NPL Report DMM(A)100

National Physical Laboratory

Particulate Metal Matrix Composites - Draft Procedure for Tensile Tests at Ambient Temperature

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The National Physical Laboratory is an Executive Agency of the Department of Trade and Industry

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ABSTRACT

This report outlines a draft procedure for the tensile testing of particulate reinforced metal matrix composites at ambient temperatures. It recommends appropriate rectangular cross-section testpiece dimensions, testing rates and methods of gripping and strain measurement. The report defines the method of measurement of Young's modulus, proportional limit, proof stress, tensile strength and elongation to failure. It also contains a recommended proforma for the test report.

ISSN 0959 2423

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1. INTRODUCTION

This document specifies a draft procedure for the tensile testing of particulate metal matrix composites (MMC) and defines the mechanical properties which can be determined at ambient temperature. It follows the European standard EN 10002 Part 1 for tensile testing of metals and its sister document for Aerospace materials EN 2002-1 Part 1. [refs 1 and 2]

2. PRINCIPLE

The test involves straining a **rectangular** cross-section testpiece by a tensile force, generally to fracture, for the purpose of determining one or more of the mechanical properties defined in section 3.

The test is carried out at ambient temperature between 10°C and 35°C, unless otherwise specified.

A double averaging strain measurement system is recommended for improved accuracy, particularly of modulus [ref 3]. If a single strain measurement system is used then this must be recorded in the test report.

3. DEFINITIONS

For the purposes of this procedure, the following definitions apply.

3.1 GAUGE LENGTH (L)

Length of the prismatic portion of the testpiece on which elongation is measured during the test. In particular, a distinction is made between:

3.1.1 Original gauge length (L_o)

Gauge length before application of force.

3.1.2 Final gauge length (L_u)

Gauge length after fracture of the testpiece.

3.2 PARALLEL LENGTH (L_c)

Length of the reduced section parallel portion of the testpiece.

3.3 ELONGATION

Increase in the original gauge length (L_o) at the end of the test.

3.4 PERCENTAGE ELONGATION (A)

Elongation expressed as a percentage of the original gauge length (L_o).

3.4.1 Percentage permanent elongation

Increase in the original gauge length of a testpiece after removal of a specified stress expressed as a percentage of the original gauge length (L_o).

3.4.2 Percentage elongation after fracture (A_p)

Permanent elongation of the gauge length after fracture (L_u - L_o) expressed as a percentage of the original length (L_o).

3.4.3 Percentage total elongation at fracture (A_t)

Total elongation (elastic plus plastic) of the gauge length at the moment of fracture expressed as a percentage of the original gauge length (L_o).

3.4.4 Percentage elongation at maximum force (A_g)

Increase in the gauge length of the testpiece at maximum force, expressed as a percentage of the original gauge length (L_o). A distinction is made between the percentage total elongation at maximum force (A_{gt}) and the percentage non-proportional elongation at maximum force (A_g).

3.5 EXTENSOMETER GAUGE LENGTH (L_e)

Length of the parallel portion of the testpiece used for the measurement of extension by means of an extensometer (this length may differ from L_o and shall be of any value greater than b (see Table 1) but less than the parallel length (L_c).

3.6 EXTENSION

Increase in the extensometer gauge length (L_e) at a given moment during the test.

3.6.1 Percentage permanent extension

Increase in the extensometer gauge length after removal from the testpiece of a specified stress, expressed as a percentage of the extensometer gauge length (L_e).

3.7 PERCENTAGE REDUCTION OF AREA (Z)

Maximum change in cross-sectional area which has occurred during the test (S_o - S_u) expressed as a percentage of the original cross-sectional area (S_o).

3.8 MAXIMUM FORCE (F_m)

The greatest force which the testpiece withstands during the test once the yield point has been passed.

3.9 STRESS (R)

Force (F) at any moment during the test divided by the original cross-sectional area (S_o) of the testpiece.

3.9.1 Tensile strength (R_m)

Stress corresponding to the maximum force (F_m).

3.9.2 Proof strength, non-proportional extension (R_p)

Stress at which a non-proportional extension is equal to a specified percentage of the extensometer gauge length (L_e). The symbol used is followed by a suffix giving the prescribed percentage of the extensometer gauge length, for example $R_{p0.2}$.

