Benchmark Tests of OPTIMAT UD coupons

OB_TG1_R006 rev. 000

Confidential

TG 1

Olaf Krause

Change record

Issue/revision	date	Pages	Summary of changes
0	13.08.2003	all	new document

Table of contents

1 Introduction

This work was carried out according to the test plan in DPA [1] and the Test Plan Report of TG1 [2]. In total, 20 UD specimens were tested under static and fatigue loading. Five coupons each were tested in static tension and five in static compression. Ten coupons were tested under fatigue loading at R=-1 (tension-compression).

2 Test coupons

For all tests Standard Optimat UD Coupons were used. The nominal dimension of the test coupons are shown in Figure 1.

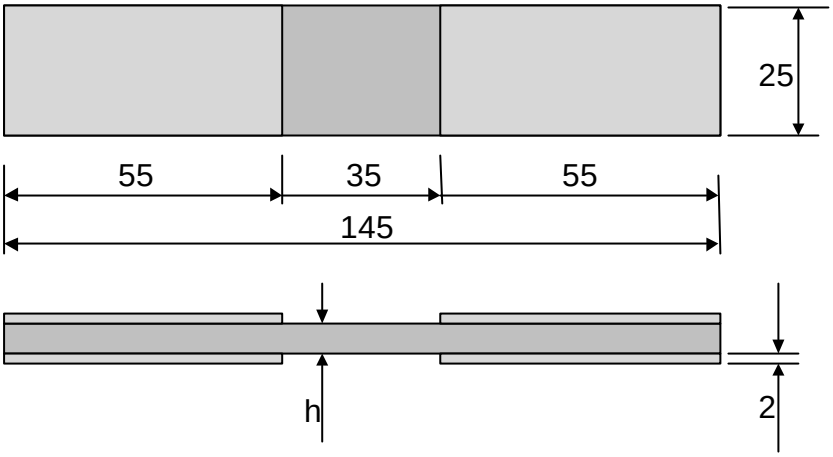

Figure 1: Geometry of Optimat UD test coupon

3 Experimental

3.1 Static tensile tests

Tests were carried out on a Zwick 200 kN test machine equipped with hydraulic grips of 100 kN capacity. Strain was measured using 2 TML gauges (one on each side of the specimen) with a gauge length of 6 mm and nominal electrical resistance of 120 Ohms, type FLA-6-11-1L. Load was applied displacement-controlled with nominal speed of 0.25 mm/min.
All tests were carried out at ambient room conditions.

3.2 Static compression tests

Tests were carried out on a Mohr und Federhaff 250 kN servo-hydraulic test machine equipped with mechanical grips using a Roell Amsler K7500 control-unit. Strain was measured using 2 TML gauges (one on each side of the specimen) with a gauge length of 6 mm and nominal electrical resistance of 120 Ohms, type FLA-6-11-1L. Strain gauge measurements were acquired using an HBM UPM100 acquisition system. Load was applied displacement-controlled with nominal speed of 1 mm/min.
All tests were carried out at ambient room conditions.

3.3 Fatigue tests

Tests were carried out on the same test machine as the static compression tests with identical strain gauge equipment and data acquisition system. Load was applied force-controlled. The three load levels and corresponding testing frequencies are given in [5]. One additional data point at a further stress level was determined.
Surface temperature was measured using a thermocouple on the narrow side on the specimen nearby the lower tab. All tests were carried out at ambient room conditions (no air-conditioned lab) using a small fan for cooling.

4 Test Results

4.1 Static tensile tests

Elastic modulus was determined for axial strains between 500 and 2500 µstrain, according to EN ISO 527-1 [3]. Values were calculated using the average of the two strain gauge measurements. Experimental results are summarized in Table 1. Failure was located within the free length of the coupon.

Material property	Unit	Measurement	COV [%]
Elastic modulus	MPa	39019	0,46
Tensile strength	MPa	838,50	3,07
Tensile strain to failure	%	2,29	2,45

Table 1: Results from static tensile tests for UD coupons

4.2 Static compression tests

Elastic modulus was determined for axial strains between 500 and 2500 µstrain, according to EN ISO 14126 [4]. Values were calculated using the average of the two strain gauge measurements. Experimental results are summarized in Table 2. Failure was located within the free length of the coupon.

Material property	Unit	Measurement	COV [%]
Elastic modulus	MPa	38928	1,56
Compression strength	MPa	588,04	4,88
Compression strain to failure	%	1,51	4,87

Table 2: Results from static compression tests for UD coupons

4.3 Fatigue tests

Ten coupons were tested in Constant Amplitude fatigue under load control keeping stress ratio constant for all tests at R=-1. Tests were stopped after coupon failure. Strain gauges measurement was set to zero before mounting the coupon in the test rig. Test was started with one “quasi-static” cycle at a frequency of 0.02 Hz to acquire data with strain gauges and determine strains and initial values of elastic modulus under tensile and under compressive loading. The fatigue test was started after this cycle by increasing the test frequency without stopping the machine.
Test results are presented in Table 3 and Figure 6 showing cyclic stress vs. cycles to failure.
The stress-strain curves for each strain gauge and coupon can be seen from Figure 7 to Figure 15, except for coupon GEV206-R0300-0116 due to one defective strain gauge. As it can be clearly seen, the curves for all coupons are very similar and lie very close together. For coupons GEV206-R0300-0117 and GEV206-R0300-0119 a slight bending could be observed.

A measure for the bending of a coupon during testing is the “bending strain”. As indicated in [3], bending of coupons is acceptable if bending strain

$$\left|\frac{e_1 - e_2}{e_1 + e_2}\right| \leq 0.1 \qquad (1)$$

is less than 10%. In this series of tests, this was the case if axial stress exceeds values about 40 – 80 MPa, except for coupon 0119 (Figure 16). In this case the bending strain lies only slightly above the limit value.

Surface temperature was measured at three coupons (GEV206-R0300-0118, GEV206-R0300-0121, GEV206-R0300-0123). As it can be clearly seen from Figure 17, temperature was kept below 35°C.

All coupons failed within the tabs during tensile loading. Failure mode of coupons was the same, regardless of the stress level.

