Shear strength of UD material at –40°C
-Iosipescu test results at WMC-

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OPTIMAT BLADES

TG 3

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Change record

Issue/revision	date	pages	Summary of changes
first version	July 28, 2005	19	

Introduction

In the framework of Task Group 3 (Extreme Conditions), material properties at ambient conditions are compared to properties at extreme conditions [1, 2]. The extreme conditions investigated in OPTIMAT are -40° [3], +60° (e.g. [4]), and 100% relative humidity (e.g. [5]).
This document contains details on the planned 5 Iosipescu shear tests conducted at arctic conditions (-40°) at WMC in July 2005. The results can be compared to the results at ambient conditions, obtained at RISØ [6]. The results can also be found in the project database OptiDAT [7].

Specimens and test set-up

The test specimens are ‘V-notched beam’ specimens, which were tested in an Iosupescu fixture according to [8]. The nominal dimensions of the specimens are shown in figure 1. These specimens were received from LM via RISØ, thickness, width, and length were measured, and the coupons were equipped with cross-gauges (type FCA-2-11 manufactured by Tokyo Sokki Kenkyujo Co., Ltd.) on the front side. In addition, a semi-conductor temperature sensor was attached to the specimen surface using hot-melt adhesive, which also served to insulate the back of the sensor.

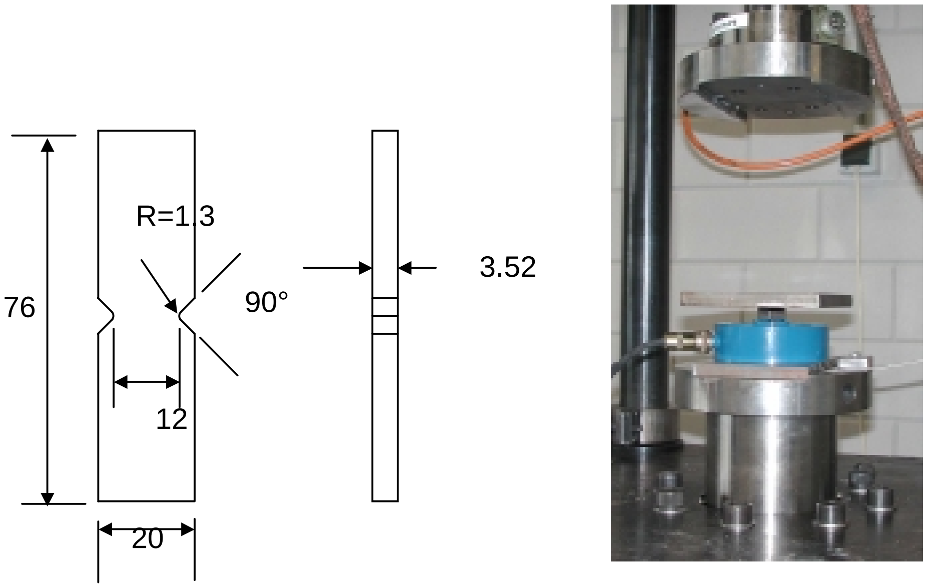


Figure 1: Nominal specimen dimensions and load frame

The shear test was carried out on the 100 kN homebuilt WMC test frame, which had been prepared with a high-resolution-low-force load cell capable of measuring loads up to 7 kN. The load frame and load cell are depicted in figure 1.

After the specimen had been prepared, it was mounted in the Iosipescu fixture. The fixture was partially covered in thermally insulating foam. One of the foam pads carried a second temperature sensor, which measured the temperature on the fixture surface. The specimen and fixture were subsequently cooled in ‘dry ice’, i.e. solid CO_2. Nominal temperature was –79.8°C. Packing and cooling

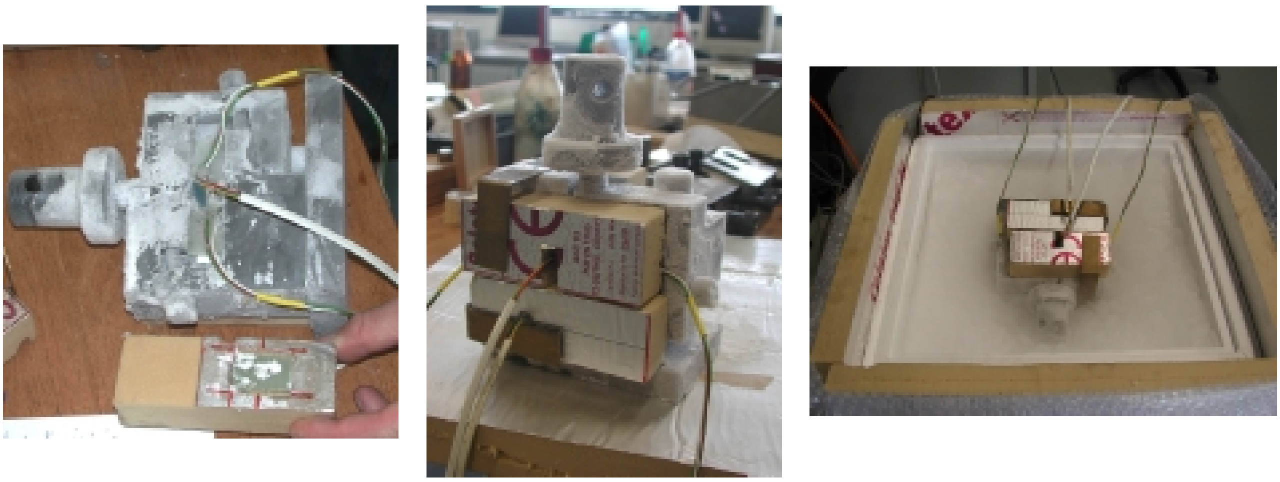


Figure 2: left to right: coupon in pre-frozen Iosipescu fixture; insulated fixture; fixture in dry ice

of the specimen is shown in figure 2.

During cooling, the cross gauges were calibrated to a zero reading at -40°, to prevent temperature influence from the cooling process on the strain measurement. The combination was cooled down to ca. -55°C, and installed in the set-up and left to re-heat. Once the temperature reached approximately -45°C, the displacement controlled test was started. The specimen was subjected to a monotonous displacement ramp. Given the specimen heating rate, and the displacement rate of 1mm/min, this procedure caused the temperature to be as close to -40°C as possible during failure of the specimen. Three specimens were quite far outside the intended temperature range.

The temperature difference between the fixture and load frame did not cause errors in the load or displacement registration, nor was movement of the two fixture halves constrained because of the low temperature. After failure, the specimens were photographed and archived.

Results

According to the DPA, 5 shear tests were scheduled. Because of the test-set-up used at WMC, the temperature during the test was in a range of ca. 5 °C. Therefore, some extra tests were carried out, and a total of 10 specimens has been tested.

The results of the tests are summarised in table I and figure 3. A selection of the failed specimens is depicted in figure 4. Failure mode was valid according to the ASTM standard [8].

Load, displacement, and strain were measured and recorded. However, The combination of strain gauges and measurement amplifier did not allow for quantification of the maximum strain. The data can be found in OptiDAT.

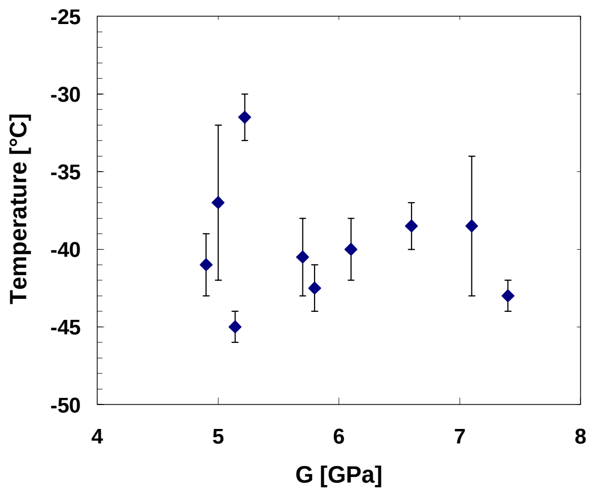
The maximum loads are within a 10% range. Shear modulus scatter is higher, moduli range between 4.9 and 7.4. A correlation between temperature, modulus and stress at failure is not evident from figure 3, although the sample size is small, even with double the amount of tests compared to the initial plan. Comparison with the results at other temperatures is shown in figure 5 (note, that at other conditions, 'loading-unloading-reloading'- tests, and tests at other labs, have been included also).

