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Report 4

MODIFICATIONS TO A CONSTANT STRESS RHEOMETER TO REDUCE THE INSTRUMENT COMPLIANCE

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MODIFICATIONS TO A CONSTANT STRESS RHEOMETER TO REDUCE THE INSTRUMENT COMPLIANCE

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ABSTRACT

In order to utilize the potential of the high torque motor used in the TA Instruments CSL^{2}500 constant stress rheometer, a modification was made to the air bearing shaft. Previous work[(1)] had indicated that the rheometer gave erroneous mechanical data for stiff materials due to the relatively low compliance of the air-bearing-measurement geometry system. This low compliance occurred at approximately 40% of the motor output, thus, a proportion of the torque developed by the motor was being dissipated by the air-bearing geometry attachment system and not through the test sample leading to a low reading of the mechanical property data for the test sample. The modification consisted of machining keyways or splines onto the air-bearing shaft thus providing a non-slip contact surface for suitably modified measurement geometries. The addition of splines on the air bearing shaft reduced the instrument compliance by approximately 15% over the original air bearing system.

This modification has resulted in:

1 an increase in the measurement range of the instrument. This formerly resulted in erroneous mechanical data as the instrument effectively 'topped out'

2 greater repeatability in measurement due to the elimination of the dependence upon the torque used in attaching the measurement geometry to the air-bearing shaft and

3 greater sensitivity in the determination of the mechanical properties.

Discussions as to the potential of the commercial development of these modifications are underway with the manufacturer of this instrument.

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1 INTRODUCTION

Previous work described the measures required to establish the machine compliance for a TA Instruments CSL^2 500 constant stress rheometer[(1)], Plate 1. It was shown that a variation in the torque applied to the draw rod in attaching the measurement geometry to the air bearing shaft altered the compliance of the instrument. A procedure to enable the application of a pre-defined torque was established by a simple modification of the geometry draw rod, Plate 2a. The draw rod was modified to include a 16 mm hexagonal head allowing fastening using a torque wrench set to 70 cNm. This simple modification allowed the quantification of the effect of the geometry tightening torque on the instrument's compliance. This report describes a further modification designed to utilize the potential of the high torque motor used in the TA Instruments CSL^{2}500 constant stress rheometer. The modification requires the machining of keyways or splines onto the air-bearing shaft thus providing a non-slip contact surface for suitably modified measurement geometries. This modification has resulted in a number of benefits, one being an increase in the measurement range of the instrument. This formerly resulted in erroneous mechanical data as the instrument effectively 'topped out' as a proportion of the torque developed by the motor was being dissipated by the air-bearing geometry attachment system which increased with the stiffness of the test material.

2 RESULTS AND DISCUSSION

The variation of the instrument's compliance with geometry attachment torque is shown in Figure 1 and tabulated in Table 1. The compliance term at 70 cNm attachment torque is similar to that quoted by the manufacturer, TA Instruments[(2)]. How the compliance correction term is applied to the mechanical property data derived by the instrument software is detailed in the Appendix of Reference 1.

Draw-rod torque (cNm)	Machine compliance (mrad/Nm)
20	4.10
30	3.90
40	3.90
50	3.92
70	2.57

Table 1. Draw rod torque compared with machine compliance

All devices attached to the rheometer's lower plate such as disposable plates or extended temperature options have their mechanical fastenings tightened using a force of 70 cNm.

This procedure has decreased the measured compliance of the instrument from the values shown in Table 1 to those in Table 2.

Draw rod torque (cNm)	Machine compliance (mrad/Nm)
20	2.64
30	1.73
40	1.75
50	1.75
70	1.90
80	2.11

Table 2. Draw rod torque compared to machine compliance with optional devices tightened at 70 cNm

These relatively simple modifications highlight the requirement for good practice when establishing properties data for low compliance materials.

In order to utilize the potential of the high torque $CSL^2$500 motor, a modification was made to the air bearing shaft. This modification involved machining keyways or splines on to the air-bearing shaft thus providing a non-slip contact surface for suitably modified measurement geometries. This splined bearing is 'keyed' which ensures repeatable positioning on the shaft of each measurement geometry. Plate 2b shows the $CSL^2$500 air bearing shaft in its original condition and Plate 3 shows the new splined profile. Plates 2c and 2d also show an original measurement geometry and the splined geometry respectively.