Coupon-ID	R	Load [kN]	Stress [MPa]	Strain [o/oo]	N	Runout	E_tens [GPa]	E_compr [GPa]	f [Hz]	Strain rate [%/s]	Temperature [°C]	Remarks
GEV206-R0300-0117	-1	28.03	300.0	8.11	6753	n	37722	37818	1.52	4.93	-	Cooling, Tab failure
GEV206-R0300-0118	-1	24.81	260.0	7.10	25565	n	37280	37266	2.00	5.68	33	Cooling, Tab failure
GEV206-R0300-0120	-1	24.86	260.0	6.97	40605	n	38028	38073	2.00	5.58	-	Cooling, Tab failure
GEV206-R0300-0123	-1	24.64	260.0	7.14	30712	n	37232	37317	2.00	5.71	33	Cooling, Tab failure
GEV206-R0300-0119	-1	20.49	210.3	5.88	135051	n	36343	36378	3.13	7.35	-	Cooling, Tab failure
GEV206-R0300-0122	-1	20.14	210.0	5.68	167968	n	37463	37507	3.13	7.10	-	Cooling, Tab failure
GEV206-R0300-0121	-1	19.80	210.0	5.69	214983	n	37564	37671	3.13	7.11	32	Cooling, Tab failure
GEV206-R0300-0115	-1	16.68	180.0	4.85	675361	n	37773	38232	4.32	8.38	-	Cooling, Tab failure
GEV206-R0300-0116	-1	16.77	180.0	4.96	658702	n	37436	37006	4.32	8.56	-	Cooling, Tab failure
GEV206-R0300-0114	-1	17.01	180.0	4.82	682835	n	38147	38052	4.32	8.33	-	Cooling, Tab failure

Table 3: CA fatigue test results

R: R-Ratio
N: cycles to failure
E_tens: Initial tensile modulus
E_compr: Initial compressive modulus
f: Frequency
Temperature: Maximum temperature during fatigue test (up to 90% of lifetime)

5 Conclusions

Within the benchmark program of TG1, 10 static and 10 fatigue tests were performed at DLR using the Optimat UD specimen.

Concerning the static tensile tests, the values for UTS, Elastic Modulus and Fracture strain were determined to 838.50 MPa, 39.019 GPa and 2.29% respectively. The corresponding values for compressive testing were found to be 588.04 MPa, 38.928 GPa and 1.51%. Failure modes were acceptable for all coupons.

Fatigue tests were performed at stress levels ranging between 180 MPa and 300 MPa. The corresponding strain rates are 4.9% s^{-1} and 8.5% s^{-1} respectively. Surface temperature was measured at three coupons, but did not exceed the limit value of 35°C. Considerable bending was not observed under fatigue loading at the present R=-1 ratio. For all coupons failure was located within the tabs.

6 References

[1] Ch.W. Kensche et al., *Detailed plan of action Task Group 1*, DLR, doc. OB_TG1_O002 rev. 4, 17.02.2003

[2] O. Krause, Test plan report, DLR, doc. OB_TG1_R003 rev. 0, 24.02.2003

[3] EN ISO 527:1996, *Plastics - Determination of tensile properties*, European Committee for Standardization

[4] ISO 14126:1999, *Fibre reinforced plastics composites – Determination of compressive properties in the in-plane direction*, European Committee for Standardization

[5] T.P. Philippidis et al., Static and Fatigue Tests on the standard OB unidirectional coupon (Static tensile tests and S-N at R=-1), UP, doc. OB_TG2_R013 rev. 0, 17.07.2003

7 Appendix

7.1 Static Test Results

Coupon Name	Width [mm]	Thickness [mm]	Modulus [MPa]	Fracture strength [MPa]	Fracture strain [%]
GEV206-RO300-0025	25,05	3,70	39156	862,02	2,35
GEV206-RO300-0026	25,00	3,65	38882	865,04	2,27
GEV206-RO300-0027	25,10	3,70	38778	840,78	2,32
GEV206-RO300-0028	25,25	3,70	39185	814,95	2,33
GEV206-RO300-0029	25,00	3,75	39094	809,73	2,21
Mean Value	**25,08**	**3,70**	**39019**	**838,50**	**2,29**
COV [%]	0,41	0,96	0,46	3,07	2,45

