

Miniature Testpieces for the Assessment of the Dimensional Stability of Monolithic and Metal Composite Aluminium Alloys

The versatility of a unique miniaturised test system, the ETMT, has been evaluated for the assessment of the dimensional stability of metal composite aluminium alloys reinforced with either SiC or Al₂O₃. Testpieces were also studied from monolithic 6000 and 2000 series Al alloys for comparison with the metal composites.

Tests for dimensional stability were conducted under conditions of zero load. Testpieces were cycled between 50-200°C either in one slow cycle or repetitively with a prescribed heating and cooling profile.

Electrical resistance changes were monitored during the tests and were shown to be useful in the evaluation of microstructural changes in the materials during the thermal cycling tests.

The tests discriminated well between the different materials with the 2000 series Al alloys showing good resistance to dimensional changes. The lower strength materials showed the least dimensional stability.

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Introduction

The effects of thermal exposure on the dimensional stability of aluminium metal matrix composites are of interest to both the aerospace and automotive industries. Metal composites provide benefits in improved strength and stiffness over those properties in unreinforced monolithic alloys. However, their elevated temperature performance requires further study, especially in comparison with the conventional monolithic aluminium alloys.

Dimensional change due to thermal and mechanical exposure in metal composites is a complex process [1-5]. Internal strains are generated by the differences of thermal expansion coefficient between the aluminium alloy matrix and the reinforcement [1,2].

A new miniaturised electrothermo-mechanical test system (ETMT) developed at NPL [6], has been used to investigate the performance of MMC in comparison with typical monolithic aluminium alloys.

A review of industrial requirements and potential applications for the metal composites specified an appropriate temperature cycle as being 50-200°C. Details of the materials tested are given in [Table 1](#).

The results showed significant differences in performance. Of the metal composites the heat treated materials with the 2000 series matrices displayed stabilities which were comparable with the monolithic 2618 Al alloy.

Table 1 - Materials

Suppliers Code	Type	Heat Treatment	Manufacturer	Composition
2618	Al alloy	T651	commercial supply	Monolithic 2618
AMC600xb	Al alloy ⁺	T1	AMC Ltd	Monolithic 6061
AMC200xb	Al alloy ⁺	T1	AMC Ltd	Monolithic 2124

F3S 20S	Metal Composite	T6	Duralcan	A359 + 20% 25 μm SiC
W2F 20A	Metal Composite	T6	Duralcan	2618 + 20% 25 μm Al_2O_3
AMC225xf or xe	Metal Composite	T1 or T4	AMC Ltd	2124 + 25% 3 μm SiC
AMC225xf 2618	Metal Composite	T4	AMC Ltd	2618 + 25% 3 μm SiC
AMC640xa	Metal Composite	T1	AMC Ltd	6061 + 40% SiC

T1 As manufactured

T4 Solution treated + naturally aged

T6 Solution treated + artificial aged

T651 Solution treated, stretched and artificially aged

+ Power metallurgy manufacturing route

xa, xb, xf and xe Processed to give different forms of SiC distribution; xf and xa, mechanically alloyed; xb and xe, blended only.

Test Procedures

The miniature test system (ETMT), is fully computer controlled using software written with a graphical software system (LABVIEW). In summary the ETMT comprises:

- An environmental chamber with electrical leadthroughs, water cooling for the testpiece grips and a facility for inert gas supply.
- Computer controlled heating via a dc power supply (0-8V, 0-200 A) with measurement of testpiece resistance and temperature (thermocouple). An adaptor is available for infra-red temperature measurement. The upper temperature limit of the tests is governed by the melting point of the test material.
- Mechanical loading assembly (0-1200 N) including a flexible grip system, load cell and displacement transducers (sub-micrometre resolution and mm range), with computer controlled motor for zero, constant or fatigue load application.
- System software to monitor and control each test type. Test data are stored on a computer (PC), and can then be analysed with conventional software.

Aluminium metal composites are metallic and so have a low electrical resistance. Therefore it was necessary to use testpieces with a small cross-section in order to generate temperatures up to 200°C with applied dc currents of less than 200 A. Rectangular testpieces, 40 mm long by 1 mm thick by 2 mm wide were produced by electrical discharge machining followed by careful diamond grinding to the final dimensions. The temperature was measured at the centre of each testpiece with a Pt/Pt-13%Rh thermocouple, manufactured (inert gas fusion welded) individually at NPL with 0.1 mm diameter wires. The thermocouples were gently spot welded to the testpieces. The resistance of the testpiece was measured before and after spot welding to check for microstructural changes, ie high temperatures can be generated at the spot weld junction. If these temperatures are too high the metallurgical condition of the material is altered. Tests were only performed on materials where the resistance did not change significantly. The uncertainty in measurement of resistance was about $\pm 0.5\%$. Spot welding did not result in a change in resistance greater than this measurement uncertainty. The resistance of the testpiece in the central 2-3 mm was measured during each test.