3.9.3 Proof strength, total extension (R_t)

Stress at which total extension (elastic extension plus plastic extension) is equal to the specified percentage of the extensometer gauge length (L_e). The symbol used is followed by a suffix giving the prescribed percentage of the original gauge length for example: $R_{t0.5}$.

3.9.4 Permanent set strength (R_r)

Stress at which, after removal of force, a specified permanent elongation or extension expressed respectively as a percentage of the original gauge length (L_o) or extensometer gauge length (L_e) has not been exceeded. The symbol used is followed by a suffix giving the specified percentage of the original gauge length or of the extensometer gauge length (L_e), for example: $R_{r0.2}$.

3.10 STRAIN (ε)

3.10.1 Extensometry

Increase in extensometer gauge length at any moment during the test divided by the original gauge length [ref 4]. For double sided extensometers strain is expressed as the average from measurements taken from opposite sides of the testpiece.

3.10.2 Strain gauges

Change in length of the strain-sensitive part of the resistive element of the strain gauge divided by the original length of the same part. For gauges mounted on opposite sides of the testpiece strain is expressed as the numerical average of the two gauges.

3.11 YOUNG'S MODULUS OF ELASTICITY (E)

The Young's modulus is defined as stress (R) divided by strain (ε) in the elastic linear region at the start of the force/extension curve.

3.12 PROPORTIONAL LIMIT (PL)

The proportional limit is defined as the stress at which the elastic region of the force/extension curve finishes; it marks the point where the linear relation between stress (R) and strain (ε) changes to a non-linear (plastic) behaviour.

3.13 SECANT MODULUS (SM)

The secant modulus is defined as the slope of the line between the origin of the stress/strain curve and any point on the curve.

3.14 TANGENT MODULUS (TM)

The tangent modulus is defined as the slope of the stress/strain curve at the point of interest on that curve.

4. SYMBOL DESIGNATIONS

An abbreviated list of important symbols and corresponding designations is given in Table 1. Further symbols corresponding to dimensions of the testpiece are given in Table A1 of Annex A.

Table 1 - Symbols and Designations

Abbreviated List

Reference	Symbol	Unit	Designation
Testpiece	a	mm	Thickness of flat testpiece
	b	mm	Width of parallel length of flat testpiece
	L_c	mm	Parallel length
	L_o	mm	Original gauge length
	L_e	mm	Extensometer gauge length
Strain	A_t	%	Percentage total elongation at fracture
Force	F_m	N	Maximum force
Strength	R_p	N mm^{-2}	Proof strength
	R_m	N mm^{-2}	Tensile strength
	PL	N mm^{-2}	Proportional limit
Modulus	E	kN mm^{-2}	Young's modulus
	SM	kN mm^{-2}	Secant modulus
	TM	kN mm^{-2}	Tangent modulus

Note: 1 N mm^{-2} = 1 MPa

5. TESTPIECES

5.1 SHAPE AND DIMENSIONS

5.1.1 General

The shape and dimensions of the testpieces to a large extent will depend on the shape and dimensions of the products of which the mechanical properties are to be determined. **However, for this test procedure for particulate reinforced metal matrix composites it is recommended that rectangular testpieces are used.**

The testpiece is usually obtained by machining a sample from the product, pressed blank or casting. However, products of constant thickness and as-cast testpieces may be subjected to test without being machined in the through-thickness direction.

Testpieces, the original gauge length of which is related to the original cross-sectional area by the equation $L_0 = k\sqrt{S_0}$, are called proportional testpieces. The internationally adopted value for k is 5.65.

The original gauge length shall be not less than 20 mm. For this procedure it is preferred that a gauge length of either 25 mm is adopted [Type 1 testpieces] for a testpiece 6 mm wide by 3 mm thick (nominal) or a gauge length of 50 mm for 12 mm wide by 6 mm thick (nominal), [Type 2 testpieces]. If the testpiece is taken from a product that is less than 3 mm thick it is recommended that the width remains at 6 mm.