Table 4: Static tensile test results of UD coupons

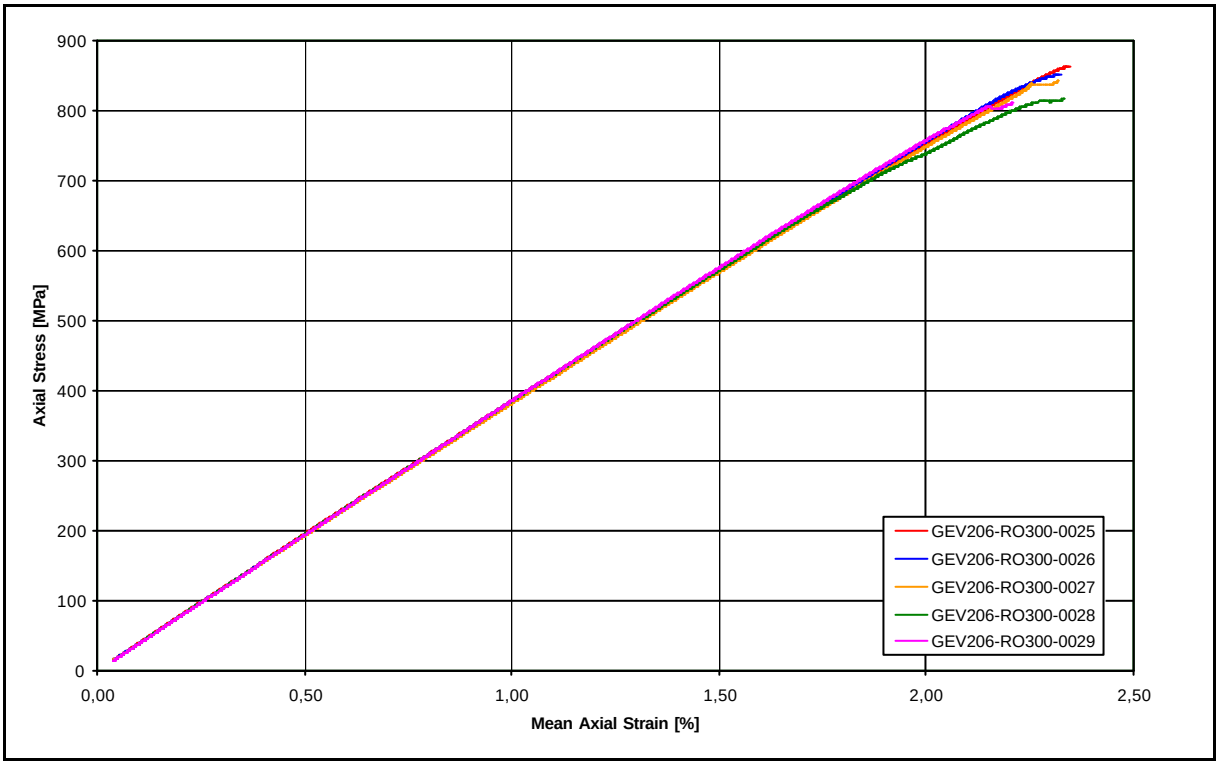

Figure 2: Axial stress vs. mean axial strain

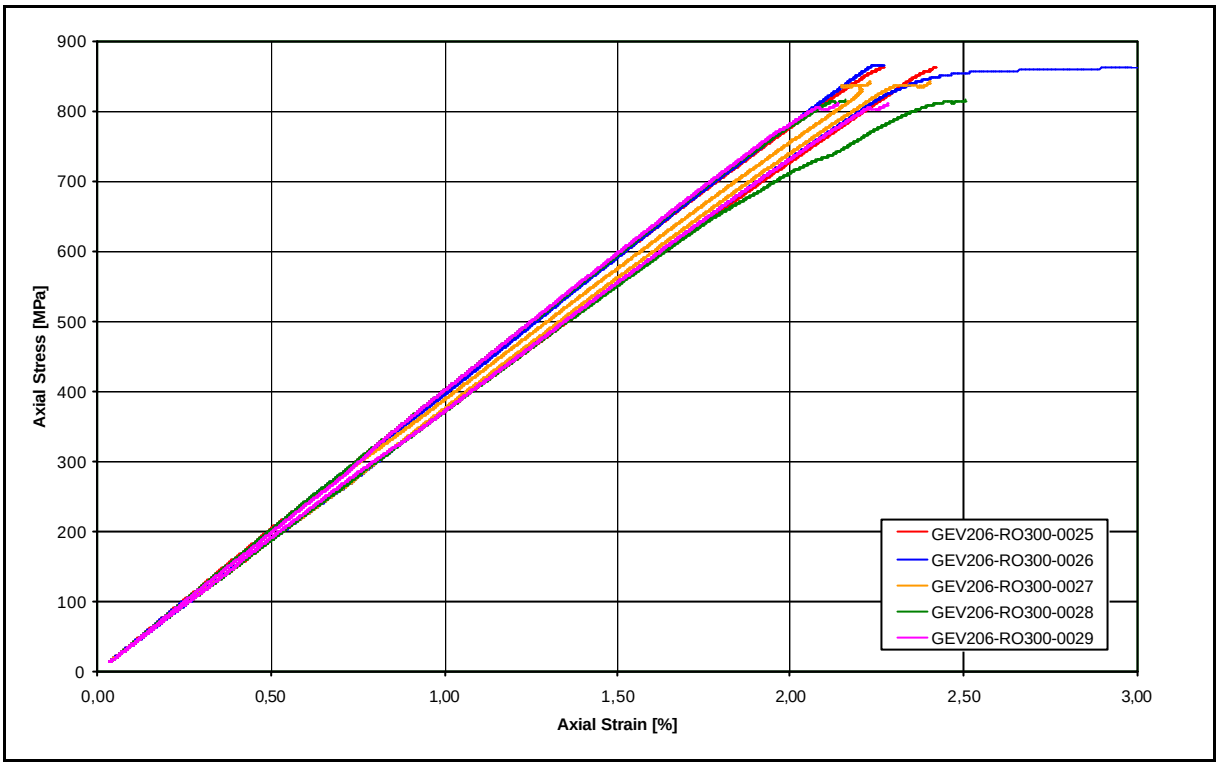

Figure 3: Axial stress vs. axial strain, both strain gauges presented

Coupon Name	Width [mm]	Thickness [mm]	Modulus [MPa]	Fracture strength [MPa]	Fracture strain [%]
GEV206-R0300-0030	25,15	3,70	38666	599,65	1,56
GEV206-R0300-0031	25,05	3,70	38496	553,11	1,43
GEV206-R0300-0032	25,15	3,70	38334	590,54	1,56
GEV206-R0300-0033	25,10	3,65	39435	627,74	1,58
GEV206-R0300-0034	25,20	3,70	39708	569,15	1,43
Mean Value	**25,13**	**3,69**	**38928**	**588,04**	**1,51**
COV [%]	0,23	0,61	1,56	4,88	4,87