The following tests were performed to discriminate between the materials, and evaluate the extent of dimensional changes.

- one slow heating cycle (20-200-20°C) under zero load. During this cycle the dimensions (expansion) and electrical resistance of the testpiece were monitored.
- Temperature cycling between 50-200°C (with fast, about 100°C/s, heating and cooling); total cycle time of 35s.

Slow Cycle Tests

[Fig. 1](#) shows typical displacement/ temperature plots for the heating part of the slow cycle test on four materials 200xb, 600xb, 225xe and 640xa, i.e. two monolithic aluminium alloys and two metal composites. The two metal composites clearly expand much less than the monolithic aluminium alloys. The measured displacement is an integrated sum of the displacements along the testpiece where there is a parabolic temperature.

A temperature dependent thermal expansion coefficient can be calculated from the displacement/temperature plots. Expansion data calculated from the four materials shown in [Fig 1](#) are compared with the results from tests on other metal composites and a 2618 monolithic aluminium alloy in [Fig 2](#).

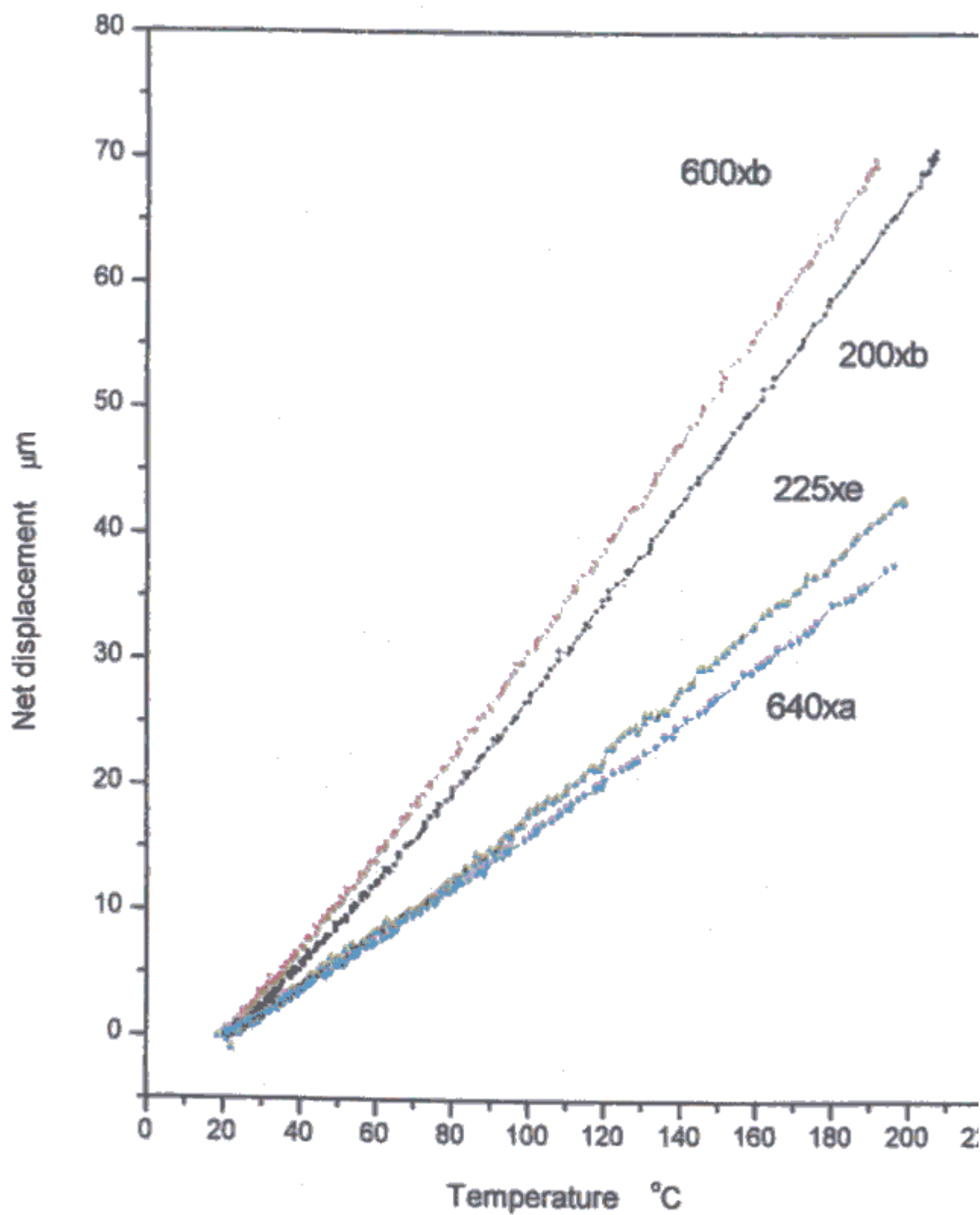


Figure 1: Dimensional change; 0-200 $^{\circ}\text{C}$.