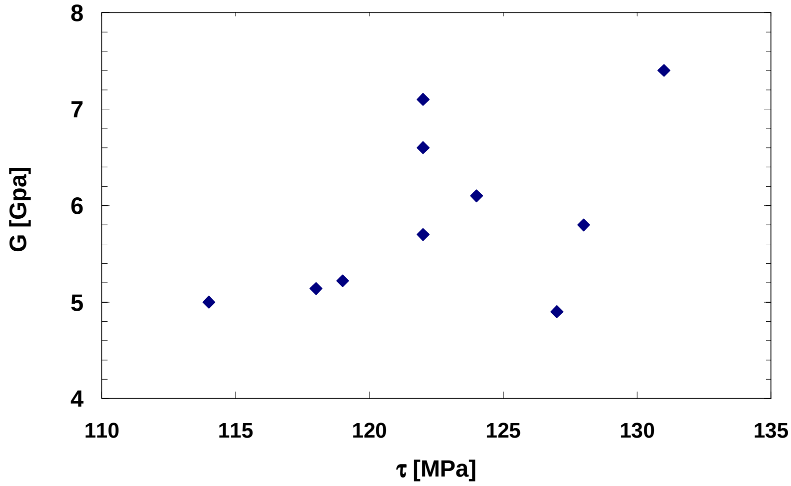
Table I: Results

Specimen	**Load [kN]**	**Shear stress [MPa]**	**Shear modulus [GPa]**	**Temperature [°C]**	
				start	***end***
GEV206_I0400_0054*	5.00	114	5	-42	-32
GEV206_I0400_0055*	5.40	122	7.1	-43	-34
GEV206_I0400_0056*	5.20	119	5.22	-33	-30
GEV206_I0400_0057	5.20	118	5.14	-46	-44
GEV206_I0400_0058	5.66	128	5.8	-44	-41
GEV206_I0400_0059	5.40	122	6.6	-40	-37
GEV206_I0400_0060	5.50	124	6.1	-42	-38
GEV206_I0400_0061	5.74	131	7.4	-44	-42
GEV206_I0400_0062	5.40	122	5.7	-43	-38
GEV206_I0400_0063	5.50	127	4.9	-43	-39

*Tests marked as 'invalid' in the database because of wrong temperature range

The full acquired data are shown in figures 6-15. The values for all parameters were normalised using the value at maximum force (except for temperature). Shear modulus was calculated using strains between 0.1% and 0.35%. This range is slightly smaller than prescribed in [8], but has been used successfully to obtain moduli that are consistent with the results of other shear test methods [9]. As is obvious from the shear modulus figures, the value of the shear modulus depends significantly on the strain range, since the τ-γ diagrams are highly non-linear.





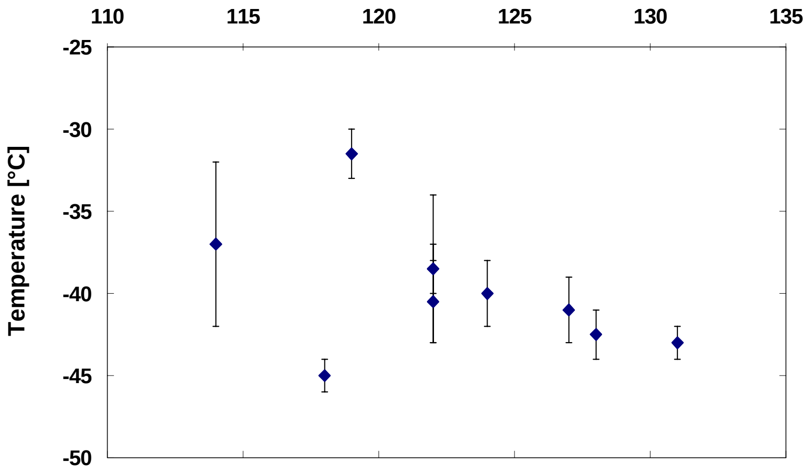


Figure 3: Results from table I

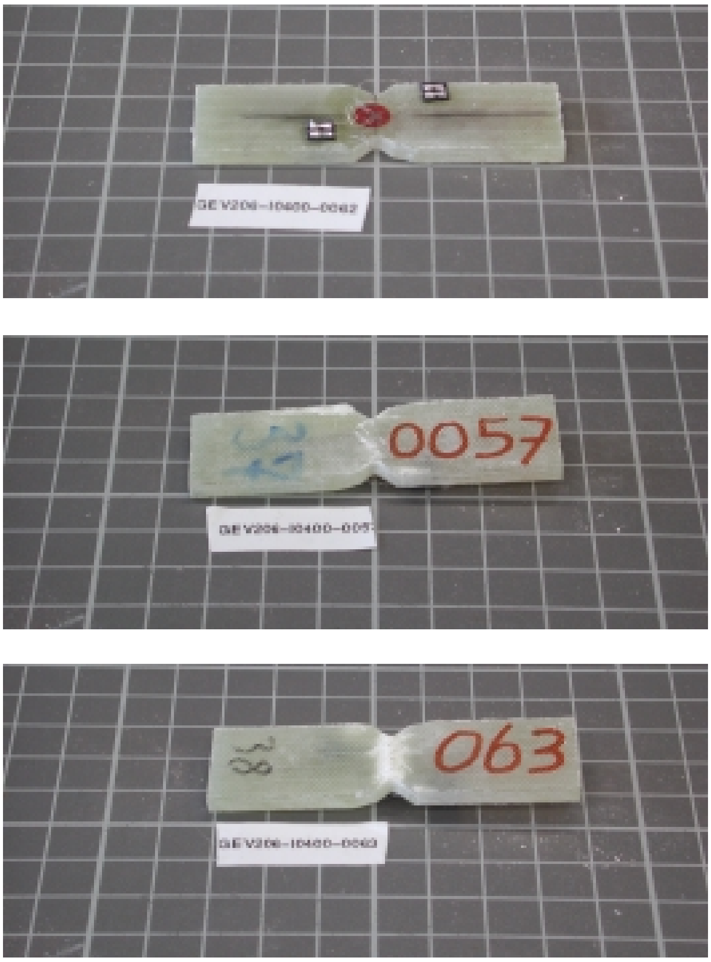


Figure 4: examples of failed specimens

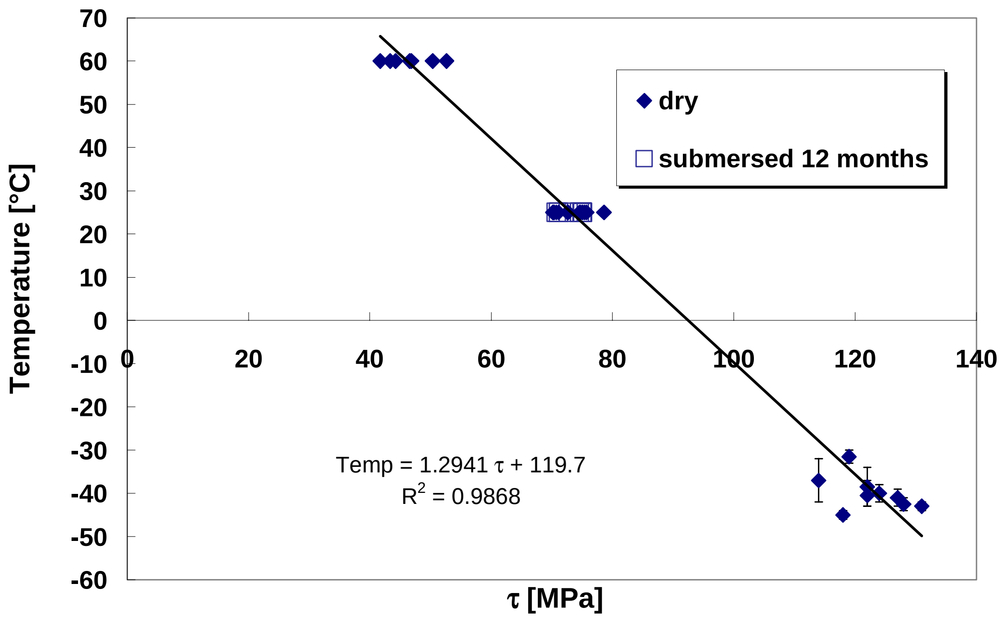
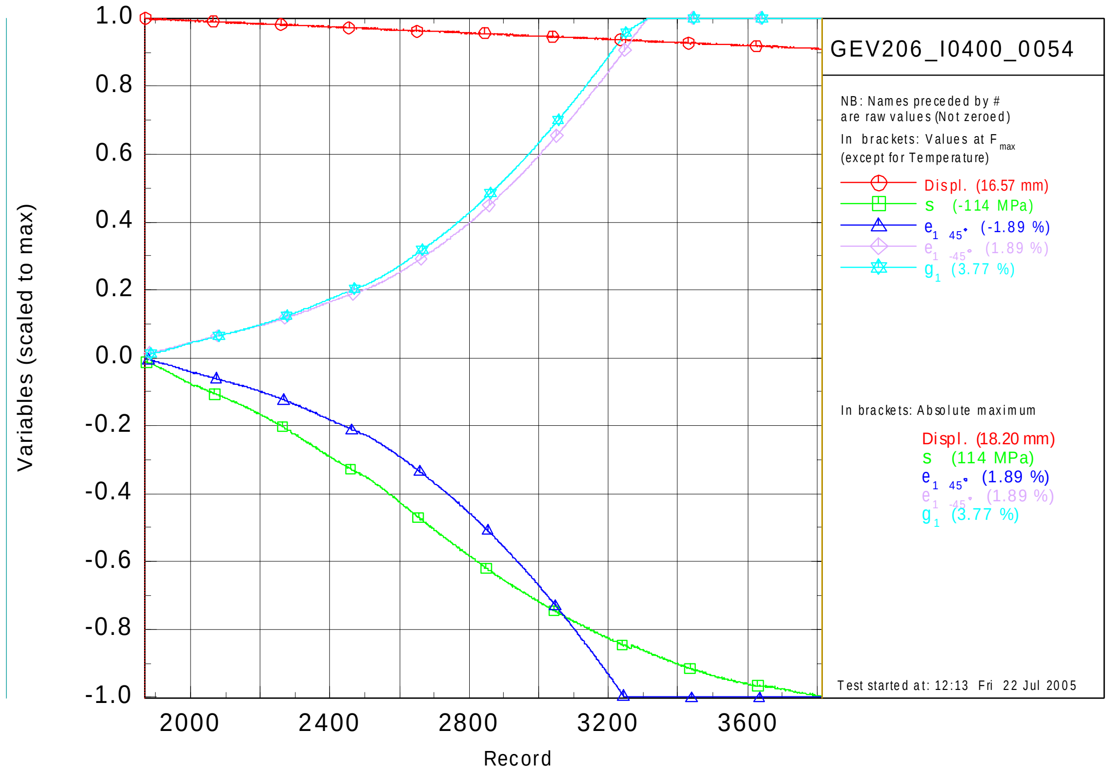


figure 5: comparison with test results at other temperatures (and labs, and test conditions. Data from OptiDAT