Table 5: Static compressive test results of UD coupons

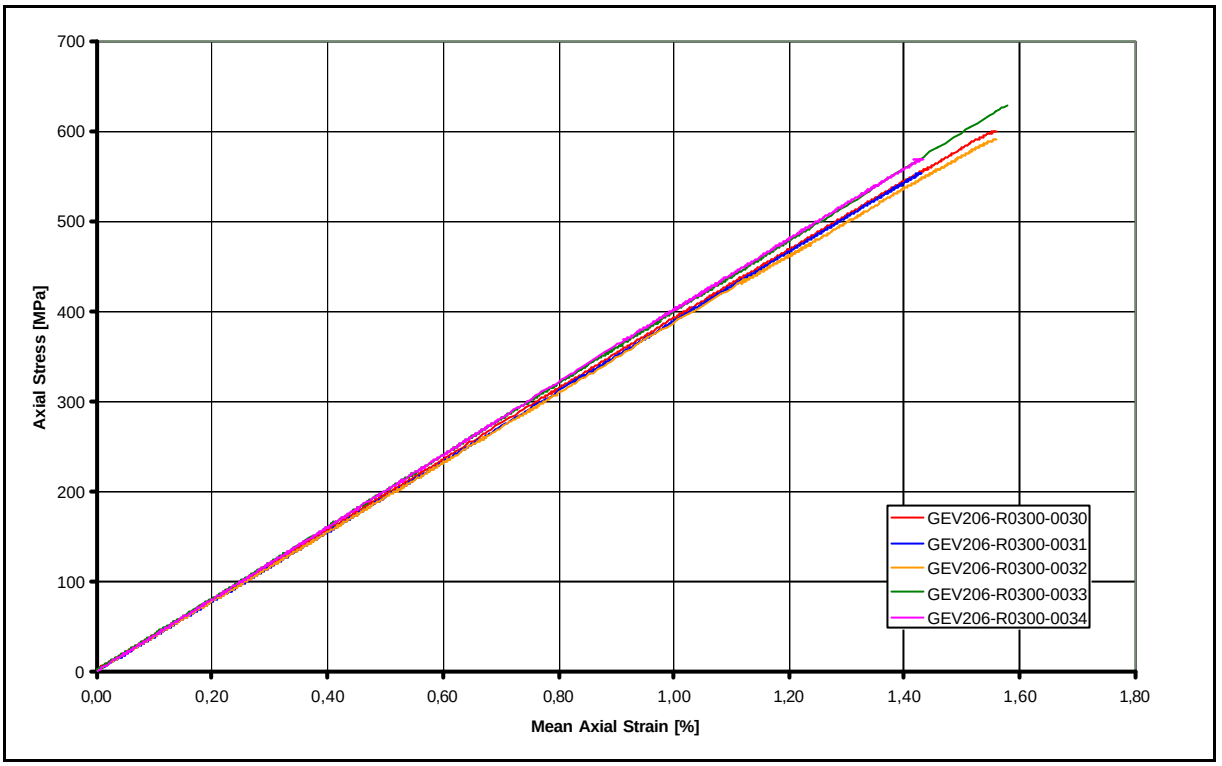

Figure 4: Axial stress vs. mean axial strain

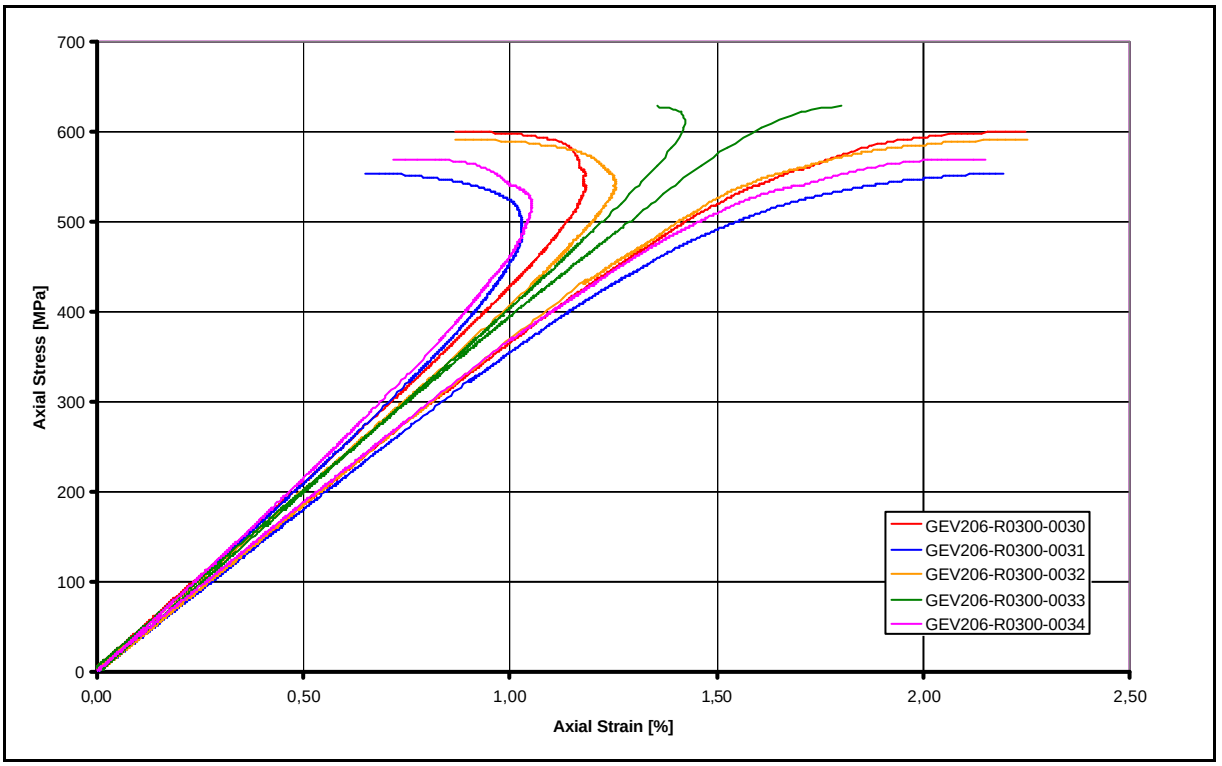