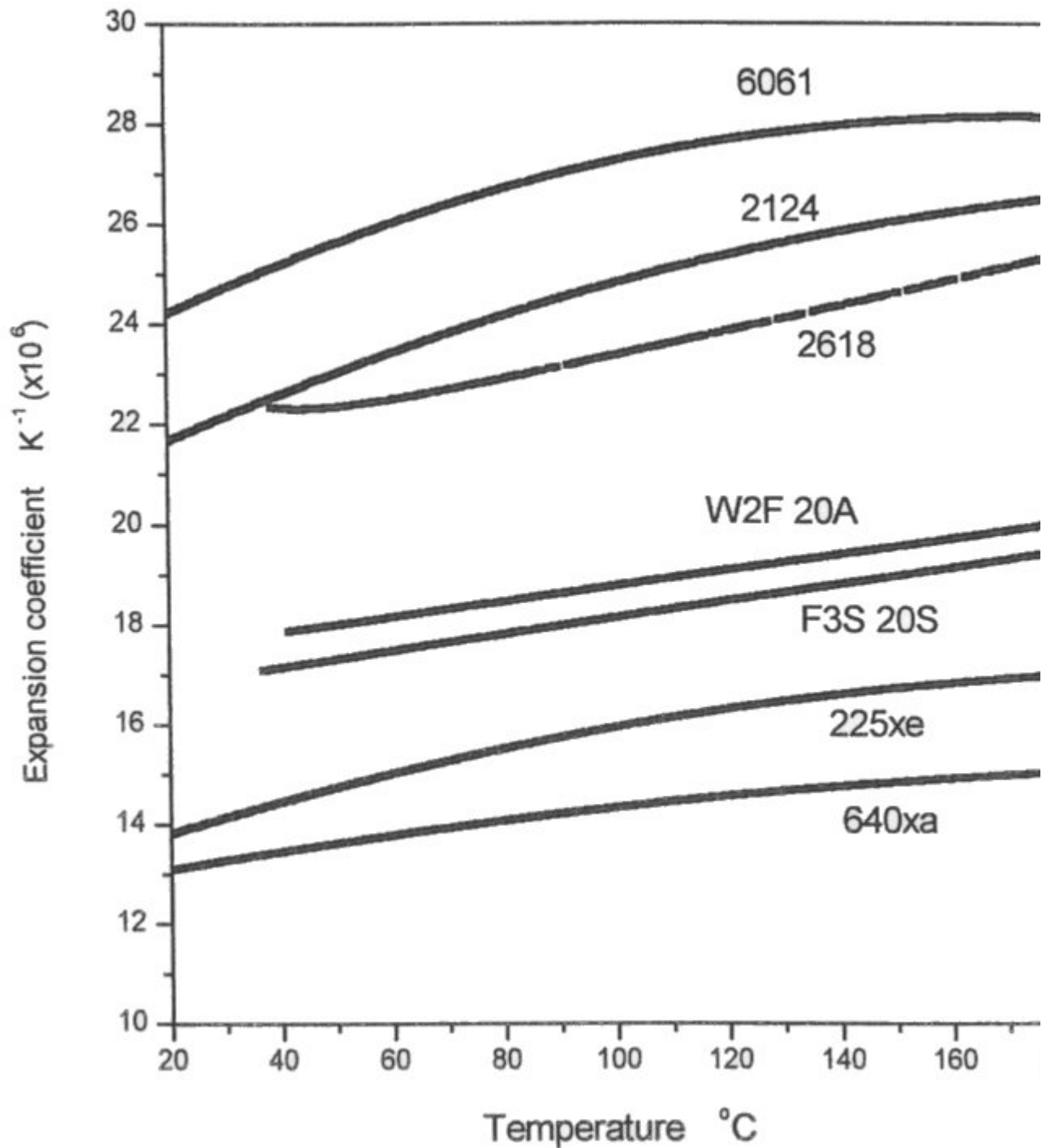


Figure 2: Temperature dependence of thermal expansion.

All the metal composites showed a small increase in dimensions after one slow cycle to 200°C (Table 2). This dimensional change probably results from a relaxation of internal stresses produced during manufacturing. In the metal composites the largest dimensional change after one cycle occurred in F3S 20S, the material with the lowest yield point. The relation between dimensional change and strength was confirmed in the tests on the monolithic materials where the change in the high strength 2618 T651 alloy was less than 1 μm , compared with the 4 and 8 μm of the softer - 2124 and 6061 alloys respectively.