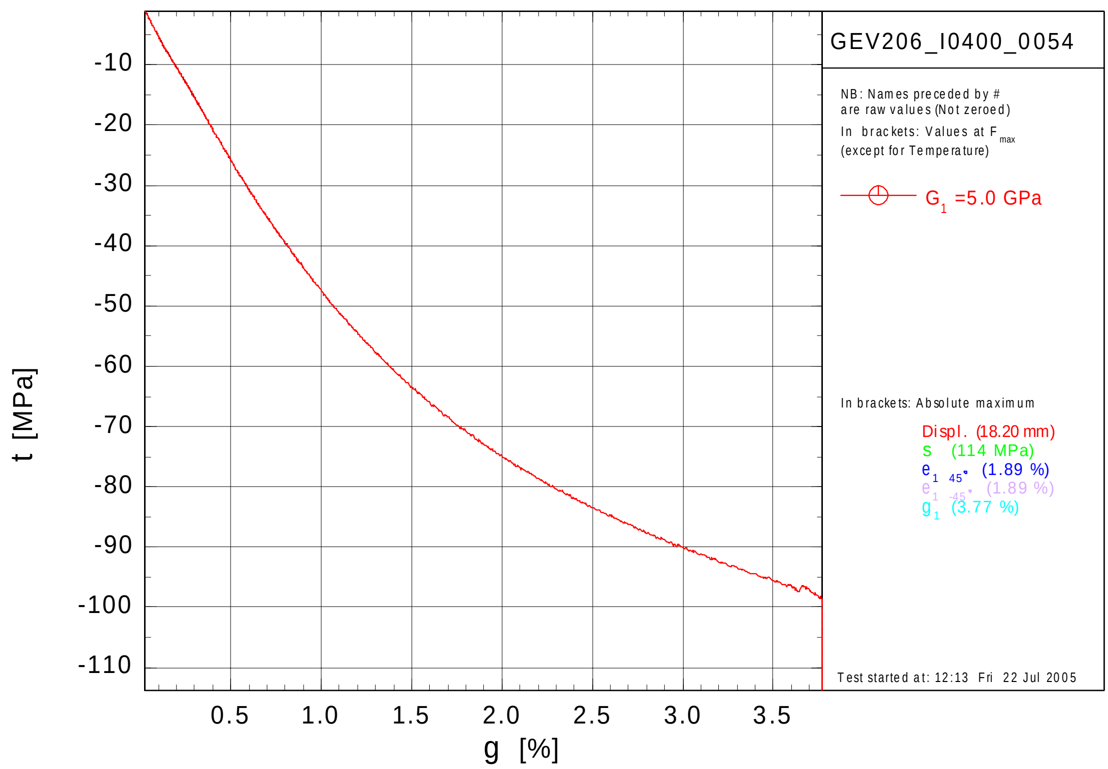
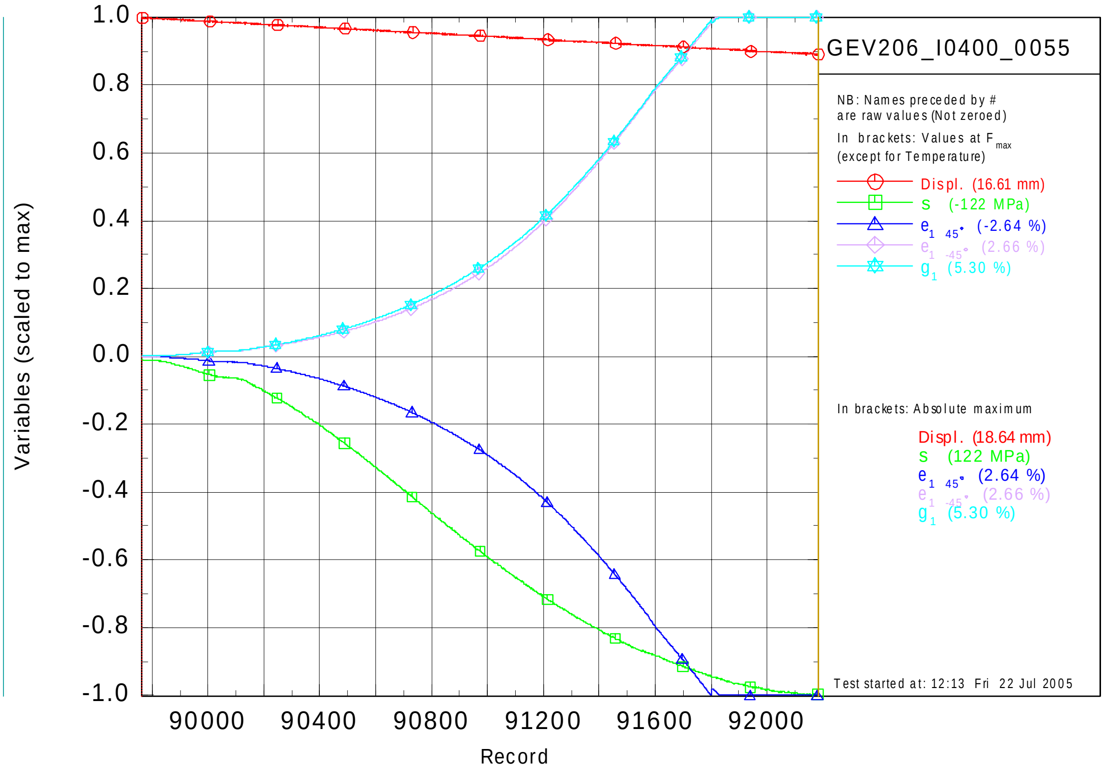