The dimensional tolerances of both Type 1 and 2 testpieces shall be in accordance with those given in Annex A.

5.1.2 Machined testpieces

Machined testpieces shall incorporate a transition radius between the gripped ends and the parallel length. The dimensions of this transition radius are important and it is recommended that for tests in accordance with this procedure the radius is either 12 or 24 mm, as defined in Annex A.

The gripped ends may be of any shape to suit the grips of the testing machine. The parallel length (L_c) shall always be greater than the original gauge length (L_0).

5.2 PREPARATION OF TESTPIECES

The parallel length section of the testpieces shall be prepared to the final dimensions using diamond tooling, taking due care to minimise the introduction of residual stresses and/or damage by careful use of machining techniques. Spark machining (EDM) can be used first of all to blank the testpiece shape from a larger block if necessary.

6. DETERMINATION OF ORIGINAL CROSS-SECTIONAL AREA (S_0)

The original cross-sectional area shall be calculated from measurements of the appropriate dimensions. The accuracy of this calculation depends on the nature and type of the testpiece, (Annex A).

7. MARKING THE ORIGINAL GAUGE LENGTH (L_0)

Each end of the original gauge length shall be marked by means of pencil or ink lines, but not by notches, marks or scribed lines, which could result in premature fracture.

The original gauge length shall be measured to an accuracy of ± 1%.

In some cases, it may be helpful to draw on the surface of the testpiece, a line parallel to the longitudinal axis, along which the marks are drawn.

8. ACCURACY OF TESTING APPARATUS

The testing machine shall be verified in accordance with EN 10002-2 and shall be of grade 1 or better.

9. CONDITIONS OF TESTING

9.1 TESTING RATE OF THE MACHINE

The testing machine can be controlled through either crosshead displacement control or direct strain (in-situ extensometry) control. The test report should state which method was used. It is **not recommended** that machines should be controlled by a strain output from strain gauges mounted directly on the testpiece.

9.1.1 General

Unless otherwise specified in a product standard, the rate of the machine shall comply with the following requirements.

9.1.2 Modulus and Proof strengths (R_p and R_t)

The rate of stressing shall be not greater than 10 N $mm^{-2}s^{-1}$ in the elastic range. Within the plastic range and up to the proof strength (non-proportional extension or total extension) the straining rate shall not exceed 0.0002 s^{-1}.

9.1.3 Tensile strength (R_m)

9.1.3.1 In the elastic range

If the test does not include the determination of a proof stress or modulus, the rate of the machine may reach the maximum permitted in the plastic range.

9.1.3.2 In the plastic range

The straining rate of the parallel length shall not exceed 0.001 s^{-1}.

9.2 METHOD OF GRIPPING

The testpieces shall be held by suitable means such as for example wedge action or hydraulic grips.

Every endeavour shall be made to ensure that testpieces are held in such a way that the force is applied as axially as possible. This is of particular importance when testing low ductility materials or when determining proof strength (non-proportional extension), proof strength (total extension), yield strength or elastic modulus.

9.3 ALIGNMENT OF TESTPIECES

Accurate alignment of the testpiece is very important for the measurement of modulus. Ideally a multi-strain gauged reference testpiece should be used to check the alignment of the test machine to ensure strains due to bending from rotation or translation of grips are less than 2% of the applied axial strains.

Small misalignments due to curvature of testpieces or misalignment of grips can be compensated for by using a double sided strain measurement system. It is highly recommended that this practice be universally adopted if modulus is to be measured in the tensile test. It is recommended that a set square or similar fixture be used to align the testpiece with respect to the grips in the vertical plane.

9.4 STRAIN MEASUREMENT SYSTEM

The preferred method of strain measurement is to use a double sided data acquisition system. There are two options

a) Double sided extensometry

b) Longitudinal strain gauges bonded to each side of the testpiece.

The method adopted shall be stated in the test report including the extensometer grade if extensometry is used [ref 4]. If a double sided system is not available and a single sided strain measurement device is used then this must also be stated in the test report.