Fast Cycle Tests

Fast cycle tests comprised a rapid heating and cooling rate of about 100°C/s between 50 and 200°C with a hold of 28s at 200°C and 7s at 50°C . The cycle profile is shown in [Fig 3](#). The fast cycle tests were all performed following one slow cycle test. Most of the materials were examined over about 50 - 100 cycles but two materials were cycled for a much longer period. The results are given in [Table 2](#). For the short period tests there was no significant change in dimension indicating that the fast heating and cooling rates were not generating sufficiently high internal stresses due to the thermal expansion mismatch between reinforcement and matrix to cause a major change in shape. There was some evidence that for much longer cycle times in the 225xe T1 composite that a small increase in length was being generated, [Fig 4](#). Further tests would be needed to evaluate this aspect of the test method as only two materials were subjected to the longer period of test.

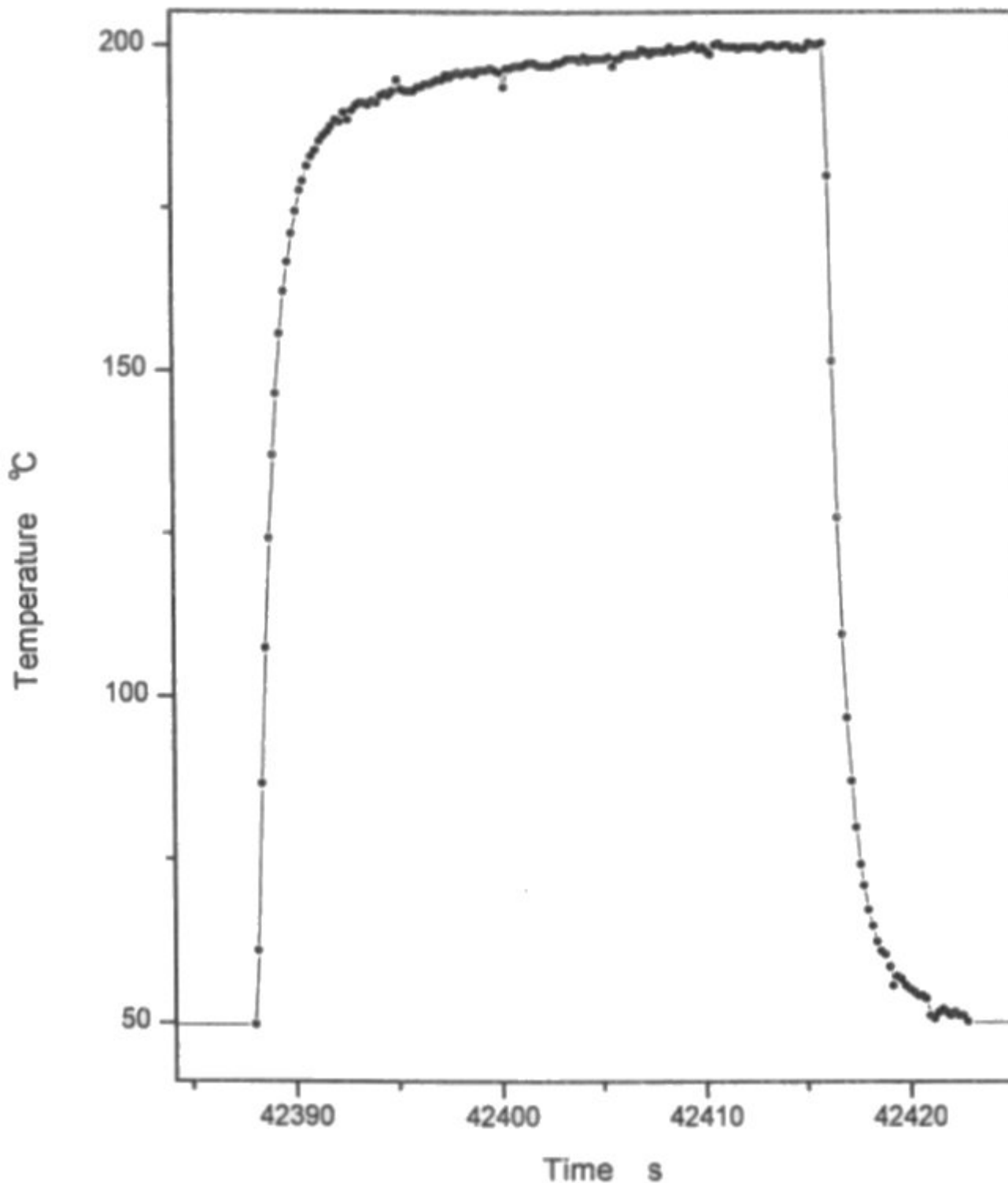


Figure 3: Fast cycle profile.