figure 6: Results for specimen 54



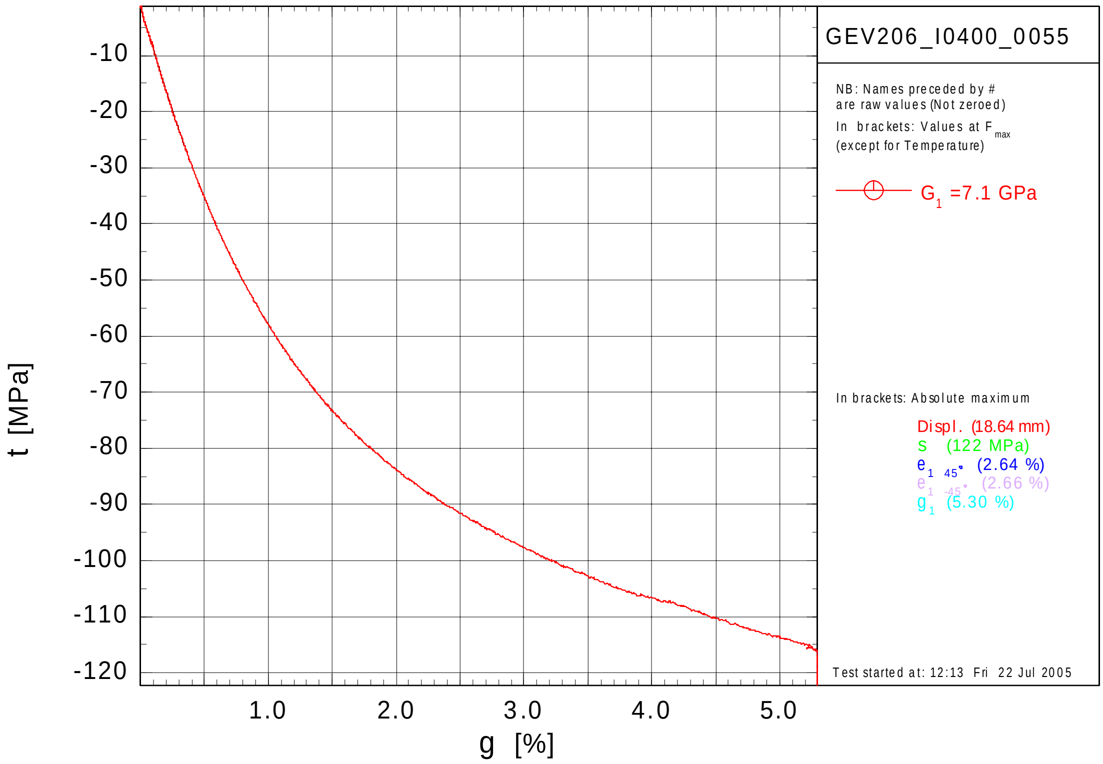
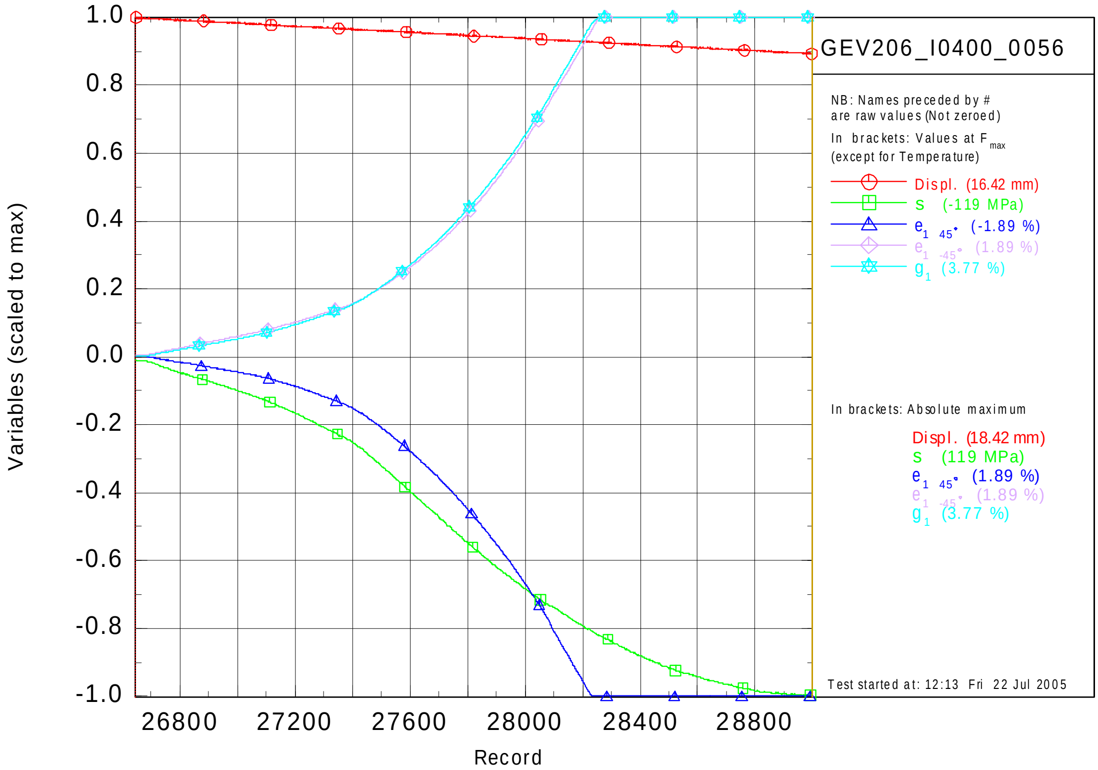


figure 7: Results for specimen 55



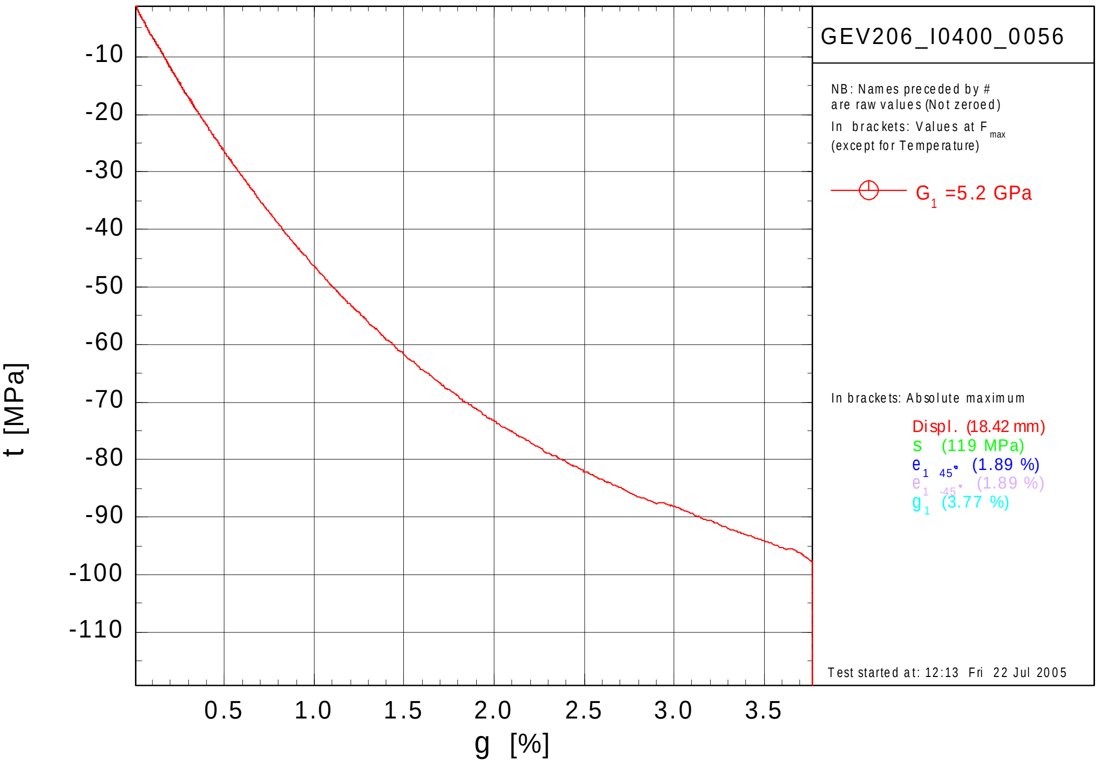
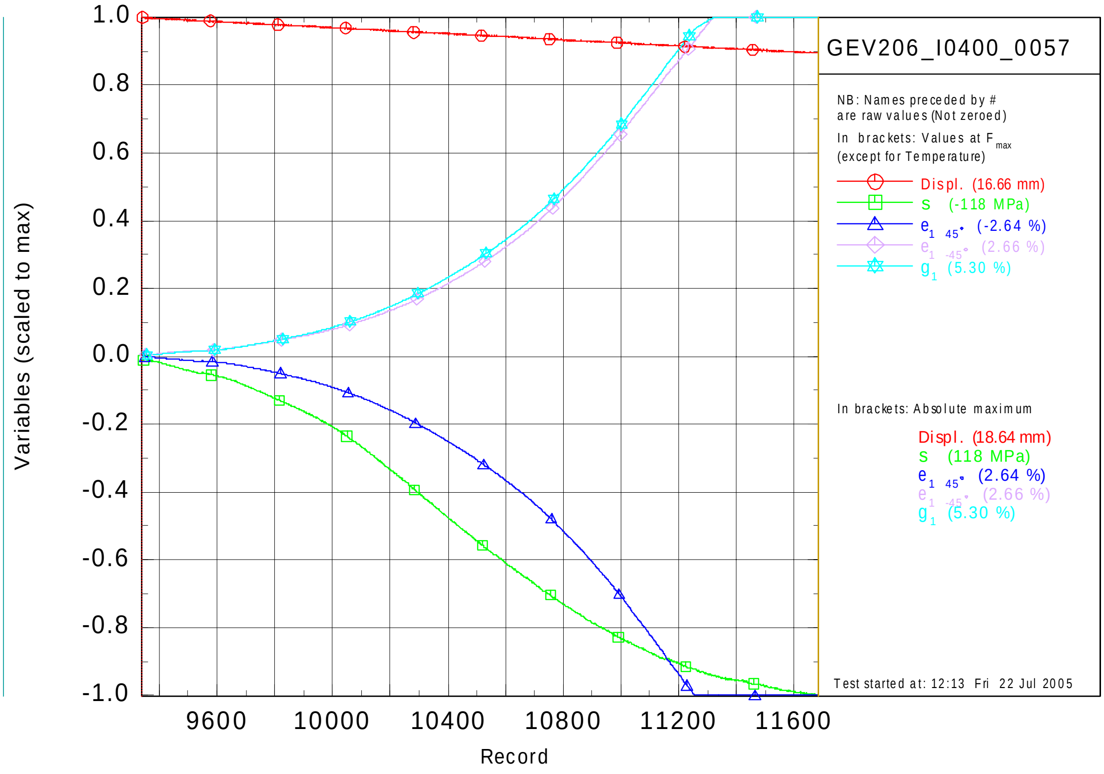