Strain gauges are only suitable for measurement of the full set of mechanical properties if the testpiece failure strains are less than about 3%. For more ductile materials it is necessary to use extensometry to obtain the full stress/strain curve; although if gauges are used then a nominal figure for the tensile strength can be obtained from the load at failure and the cross sectional area of the original testpiece, and the elongation at failure can be obtained directly from the marked testpiece.

10. DETERMINATION OF PERCENTAGE ELONGATION AFTER FRACTURE (A_p)

10.1 Percentage elongation after fracture shall be determined in accordance with the definition given in 3.4.

For this purpose, the two broken pieces of the testpiece are carefully fitted back together so that their axes lie in a straight line. **If fractography is to be performed, it is recommended that this is performed before measurement of A_p to prevent damage to the fracture surfaces.** Special precautions shall be taken to ensure proper contact between the broken parts of the testpiece when measuring the final gauge length. This is particularly important in the case of testpieces having low elongation values.

Elongation after fracture (L_u - L_o) shall be determined to the nearest 0.25 mm with a measuring device with 0.1 mm resolution, and the value of percentage elongation after fracture shall be rounded to the nearest 0.5%. If the specified minimum percentage elongation is less than 5%, it is recommended that special care is taken when determining elongation. If failure occurs outside the original gauge length, L_o, this should be reported.

10.2 For machines capable of measuring extension at fracture using an extensometer, it is not necessary to mark the gauge lengths. The elongation is measured as the total extension at fracture, and it is therefore necessary to deduct the elastic extension in order to obtain percentage elongation after fracture.

In principle, this measurement is only valid if fracture occurs within the extensometer gauge length (L_e). The measurement is valid regardless of the position of the fracture cross-section if the percentage elongation after fracture at least reaches a specified value and this shall be stated in the test report.

10.3 **The property should be quoted to two significant figures.**

11. DETERMINATION OF PROOF STRENGTH (NON-PROPORTIONAL EXTENSION) (R_p)

11.1 The proof strength (non-proportional extension) is determined from the force/extension diagram by drawing a line parallel to the straight portion of the curve in the elastic-region and at a distance from this equivalent to the prescribed non-proportional percentage, for example 0.2%. The point at which this line intersects the curve gives the force corresponding to the desired proof strength (non-proportional extension). The latter is obtained by dividing this force by the original cross-sectional area of the testpiece (S_o).

Accuracy in drawing the force-extension diagram is essential, particularly in the linear elastic region of the curve. A method for doing this is described in section 13.

11.2 The proof strength may be obtained without plotting the force/extension curve by using automatic devices, such as computer based data acquisition systems directly from the stress/strain curve.

11.3 **The property should be quoted to three significant figures.**

12. DETERMINATION OF PROOF STRENGTH (TOTAL EXTENSION) (R_t)

12.1 The proof strength (total extension) is determined on the force/extension diagram by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage extension. The point at which this line intersects the curve gives the force corresponding to the desired proof strength. The latter is obtained by dividing this force by the original cross-sectional area of the testpiece (S_o).

12.2 This property may be obtained without plotting the force/extension diagram by using automatic devices such as computer based data acquisition systems directly from the stress/strain curve.

12.3 **The property should be quoted to three significant figures.**

13. DETERMINATION OF YOUNG'S MODULUS (E)

One of three methods shall be used to determine the Young's modulus. The three methods; M1, M2 and M3 are outlined in sections 13.1 to 13.3. The method adopted shall be quoted in the test report. **The modulus should be quoted to the nearest 0.5 kN mm^{-2}.**

13.1 METHOD M1 - GRAPHICAL METHOD

The load and strains (single or averaged) shall be plotted on a chart recorder using A3 graph paper. **The plot should occupy a significant proportion of the paper and the angle between the plot and the strain axis should be $45^o \pm 2^o$.** A straight line shall be drawn parallel to the initial portion of the load/strain curve. The slope of this line, (when the load has been divided by the testpiece cross-section to convert to values of stress) is the Young's modulus.

13.2 METHOD M2 - CHORDAL METHOD

This method shall in general be adopted when machine dedicated software is available to calculate modulus values. **It is strongly recommended that the software is validated/calibrated by the use of reference testpieces of known stiffness.**

13.2.1 Two values of stress are chosen on the stress/strain plot to mark the lower and upper limits of a chordal modulus. The two values of stress are arbitrarily chosen by inspection of the stress/strain curve and must be quoted in the test report. A straight line is drawn between the two points using a validated software procedure. The slope of this line corresponds to the Young's modulus value. This method shall be identified as method M2A.