A consequence of splining the air bearing is that the variation in instrument compliance due to the effect of the geometry attachment torque is eliminated. The data for instrument compliance for the splined air bearing was collected without use of the draw rod. The close fit between the measurement geometry and the air bearing was found to be sufficient in preventing the measurement geometry moving in the vertical plane. In general practice the draw rod will be utilized to prevent any slippage of the measurement geometry in the vertical plane.

A comparison of the instrument's compliance with the original shaft and the splined shaft is shown in Table 3 and Figure 2.

Air bearing type	Average instrument compliance (mrad/Nm)
original (from table 2)	1.96
splined	1.64

Table 3: Instrument compliance for modified and original CSL^2 500 air bearings

As can be seen from Table 3, the addition of splines on the air bearing shaft decreases the instrument compliance by approximately 15% over the original air bearing system. This translates in testing to a greater sensitivity in the determination of the mechanical properties of a material. Figure 3 shows a comparison of the cure behavior of a test adhesive, 3M DP190 at 20^{o}C, measured using the original and the splined air bearing systems. It can be seen that the modified bearing gives higher values for the storage modulus. This is due to the increase in mechanical moment imparted to the sample due to less slip in the air-bearing-measurement geometry interface. Figure 4 gives an indication of the increase in instrument torque used in obtaining the mechanical properties of a test material. For nominally the same cure period, i.e. 3000 minutes the input torque of the instrument has increased by 5000 micro Nm., i.e. from 11,000 to 16,000 micro Nm. This again highlights the increase in overall stiffness of the instrument. This decrease in instrument compliance allows a greater flexibility in the choice of the size of measurement geometry and the measurement gap, i.e. larger amounts of test material and thus greater overall precision in the measurements.

3 CONCLUSIONS

The modifications to the TA Instruments $CSL^2$500 constant stress rheometer have improved and simplified the determination of the instrument compliance.

This modification has resulted in:

1. an increase in the measurement range of the instrument. This formerly resulted in erroneous mechanical data as the instrument effectively 'topped out'

2. greater repeatability in measurement due to the elimination of the dependence upon the torque used in attaching the measurement geometry to the air-bearing shaft and

3. greater sensitivity in the determination of the mechanical properties of adhesives during the cure cycle and other similar materials.

This instrument is now capable of using more of its "reserves of torque" thus extending its measurement range which also increases the repeatability of the measured mechanical data.

The results of these modifications are being discussed with the manufacturer of this instrument as to the potential for commercial development.

4 REFERENCES

1 MTS Adhesives Programme 1993-1996: Performance of Adhesive Joints: Project 5: Measurements for Optimising Adhesives Processing: Report 10, A Comparison of Techniques for Monitoring the Cure of Adhesives. NPL Report CMMT(B104), November 1996.