Figure 5: Axial stress vs. axial strain, both strain gauges presented

7.2 Fatigue Test Results

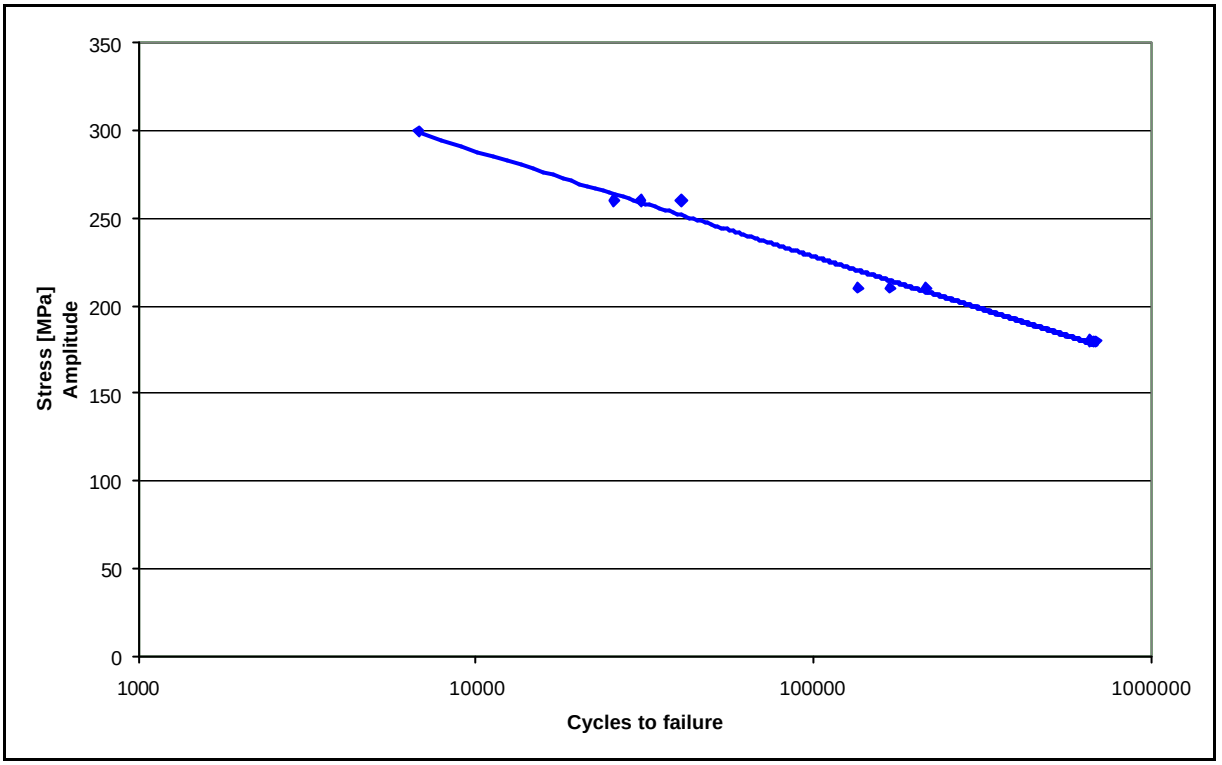

Figure 6: S-N Curve for R=-1

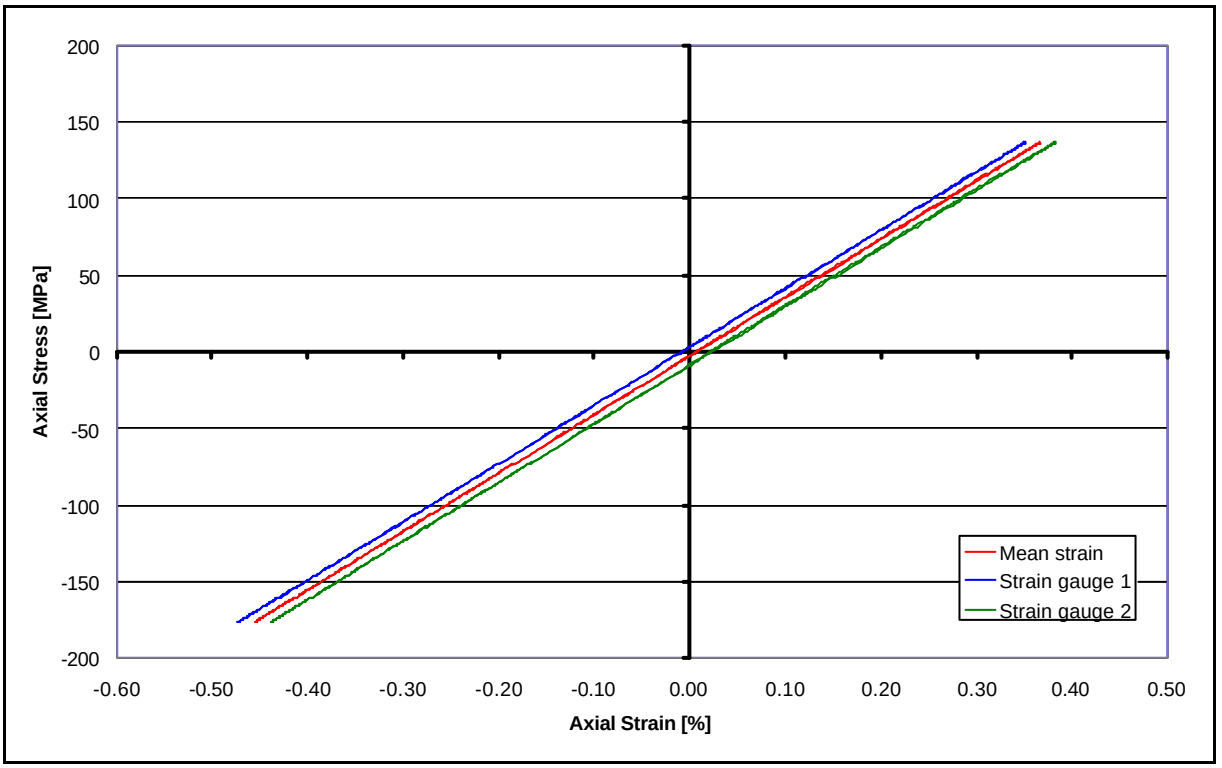

Figure 7: Stress-strain loops of coupon GEV0206-R0300-0114