13.2.2 Two values of stress are chosen in the stress/strain plot to mark the lower and upper limits of the chordal modulus. The two values of stress are arbitrarily chosen by inspection of the stress/strain curve and must be quoted in the test report. A straight line regression fit is made to the experimental data between these two chosen values of stress. The slope of the fitted line corresponds to the value of Young's modulus. This method shall be identified as method M2B.

13.3 METHOD 3 - TANGENT METHOD

The full procedure for this method is given in Reference 3. Essentially the following steps are followed.

i) The stress/strain data is captured using a computer based acquisition system. It is recommended that the data acquisition system collects at least 200(X) data points up to a **total** strain of 1.0%.

ii) a quadratic polynomial is sequentially fitted to the data, point by point along the curve, by least squares regression analysis. A n point fit is recommended where n is 15X/200.

iii) the fitted polynomial is differentiated at each point to obtain a value for the tangent modulus

iv) the tangent modulus is plotted against stress

v) the best horizontal fit to the tangent modulus/stress curve is obtained either

  a) by operator choice - moving a horizontal cursor on the monitor screen, or

  b) automatically by sequentially examining the data in sets of m data points along the curve to find the most horizontal portion, where m is 5X/200

vi) the horizontal fit is taken as the first choice of Young's modulus

vii) this value is used to define a new origin for the stress/strain data

viii) the data is replotted and a secant modulus/stress curve is calculated

ix) step v) is repeated but using the secant modulus/stress plot

x) The most horizontal portion of the secant modulus/stress plot is taken to be the final value of Young's modulus.

The value obtained in Step x, is the Young's modulus of elasticity. This method shall be identified as Method M3.

14. DETERMINATION OF PROPORTIONAL LIMIT

One of the following methods shall be used to obtain a value for the proportional limit. **The value obtained should be quoted to three significant figures.**

Software-based Systems

The equation of the straight line representing the Young's modulus is used to calculate nominal strain values, ε_i', for consecutive stress values, σ_i. The proportional limit is defined as the first point on the stress/strain (ε_i) experimental curve where

$$(\varepsilon_i - \varepsilon'_i) > 0.005\ \varepsilon_i'$$

Graphical Outputs

A line is drawn from the origin with a slope equal to 0.995 E. The point where it intersects the experimental data is the value of the proportional limit.

15. DETERMINATION OF TENSILE STRENGTH

The tensile strength is the largest stress value that is obtained on the stress/strain curve. **The value obtained should be quoted to three significant figures.**

16. TEST REPORT

It is recommended that the proforma given in Annex C is used for the test report and shall contain at least the following information, preferably in tabular form for eventual computerisation of data bases as indicated in Annex C.

- reference to this procedure
- nature of the material, if known
- identification of the testpiece
- type of testpiece
- location and direction of sampling of testpieces
- characteristics measured and results, using the proforma given in Annex C.

17. REFERENCES

1 EN 10002 pt 1 Metallic materials; tensile testing.

2 EN 2002-1 pt 1 Tensile tests for metallic materials: aerospace series

3 B Roebuck, J D Lord, P M Cooper and L N McCartney. Data Acquisition and Analysis of Tensile Properties for Metal Matrix Composites. ASTM J. Testing and Evaluation, Jan, 1994.

4 EN 10002 pt 4 Extensometer grading

Annex A

(This annex forms an integral part of the procedure).

Types of testpiece to be used in the case of sheets and flat sections of thickness equal to or greater than 3 mm, and bars and sections of thickness equal to or greater than 4 mm. For testpieces from these products less than 3 mm thick it is recommended that all dimensions remain the same as those for testpieces from further products except the thickness.

A.1 Shape of the testpiece

In general, the testpiece is machined and the parallel length shall be connected by means of transition radii to the gripped ends which may be of any suitable shape for the grips of the test machine.