2 TA Instruments - Private Communication, September 1994.

5 LIST OF PLATES AND FIGURES

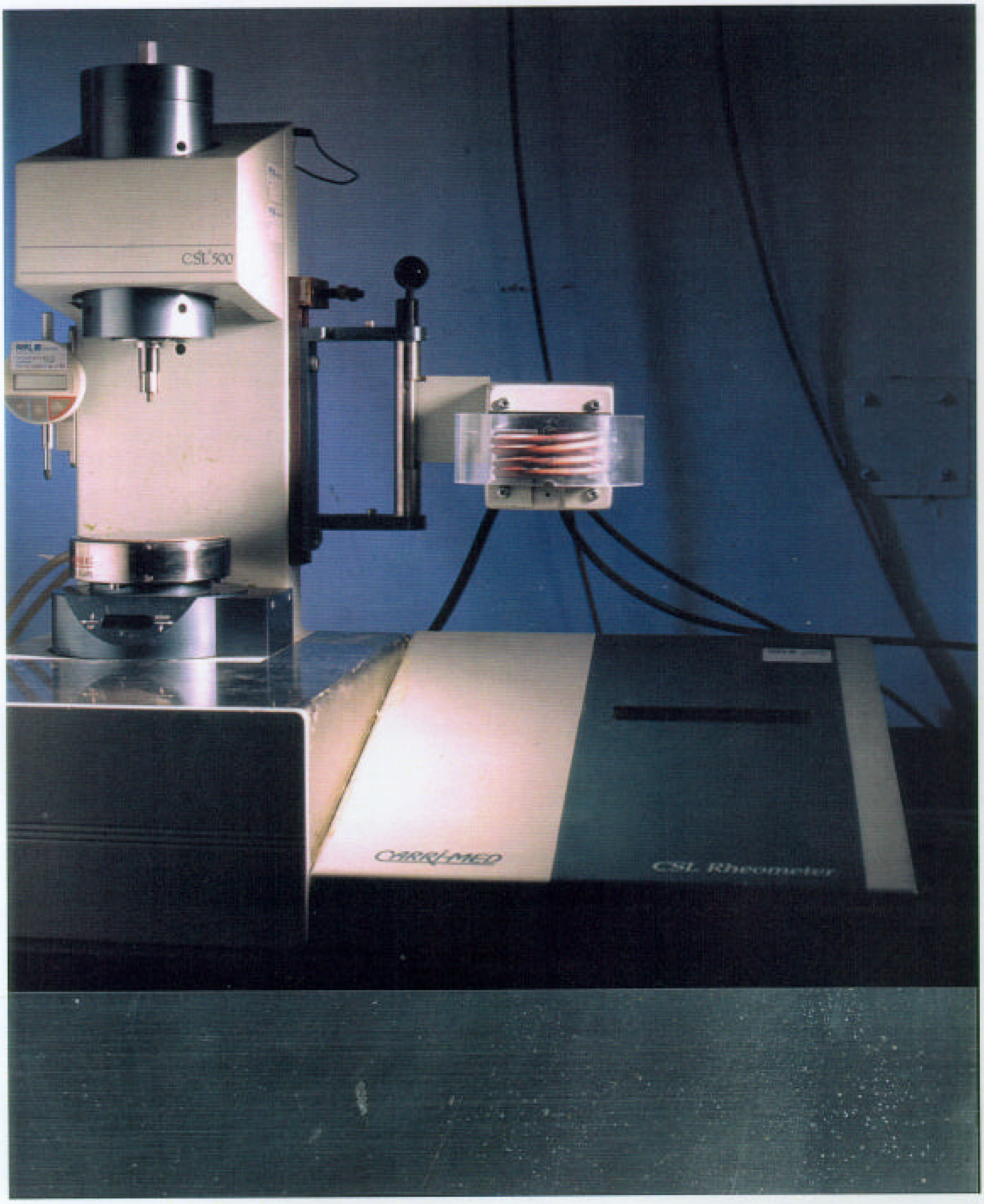


Plate 1 TA Instruments CSL^2 500 constant stress rheometer.