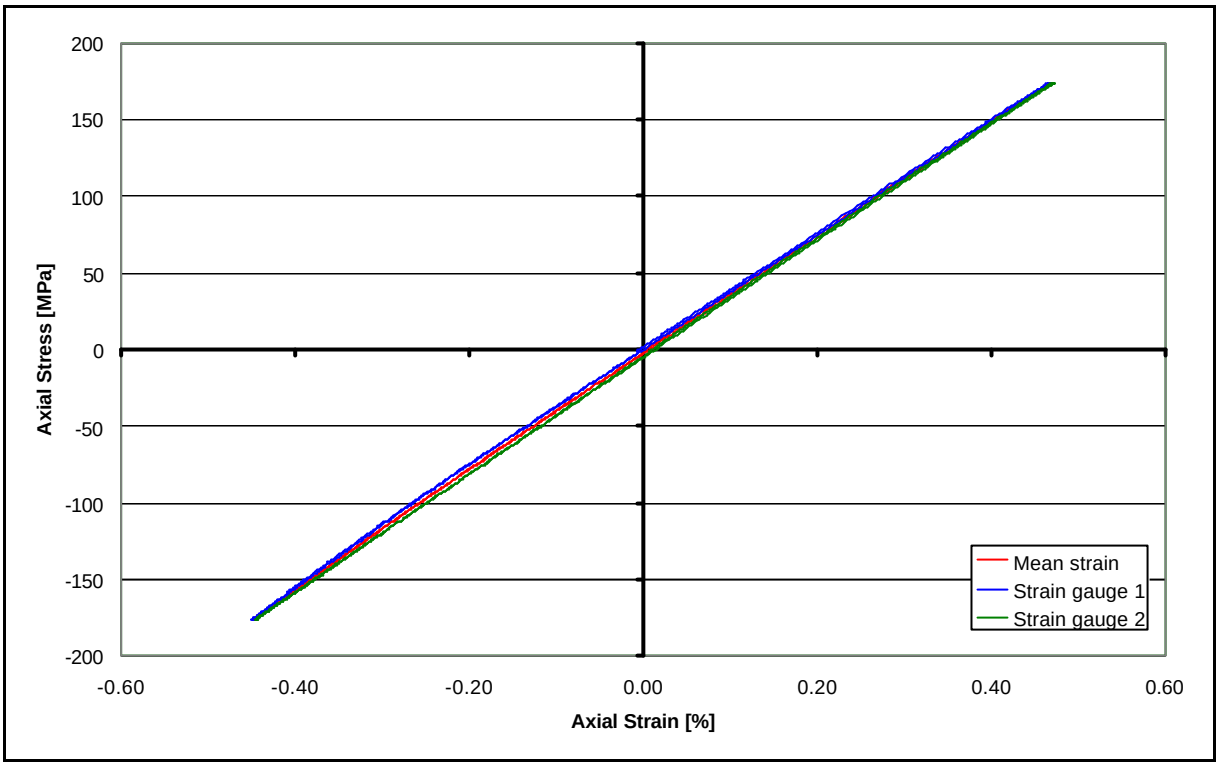

Figure 8: Stress-strain loops of coupon GEV0206-R0300-0115

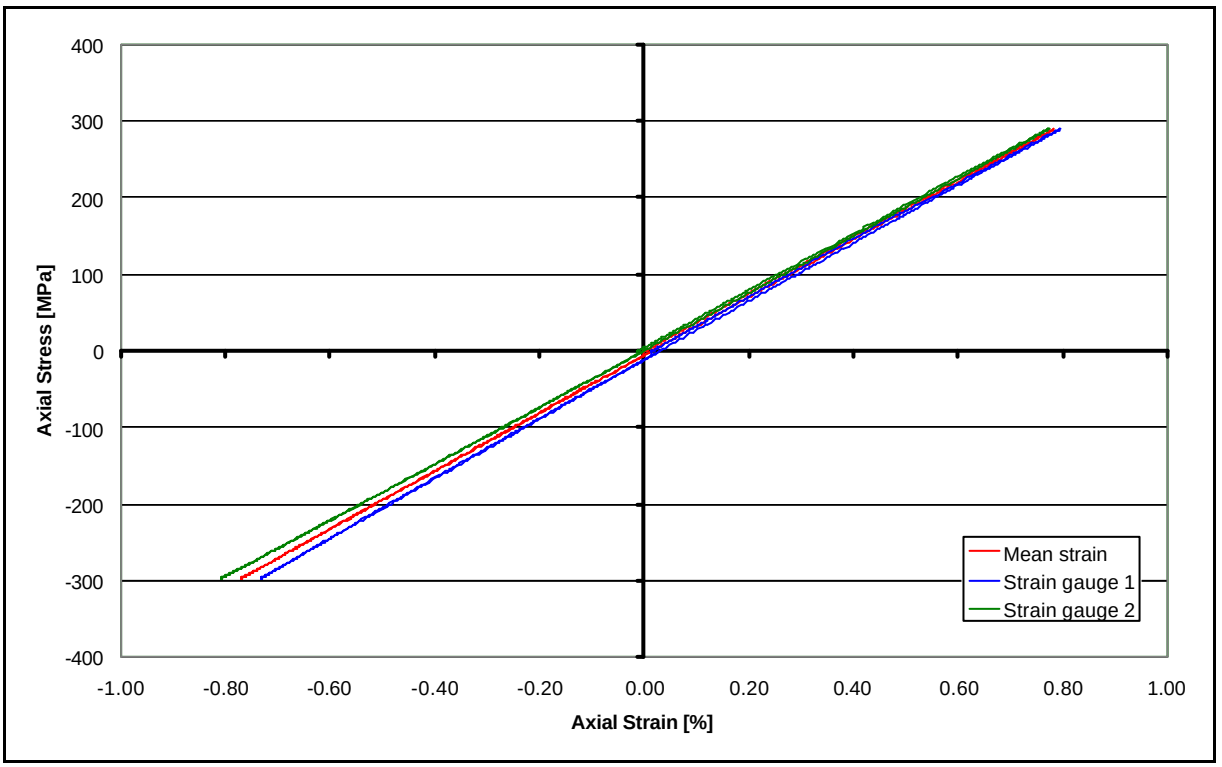

Figure 9: Stress-strain loops of coupon GEV0206-R0300-0117