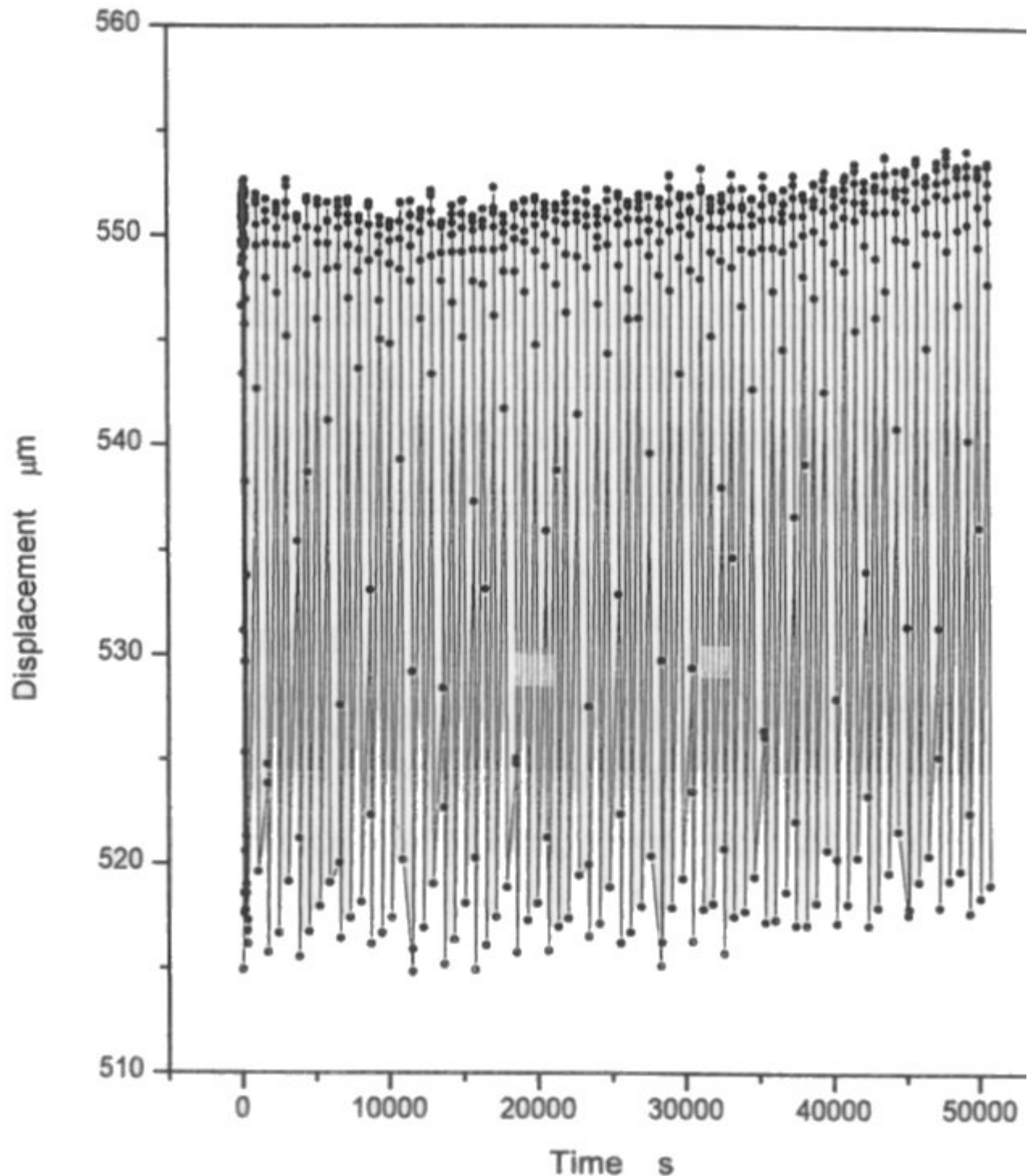


Figure 4: Dimension at 200°C for long duration cyclic temperature tests with zero applied load in 225xe T1.

Microstructural Stability

Changes in electrical resistance (or resistivity) were monitored during the tests to assist in the evaluation of microstructural stability during the thermal cycling tests.

A plot of the temperature dependence of electrical resistivity for materials 600xb, 200xb, 225xe and 640xa up to

about 200°C in the slow cycle tests is shown in [Fig 5](#).

The rate of increase of resistivity with temperature is dependent on the amount of reinforcement in the composite. Higher amounts of particulate give rise to an increase in the temperature coefficient of resistivity.