The transition radius shall be at least 12 mm for testpieces of rectangular cross-section (3 x 6 mm) and 24 mm for testpieces of rectangular cross-section (6 x 12 mm).

A.2 Dimensions of the testpiece

For tensile tests on particulate reinforced MMC it is recommended that one of two testpiece types are used, Type 1 (T1) or Type 2 (T2). Figure A1 shows the testpiece geometry. Both sizes are commensurate with the standard EN 10002 pt 1. The dimensions are given in Table A1.

Table A1

Dimensions of testpiece

Type	Total length mm	Transition radius mm	Width of grip ends mm	Length of grip ends mm	Parallel length mm	Original gauge length mm	Width of parallel length mm	Thickness of parallel length mm
	L_t	r	W_g	L_g	L_c	L_o	b	a
T1 T2	100 200	12 24	12 24	25 50	36 72	25 50	6 12	3 6

A.2.1 Parallel length of machined testpiece

The parallel length (L_c) shall be at least equal to:

$$L_o + 1.5\sqrt{S_o}$$

For this procedure it is recommended that L_c is 36 mm (Type 1) or 72 mm (Type 2).

A.2.2 Length of unmachined testpiece

The free length between the grips of the machine shall be adequate for the gauge marks to be a reasonable distance from these grips.

A.3 Preparation of testpieces

When measuring the dimensions of each testpiece the tolerances on shape given in Table A.2 can be used as a guideline but finally the tolerances on thickness and width shall be such that the cross-sectional area of the testpiece does not vary by more than ± 1% from the nominal.

The testpieces shall be prepared so as to minimise the effects of changes to the properties of the metal composite. **Diamond tooling is recommended.**

Table A2

Tolerances on dimensions of testpiece, mm

Type	Nominal width/thickness	Machining tolerances	Shape tolerance†
T1	6/3	± 0.05	0.05
T2	12/6	± 0.1	0.10

† Maximum deviation between measurements of a dimension along the parallel length.

A.4 Determination of the cross-sectional area (S_o)

The original cross-sectional area shall be calculated from measurements of the appropriate dimensions, with an error not exceeding ±0.2% on each dimension for testpieces thicker than 3 mm. For tests on thinner material, the uncertainty associated with the measurement of the thickness dimension should be assessed and used to calculate and express the uncertainty which this contributes to the measurement of stress (R).