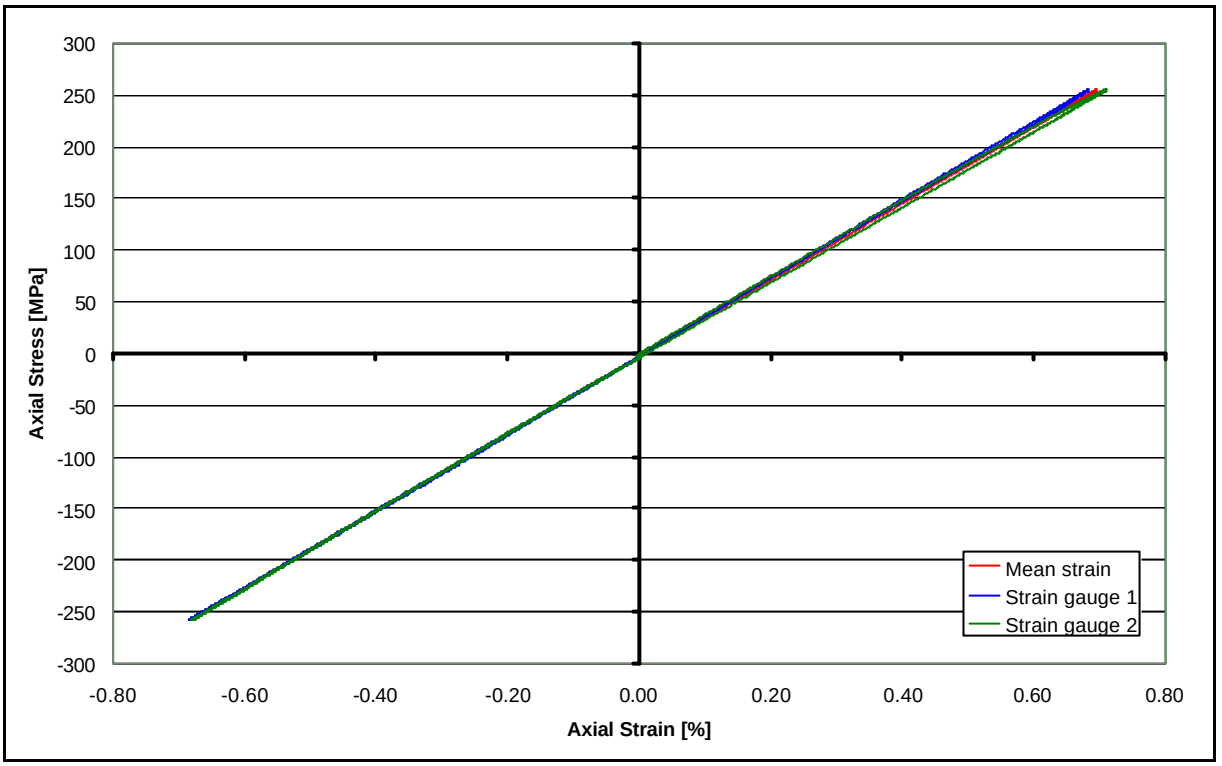

Figure 10: Stress-strain loops of coupon GEV0206-R0300-0118

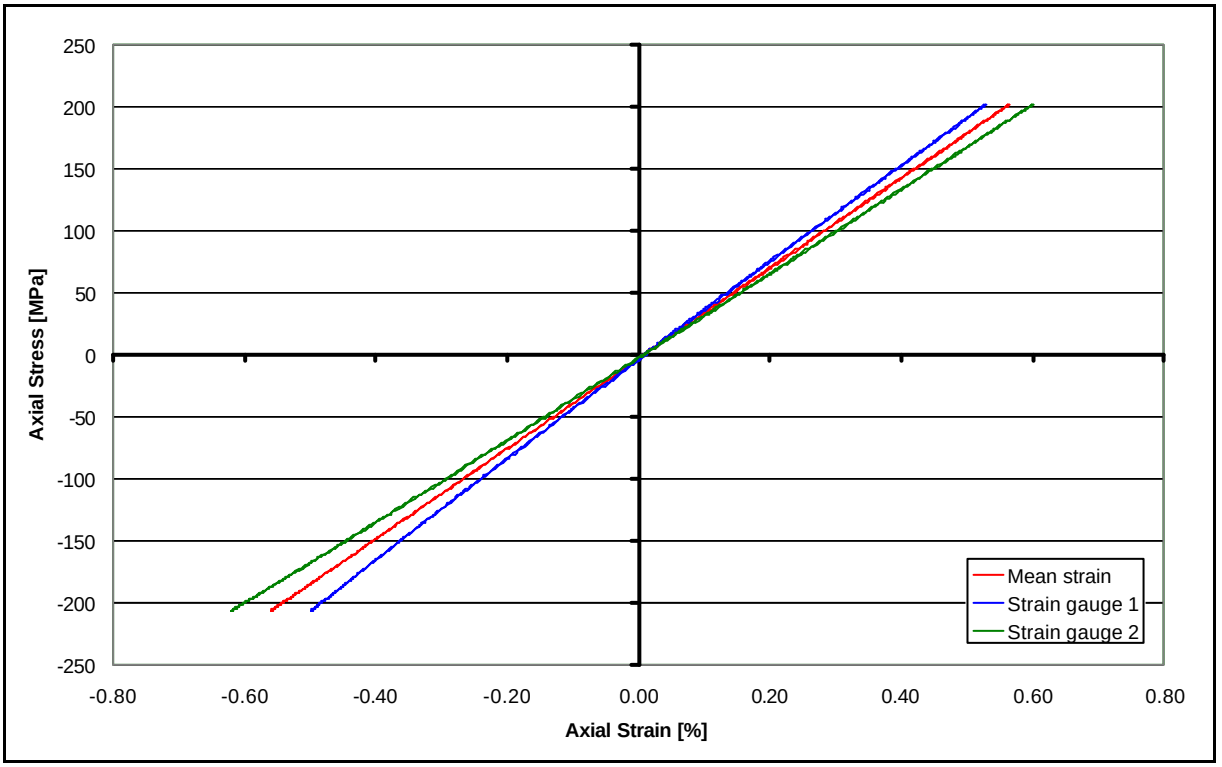

Figure 11: Stress-strain loops of coupon GEV0206-R0300-0119