figure 8: Results for specimen 56



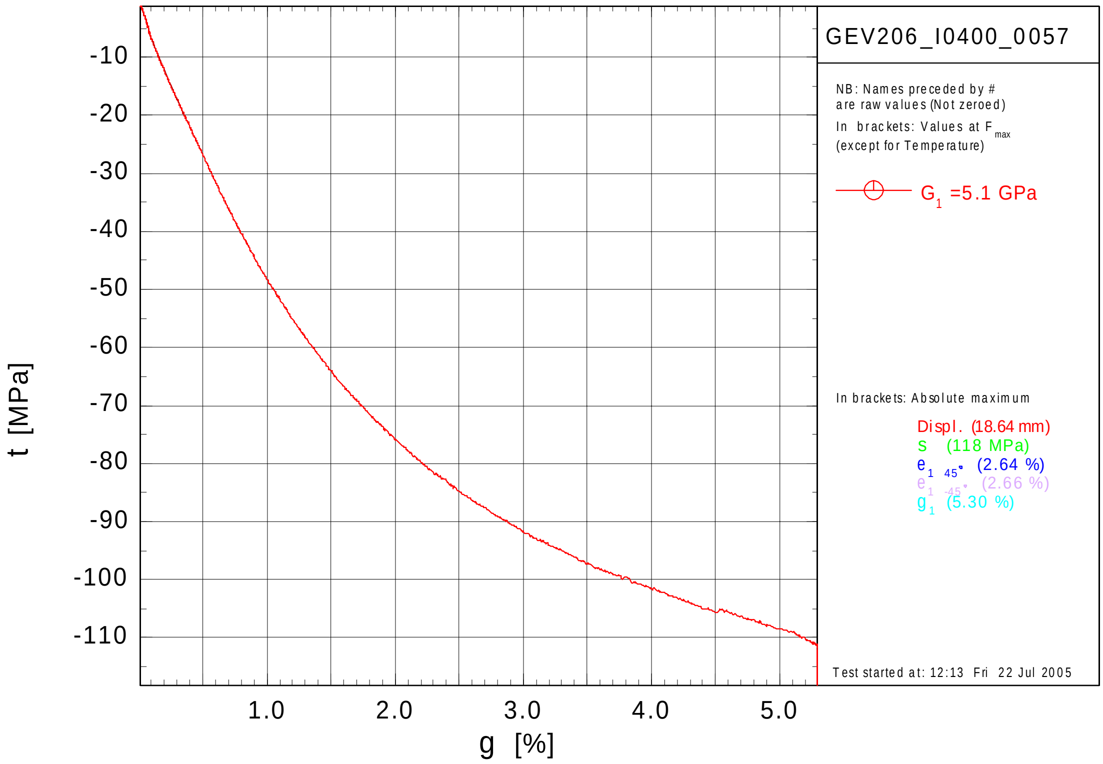
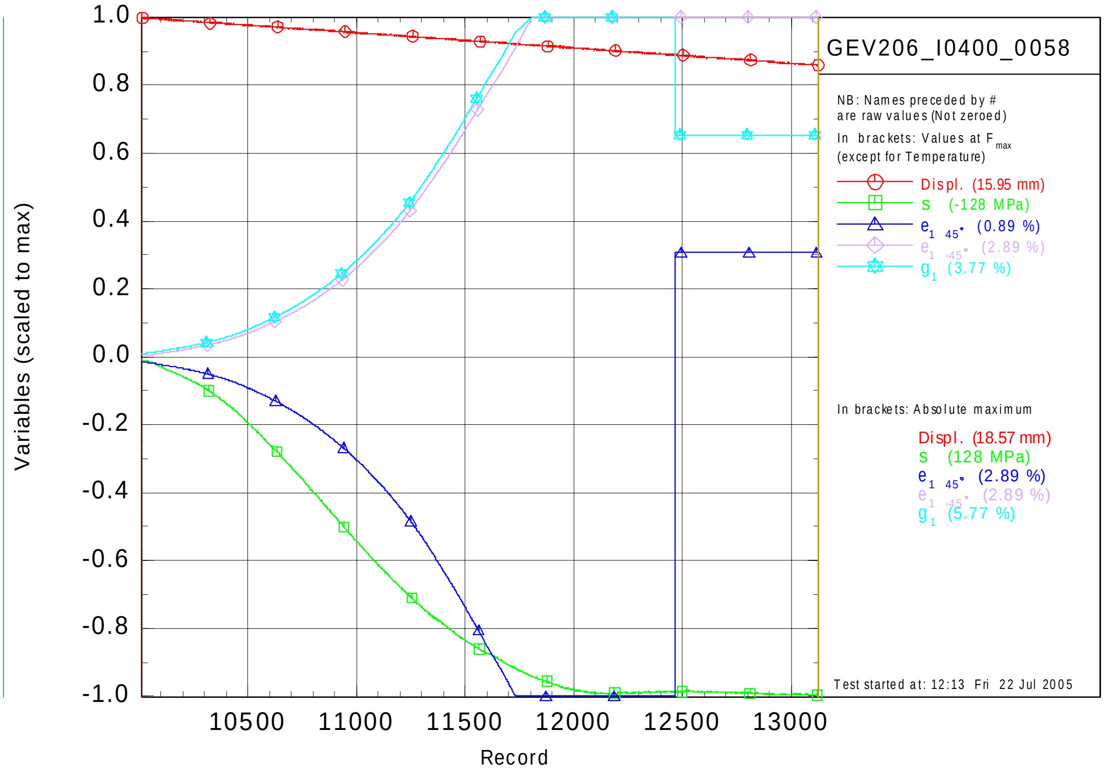


figure 9: Results for specimen 57



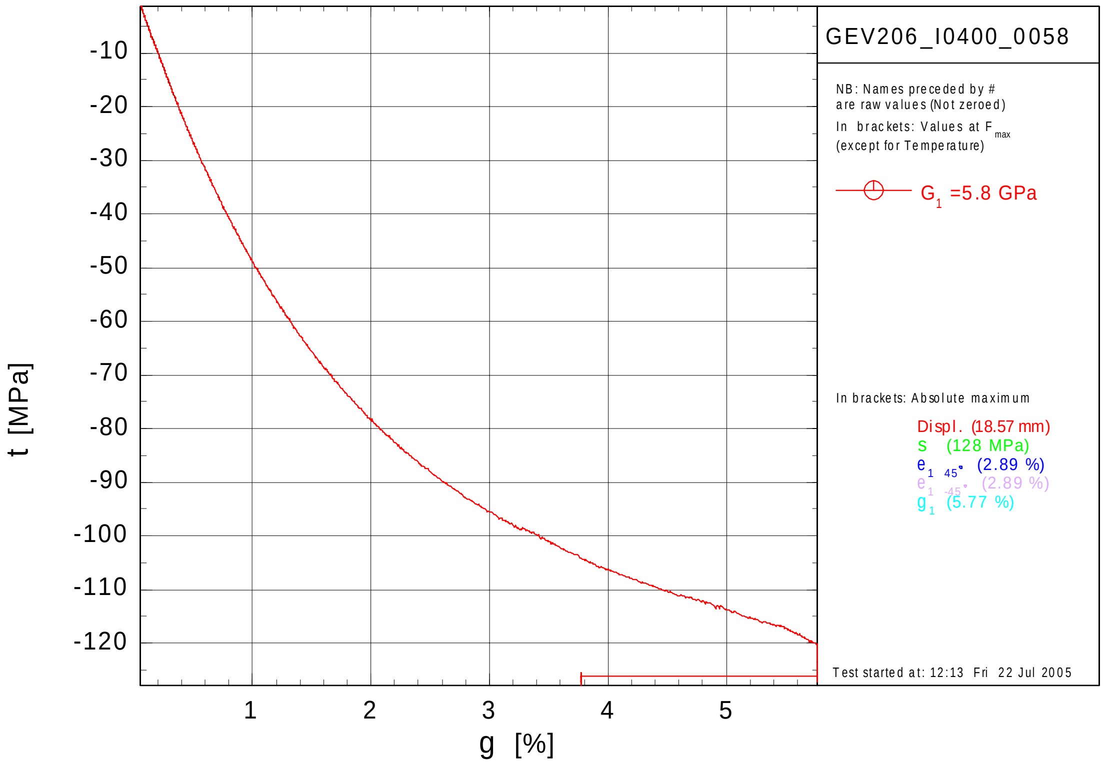
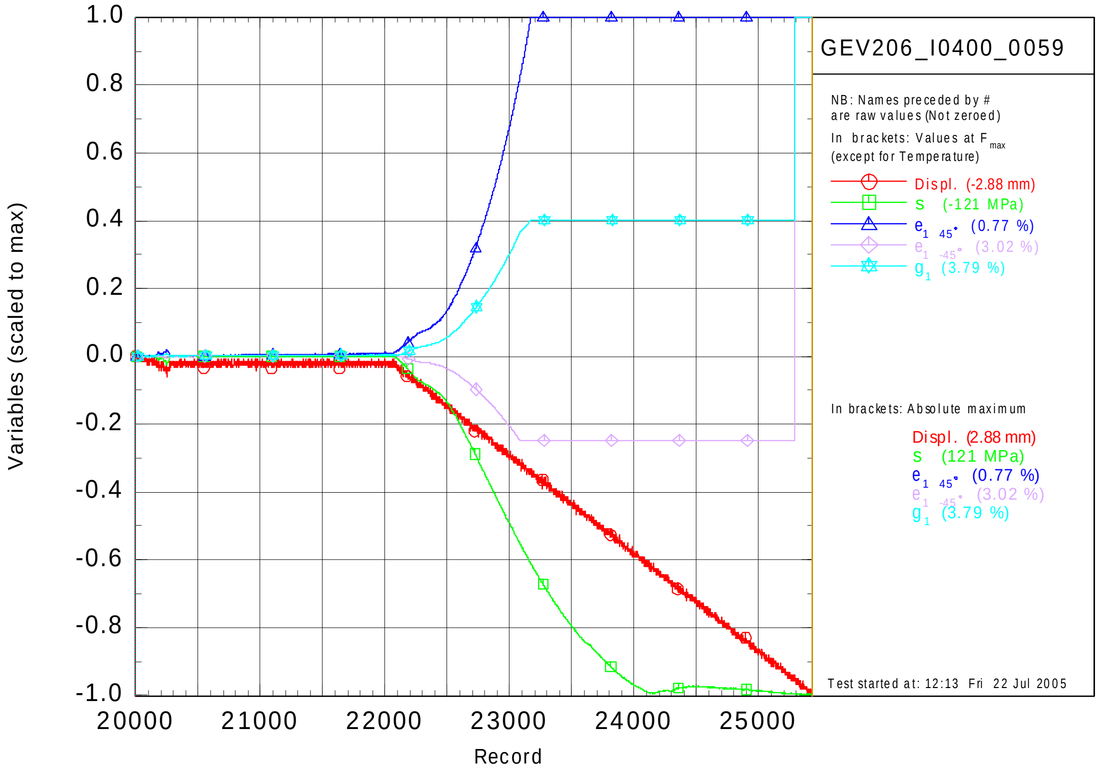