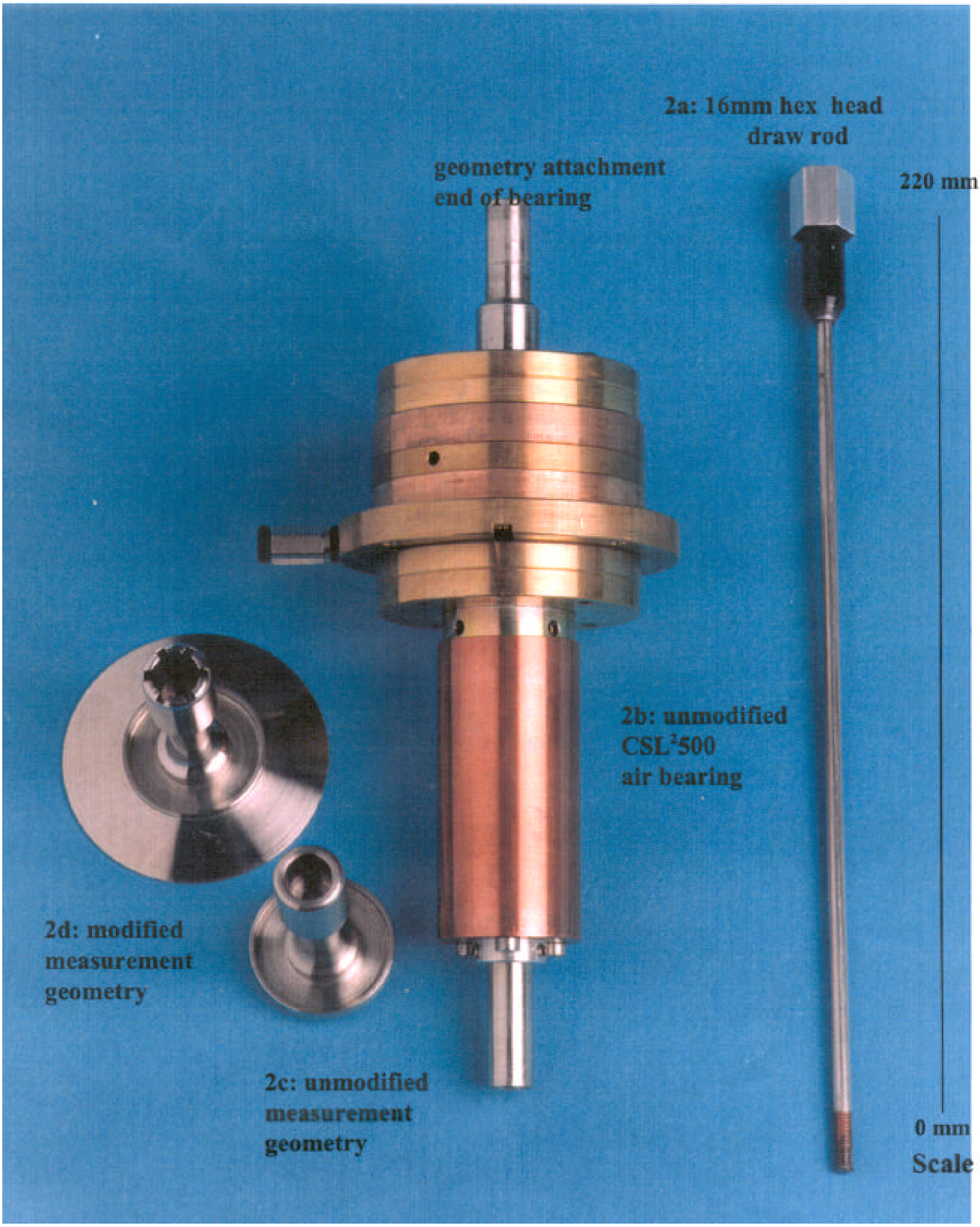


Plate 2: Components of TA Instruments CSL^2 500 constant stress rheometer

Plate 3: Close up of CSL^2 500 modified air bearing