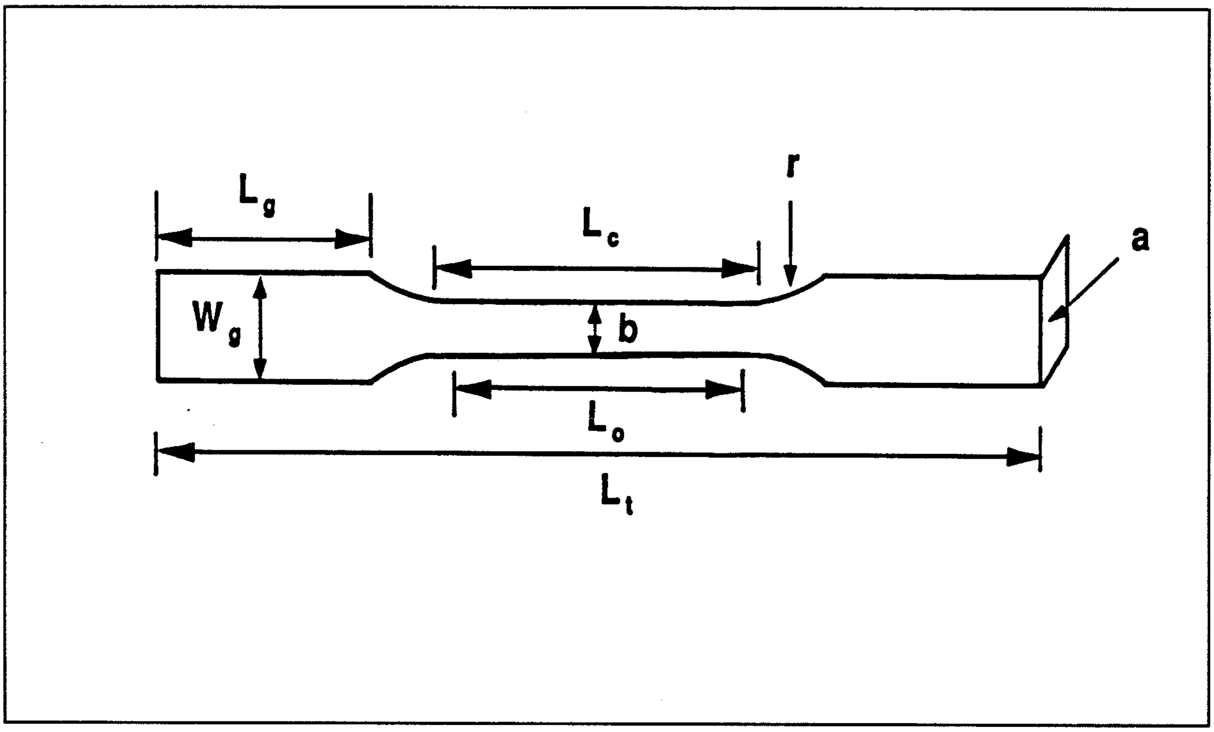

Fig A1 Rectangular testpiece geometry

Annex B

Test Report

It is recommended that the test report is in tabular form as follows (typical values have been given for illustration).

Table B1

Particulate Metal Matrix Composites

Tensile Test Report

Reference	Description	Input value
Material	Source Identifier Common name Modifiers (Processing details)	BP Metal Composites BP 217 SiC particulate reinforced Al alloy Extruded plate (15 mm x 50 mm) T6 Heat treatment
Testpiece preparation	Orientation (relative) Method Geometry Applicable standard(s)*	Longitudinal with respect to extrusion direction. Diamond machined from spark machined blank. Rectangular, 3 mm thick x 6 mm wide A*
Testpiece information	Number identification Testpiece width (average) Tolerance on width Testpiece thickness Tolerance on thickness Total length Gauge length (if extensometry used) Cross-sectional area Uncertainty in cross-sectional area (estimated)	BPRR 07 6 mm ± 0.01 mm 3 mm ± 0.01 mm 100 mm - 18 mm^2 ± 0.02 mm

Reference	Description	Input value
Test procedure	Type of test	Tensile
	Date of test	20 July 1992
	Applicable standard(s)*	A*
	Test machine	Instron 1197
	Test environment	air
	Humidity	nominal
	Temperature	22 °C
	Grips	Wedge
	Alignment? - give details	Yes - Special fixture
	Test control	Cross head displacement
	Use of Reference Testpiece	No
	Rate of application of strain	
	Elastic	0.00015 s^{-1}
	Proportional limit to 0.2% proof stress	0.0002 s^{-1}
	Plastic (> 0.2% proof stress)	0.0005 s^{-1}
	Method of strain measurement- gauges (G) or extensometers (E)	G
	Extensometer grading	-
	Extensometer gauge length	-
	Double sided (D) or single sided (S)	D
	Size of strain gauges (if used)	5 mm, longitudinal
	Data collection method	In-house computer based acquisition system (Archimedes plus ADU)
	Sampling rate	0.5 Hz
	Method of calculating results*	
	Young's modulus	M3*
	Proportional limit	A*
	Proof stress	A*
	Tensile strength	A*
	Elongation to failure	A*
	Reduction in area	A*
Test Results	Maximum load	9.5 kN
	Tensile strength	540 N mm^{-2}
	Proof strength (x%)	360 N mm^{-2} (0.2%)
	Proportional limit	160 N mm^{-2}
	Young's modulus (method M1 or M3)	101 N mm^{-2} (M3)
	Young's modulus (Chord method - M2)	
	(α_1 to α_2 Nmm^{-2} - method Mx)*	100 N mm^{-2} (20-100 N mm^{-2} - M2A)
	Elongation to failure	2.4%
	Reduction in area	-
Observations (Footnotes)	Failure mode, position of fracture	Semi-brittle-failed 10 mm from centre, from testpiece corner.
	Validity of test	Yes, but gauge debonded at 1.8% strain.

* A - refer to standard or procedure adopted; use a recommended letter code.