figure 10: Results for specimen 58



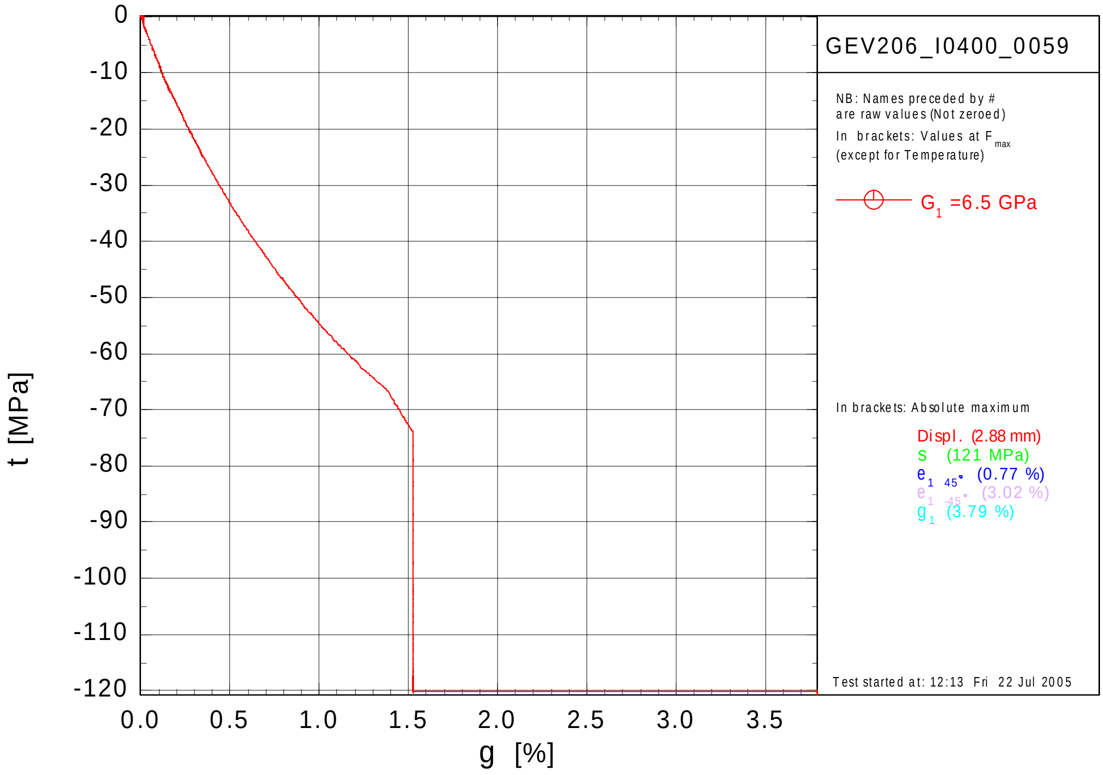
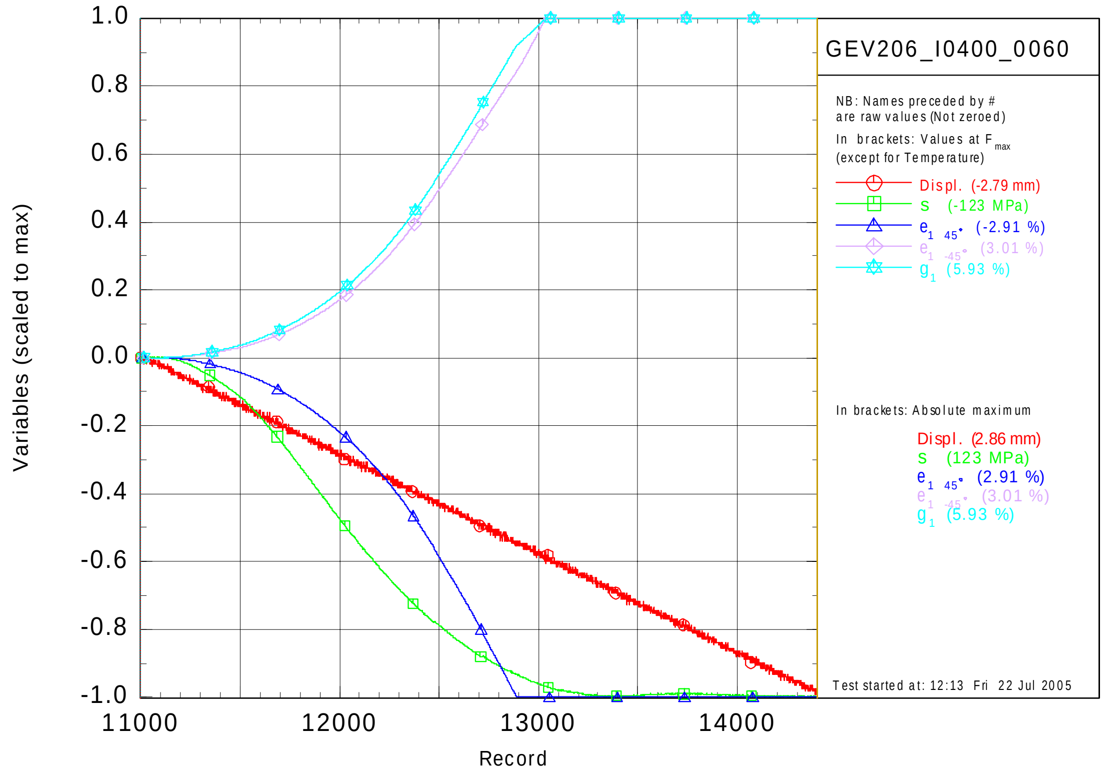