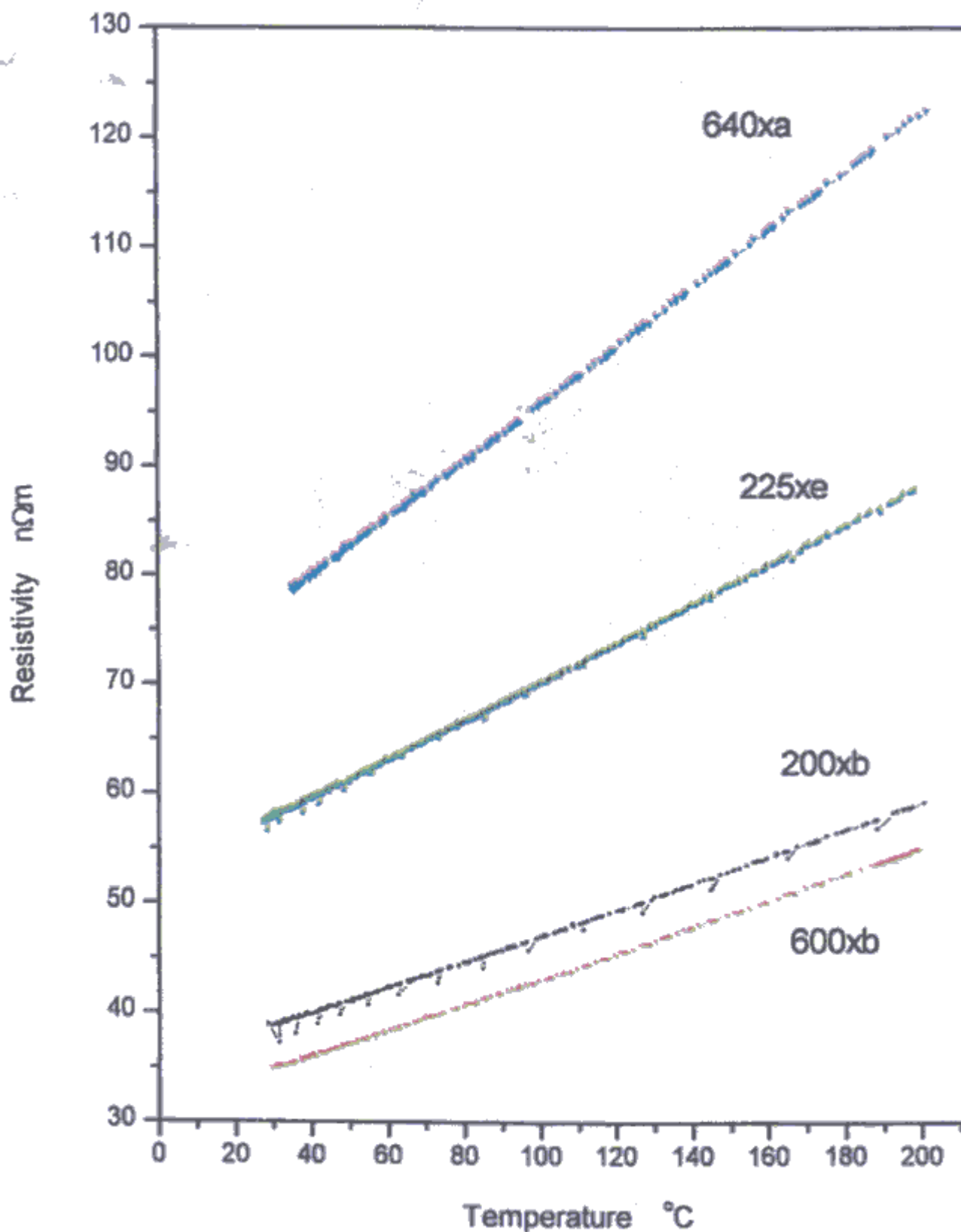


Figure 5: Electrical resistivity, 0-200°C.

Plots of resistance against time for two MMC, 640xa and 225xe in the T1 conditions, are shown in [Fig 6](#). The samples were held at 0N load during these isothermal tests. At both 200°C and 250°C the resistance of the 640xa MMC remained reasonably constant indicating a fairly stable microstructure in this material at these temperatures over a period of about 4h. This information is useful in the interpretation of mechanical test data as there are no standards for defining the period prior to conducting a strength test at elevated temperature. By contrast, the 225xe MMC, at both 200°C and 250°C, showed a significant decrease in resistance. The rate of decrease was faster at the higher temperature. A comparison of the 2000 series MMC with the 2000 series monolithic alloy is shown in Fig 7 at 150°C and 200°C where a normalised value of resistance is plotted against time. The two materials have similar characteristics, showing only a small change at 150°C for 15h but a considerable decrease over a period of 4h at 200°C. These results indicate that in tests at 200°C or above the temperature history of the testpiece must be well characterised because the microstructure is not stable in the 2000 series alloys and depends on heat treatment.