Figure 1:Compliance of CSL air bearing at various tightening torques

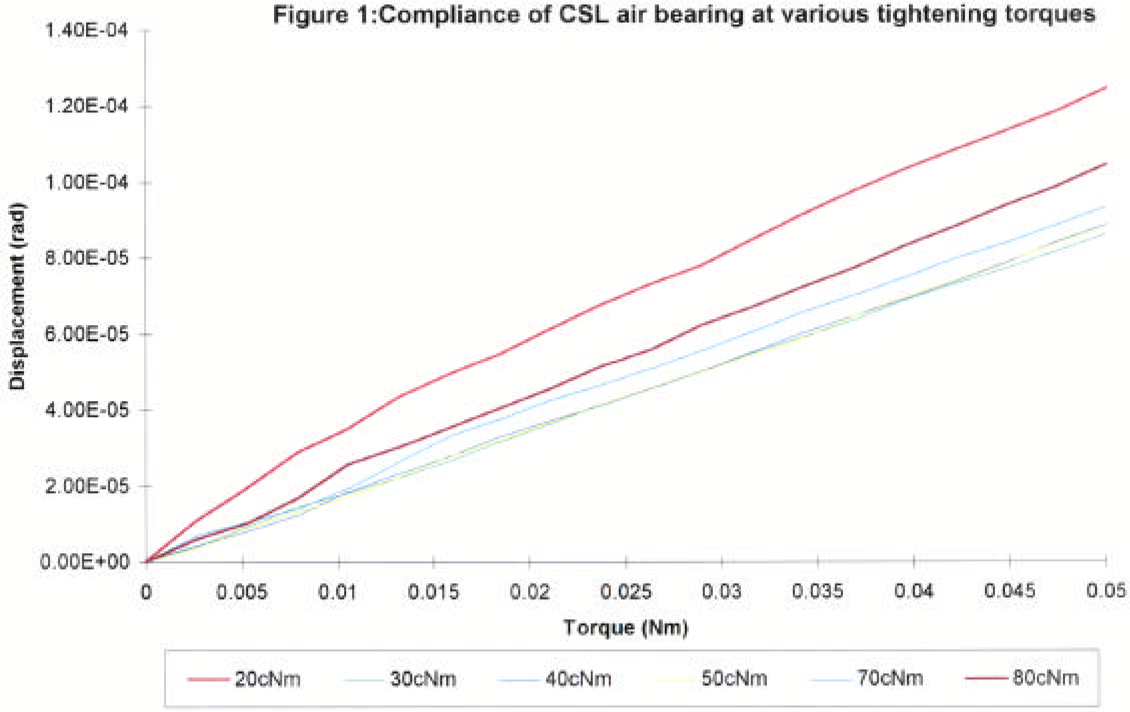
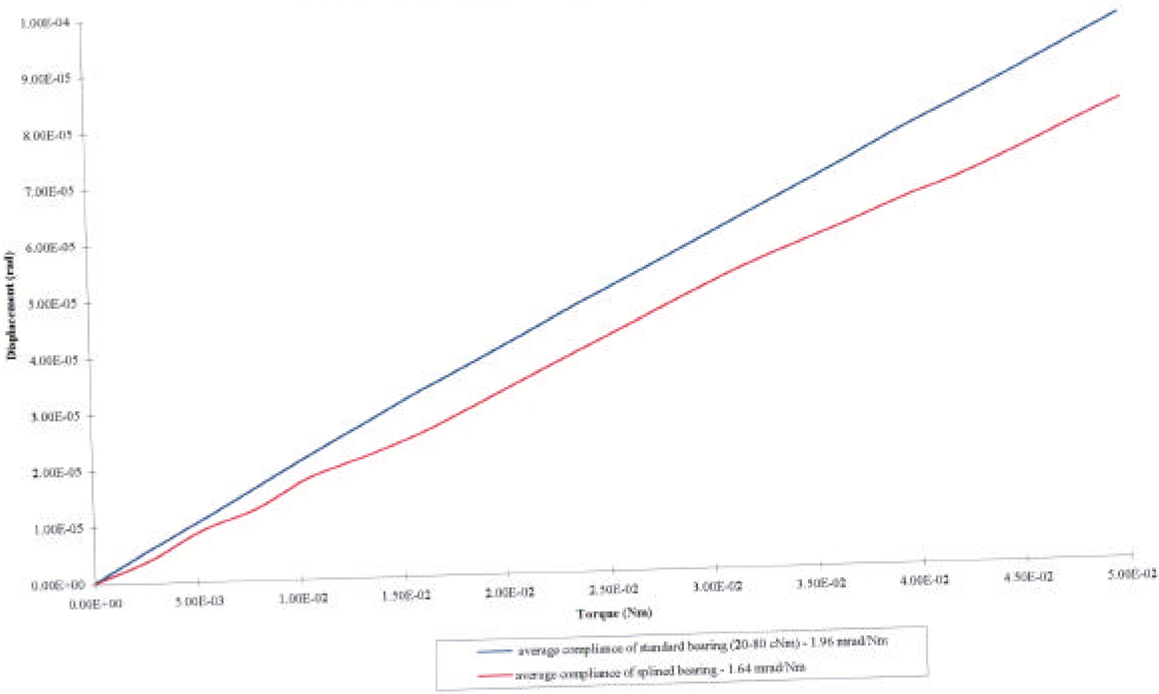