figure 11: Results for specimen 59



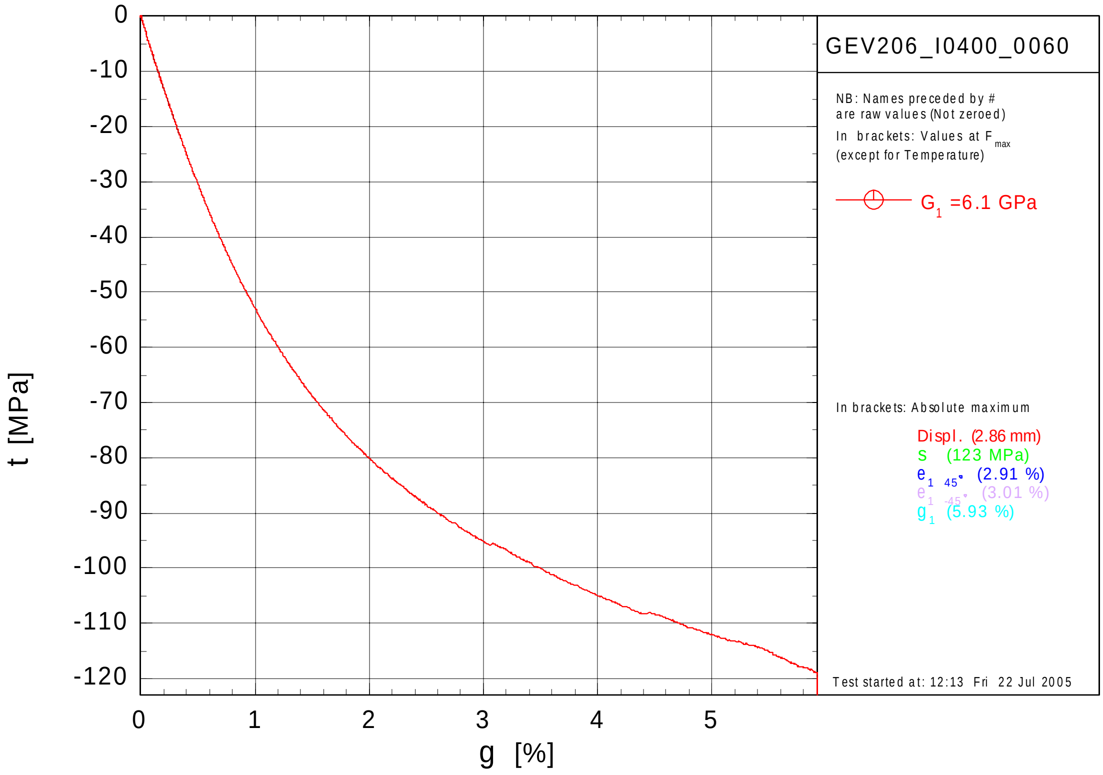
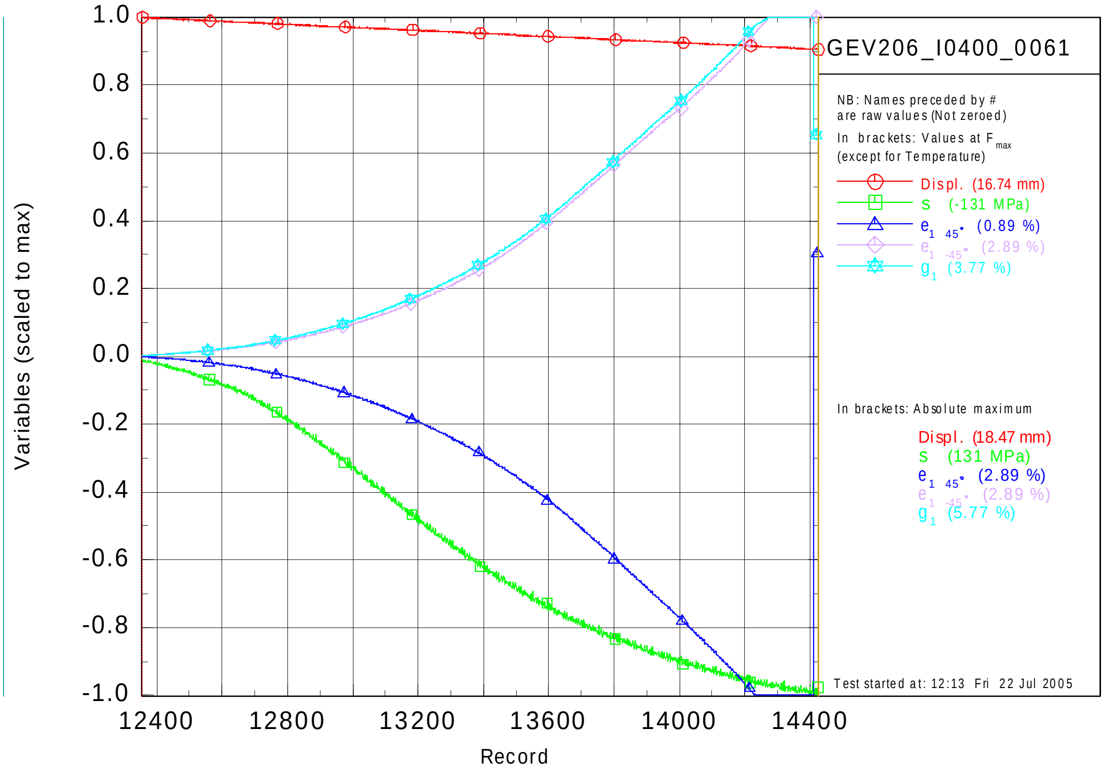


figure 12: Results for specimen 60



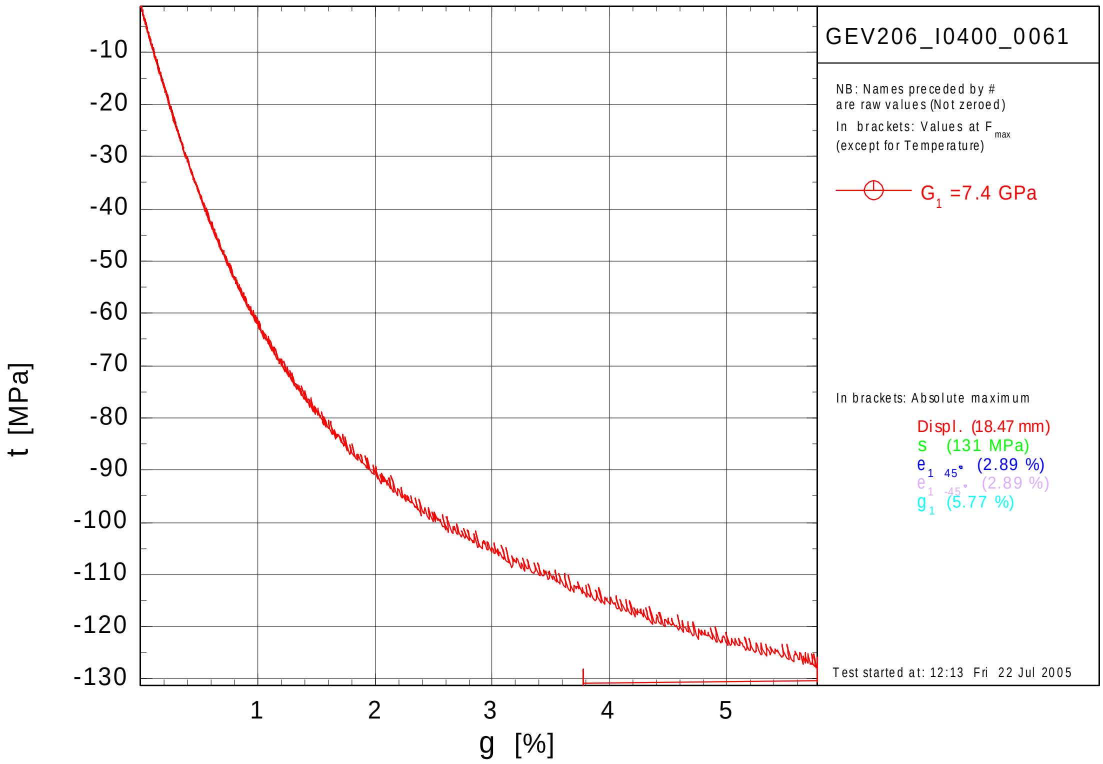
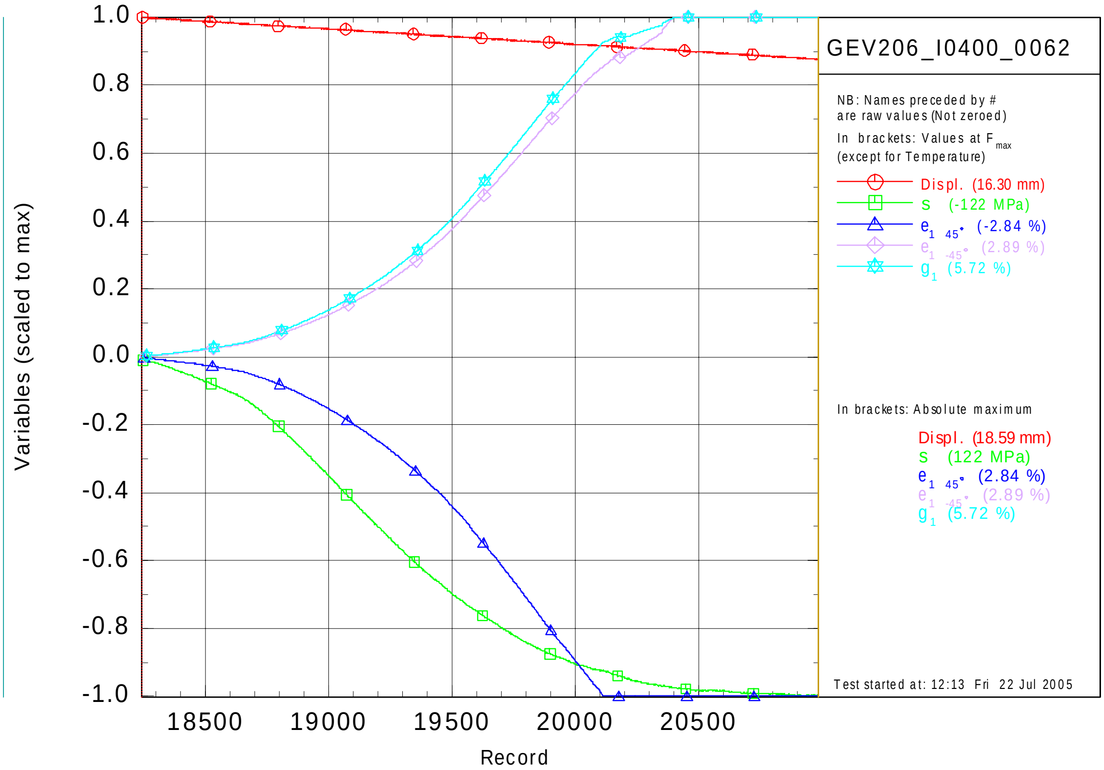