Table 2 - Dimensional Changes - μm

Material	One slow cycle 20 - 200°C	(N) fast cycles 50 - 200°C <i>Short period</i>	(N) fast cycles 50 - 200°C <i>Long period</i>
F3S 20S T6	+ 3	(60) -1	-
W2F 20A T6	< 1	(50) <1	-
225 xe T1	< 1	(80) <1	(1450) +3
225 xf T1	+ 2	(75) <1	-
225 xe T4	+ 1.5	(85) <1	-
225 xf T4	+ 1	(150) <1	-
640 xa T1	< 1	(100) <1	(1600) <1
2618 T651	< 1	(60) <1	-
200 xb	+ 4	(100) <1	-
600 xb	+ 8	-	-

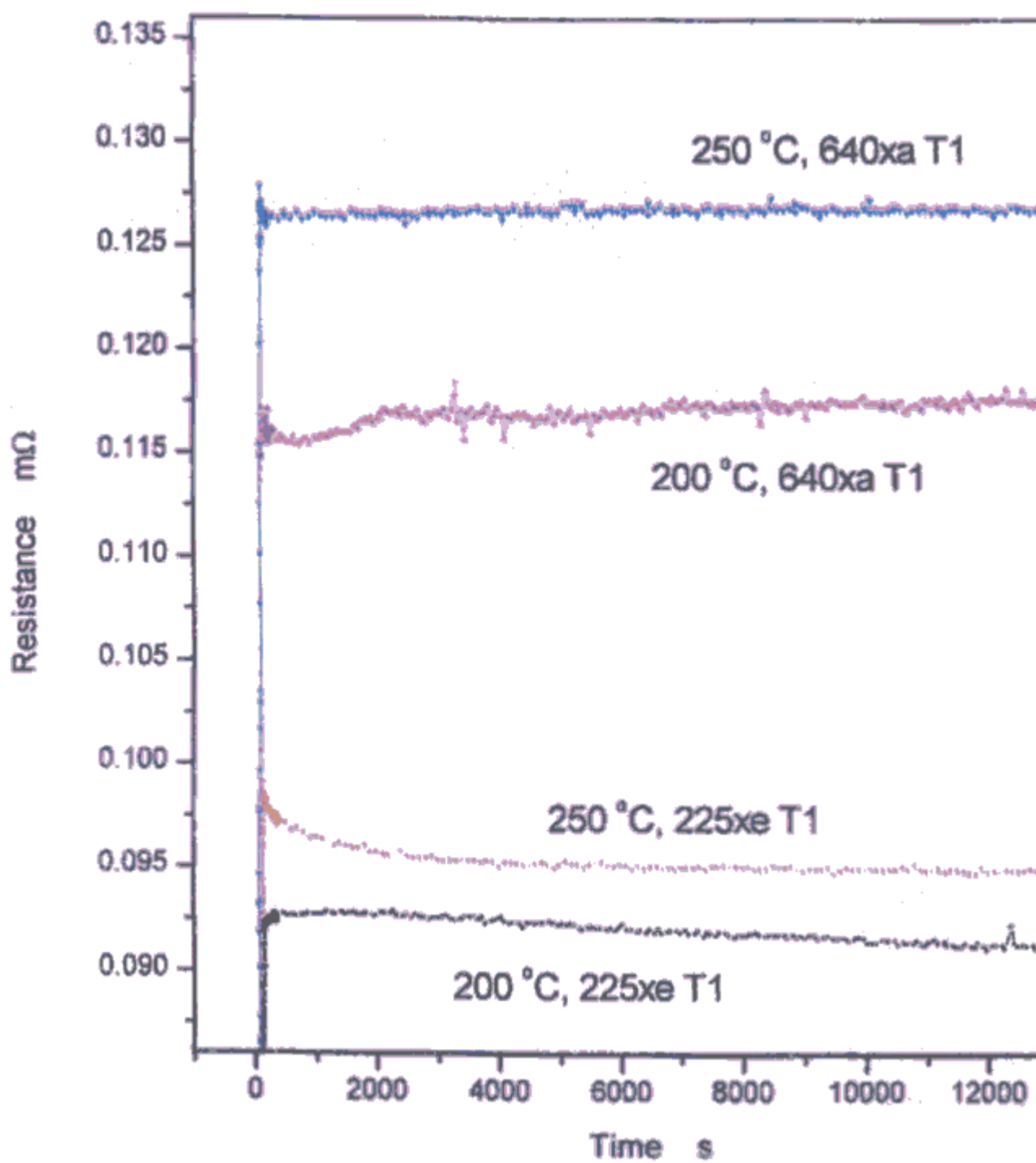


Figure 6: Resistance changes for 640xa and 225xe MMC.

