation of Data for Design in 'Harmonisation of Testing Practice for High Temperature Materials' eds M S Loveday and T B Gibbons, Elsevier Applied Science, London, 1992, 295-330.
2. C P You, A w Thompson and I M Bernstein. Ductile Fracture Processes in 7075 Aluminium, Metallurgical and Materials Transactions, 1995, vol 26A, pp 407-415.
3. B Derby. Microstructure and Fracture Behaviour of Particle- Reinforced Metal-Matrix Composites. Journal of Microscopy, 1994, vo1177, pp 357-368.

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