figure 13: Results for specimen 61



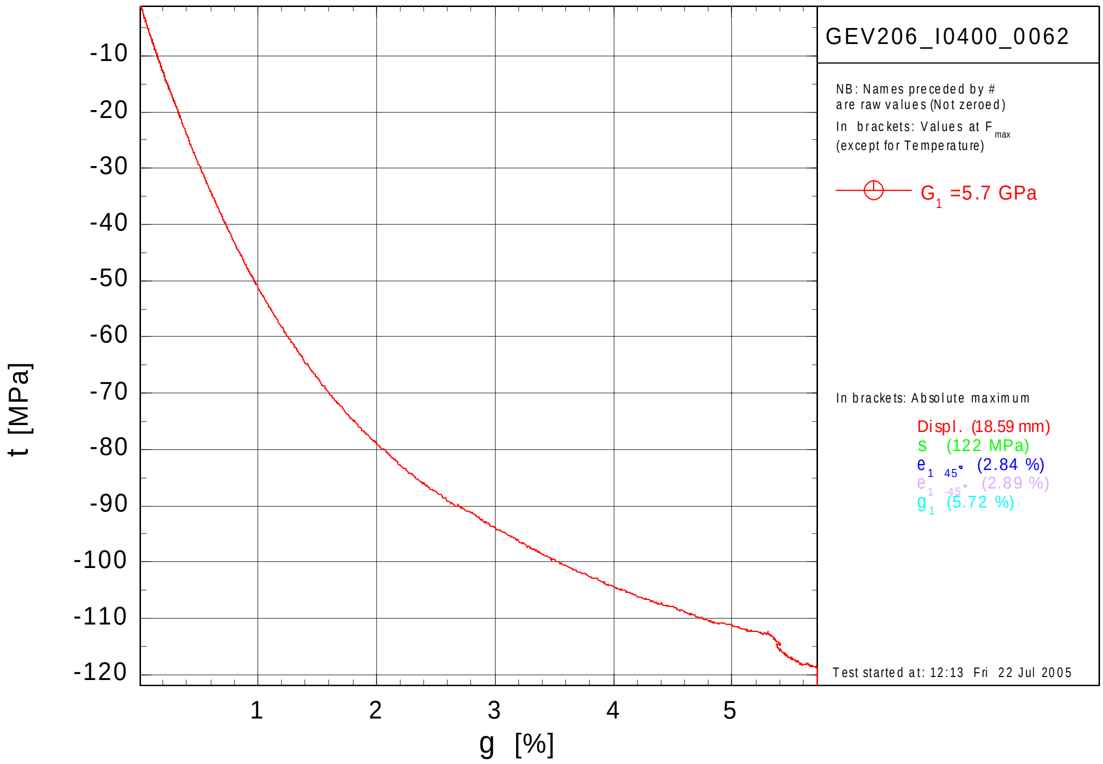
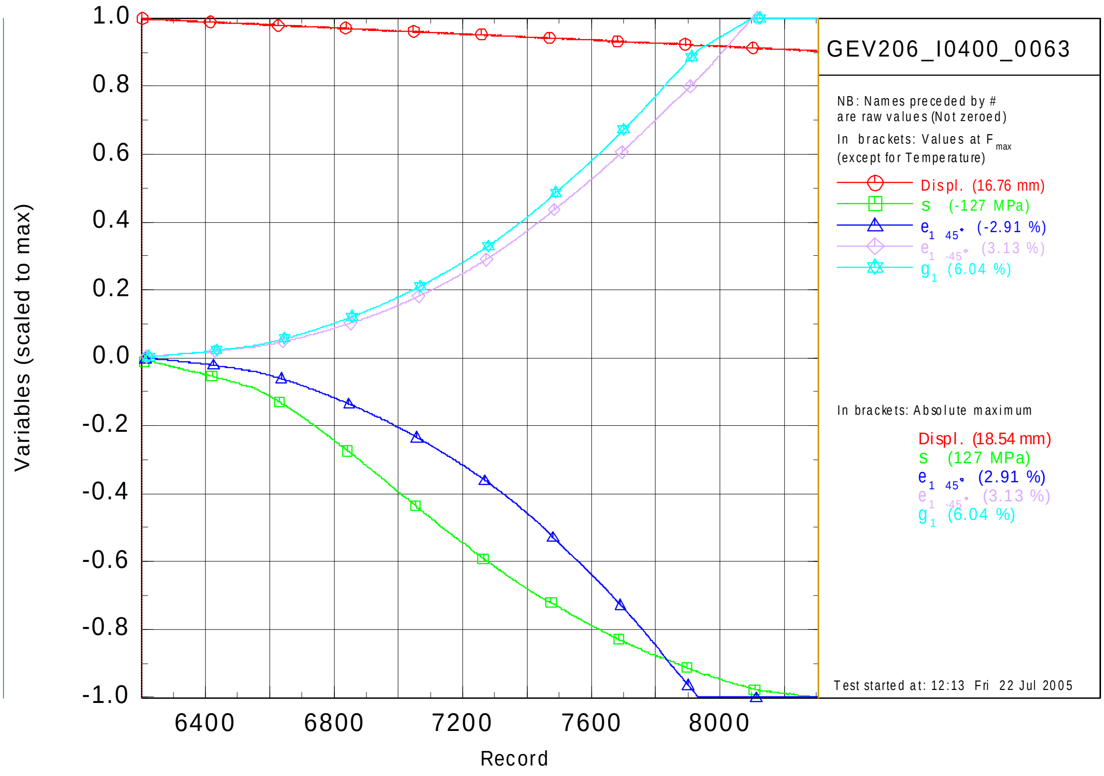


figure 14: Results for specimen 62



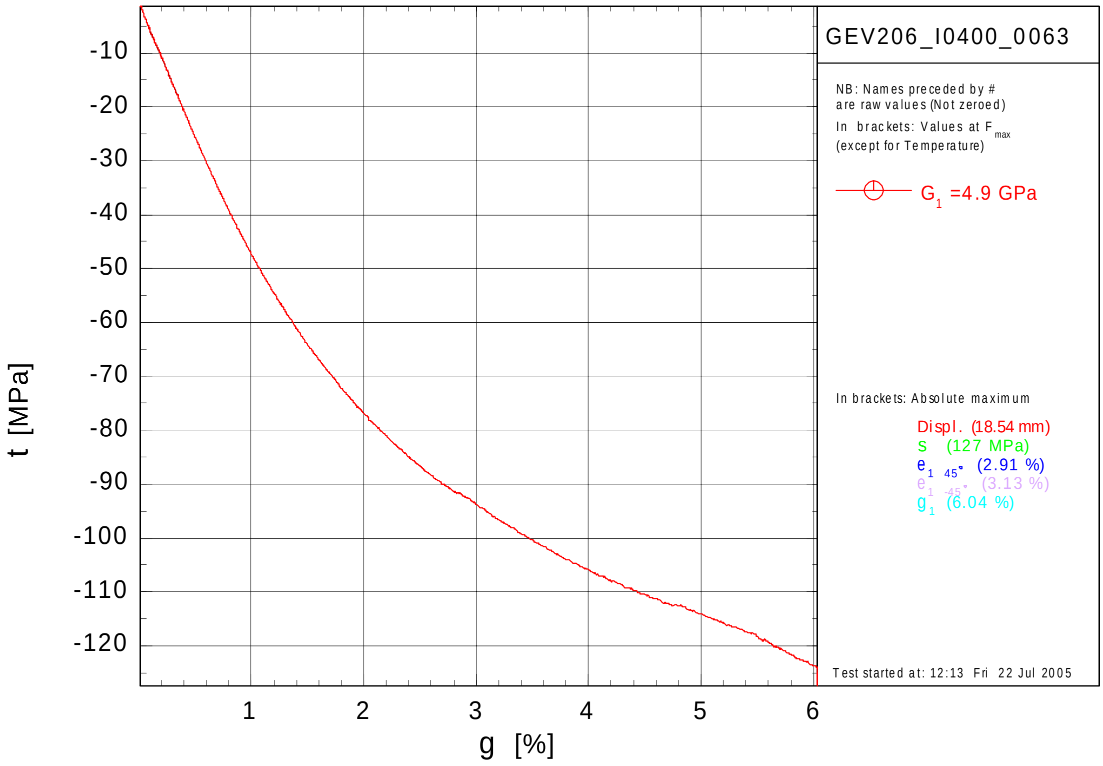


figure 15: Results for specimen 63

Conclusions

From results on 10 Iosipescu specimens tested in shear at –40°C, the maximum shear load is an estimated 100% higher than for similar specimens tested at ambient conditions, or almost three times as high for specimens tested at 60°C. This makes the relation between maximum shear strength and temperature approximately linear. Significant scatter was found in shear modulus, but no correlation is evident between strength, modulus, and temperature.

References

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