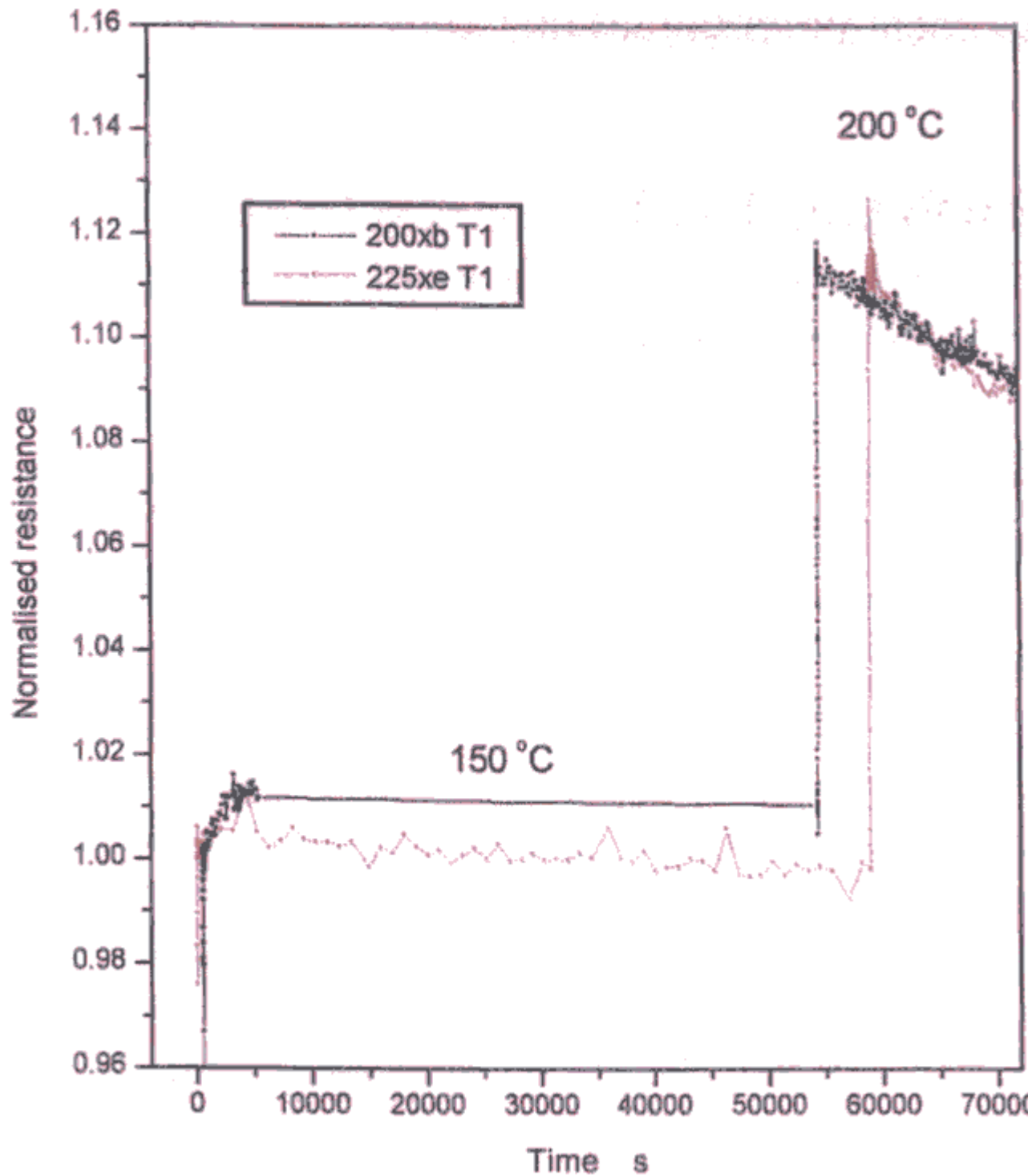


Figure 7: Change in normalised resistance for 2000 series based materials at 150°C and 200°C.

Summary

The results of tests in the new multi-property miniature test system (ETMT) allowed the following conclusions to be reached:

- Thermal cycling tests on miniature testpieces discriminated well between different aluminium based MMC and monolithic aluminium alloys.
- MMC materials with heat treatable 2000 series aluminium alloy matrices showed good resistance to

thermal cycling at elevated temperatures.

- The materials with annealed or as-manufactured matrices were the least dimensionally stable. Heat treatment improved stability.
- A slow heating cycle between RT and 200°C resulted in an expansion in dimensions. The expansion was greatest in the lowest strength materials.
- The T4 heat treatment was the most thermally resistant condition for the AMC MMC materials. Their characteristics were comparable with the monolithic alloy 2618 T651.
- Electrical resistance changes are useful indicators of microstructural stability.

References

1. T W Clyne and P J Withers. An Introduction to Metal Matrix Composites, Cambridge University Press, 1993.
2. M R Daymond and P J Withers. Scripta Materialia, V35 No 6, 1996, 717-720.
3. B Y Zong and B Derby. Acta. Mater. V45 No 1, 1997, 41-49.
4. P L Lui, Z G Wang, H Toda and T Kobayashi. Scripta Materialia, V36 No 7, 1997, 807-812.
5. L Wang, Z M Sun and T Kobayashi. Scripta Materialia, V35 No 8, 1996, 973-978.
6. B Roebuck and M G Gee. Miniaturised Thermomechanical Tests on Hardmetals and Cermets. Mater. Sci and Eng., A209/1-2, 1996, 358-362.

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