Figure 2: Comparison of standard and splined CSL air bearings



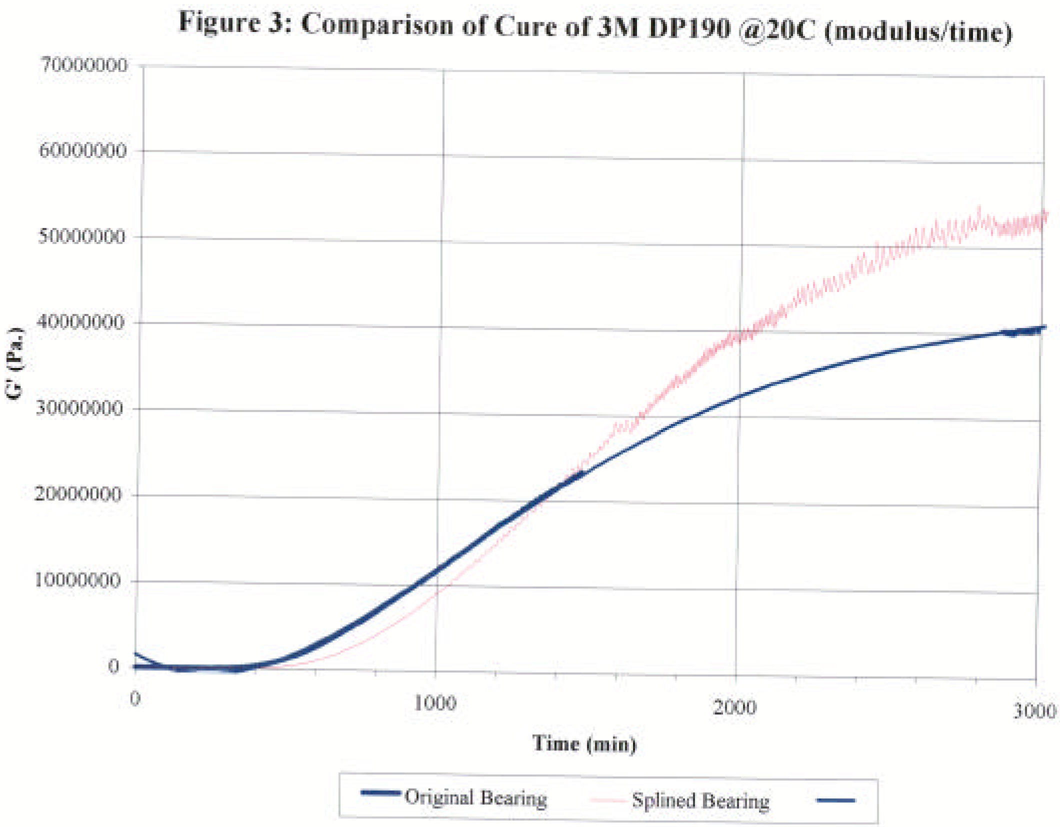


Figure 3: Comparison of Cure of 3M DP190 @20C (modulus/time)
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
G' (Pa.)
0
1000
2000
3000
Time (min)
Original Bearing
Splined Bearing

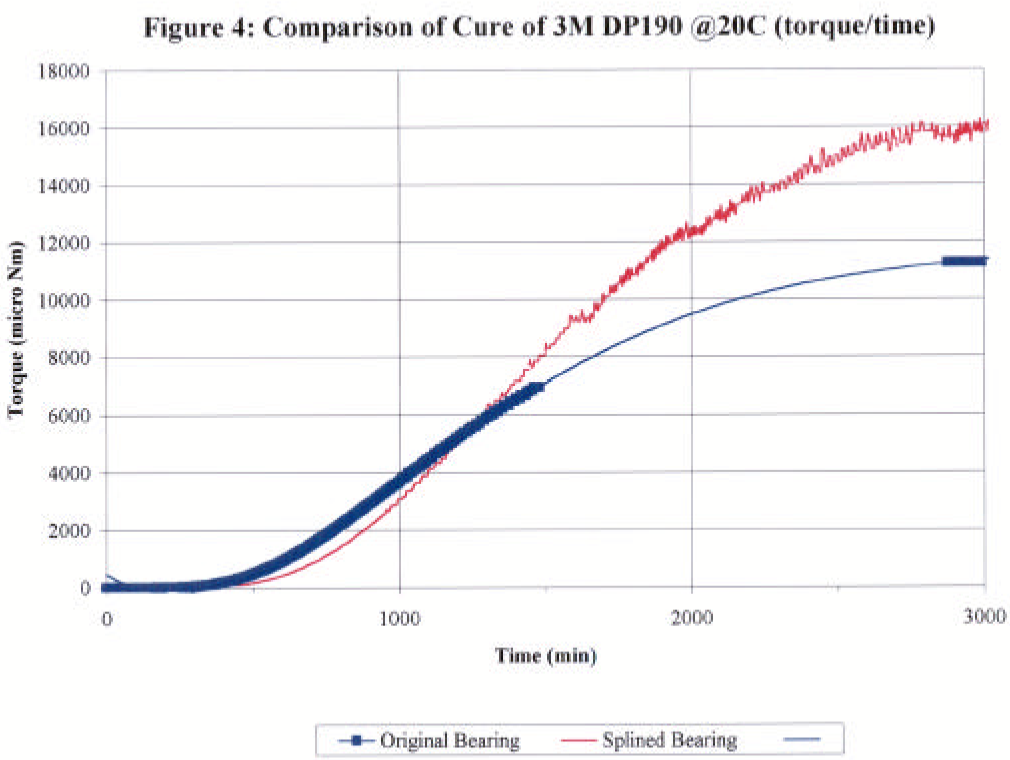


Figure 4: Comparison of Cure of 3M DP190 @20C (torque/time)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Torque (micro Nm)
0
1000
2000
3000
Time (min)
Original Bearing
Splined Bearing