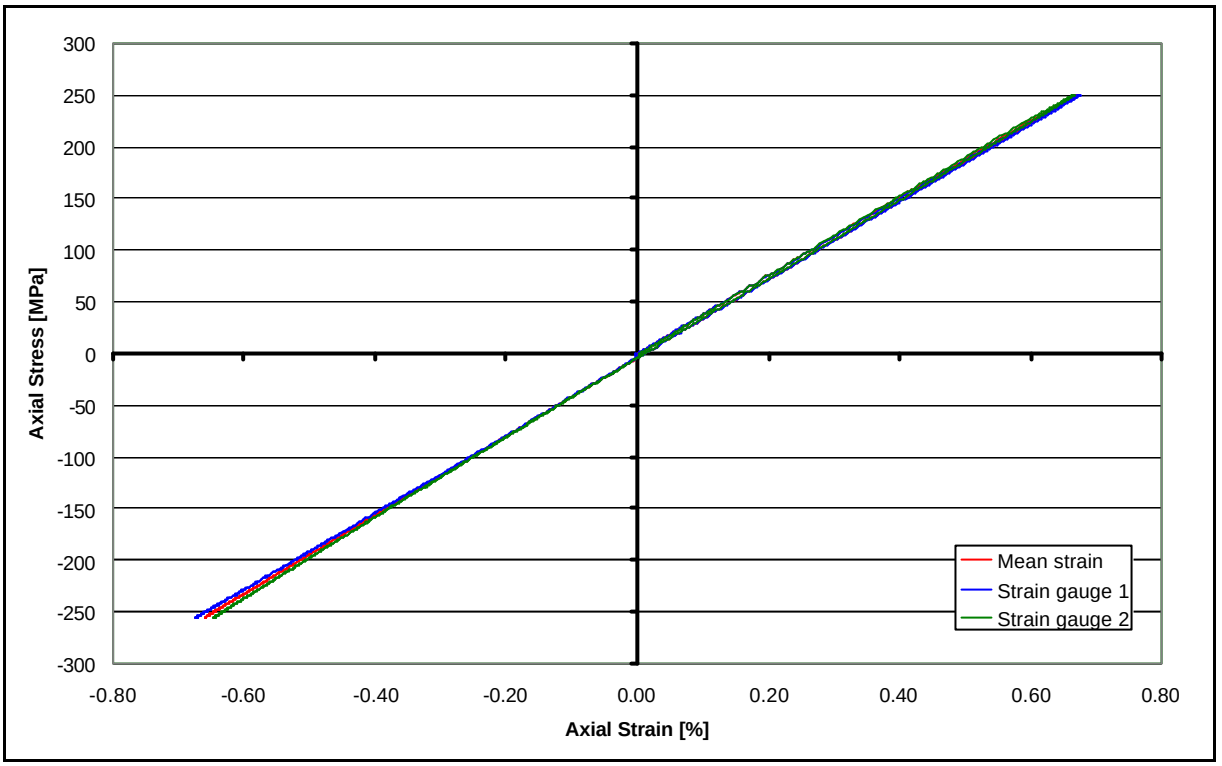

Figure 12: Stress-strain loops of coupon GEV0206-R0300-0120

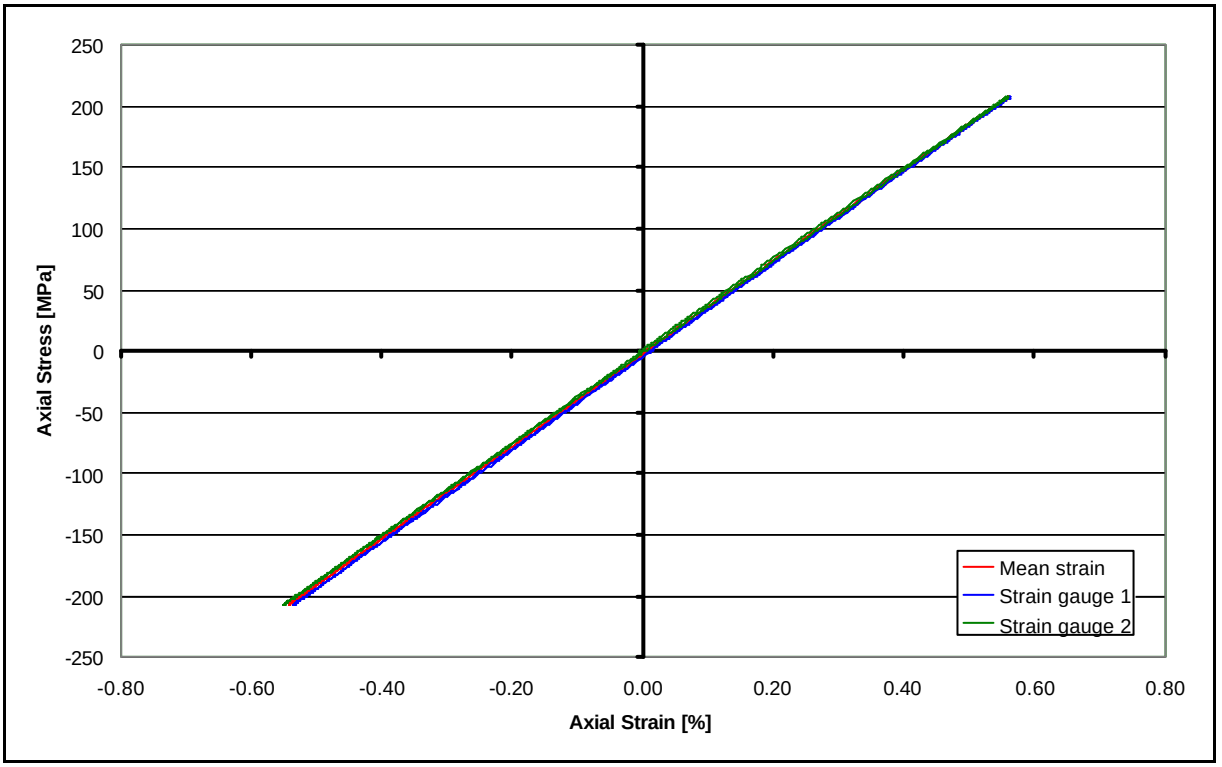

Figure 13: Stress-strain loops of coupon GEV0206-R0300-0121

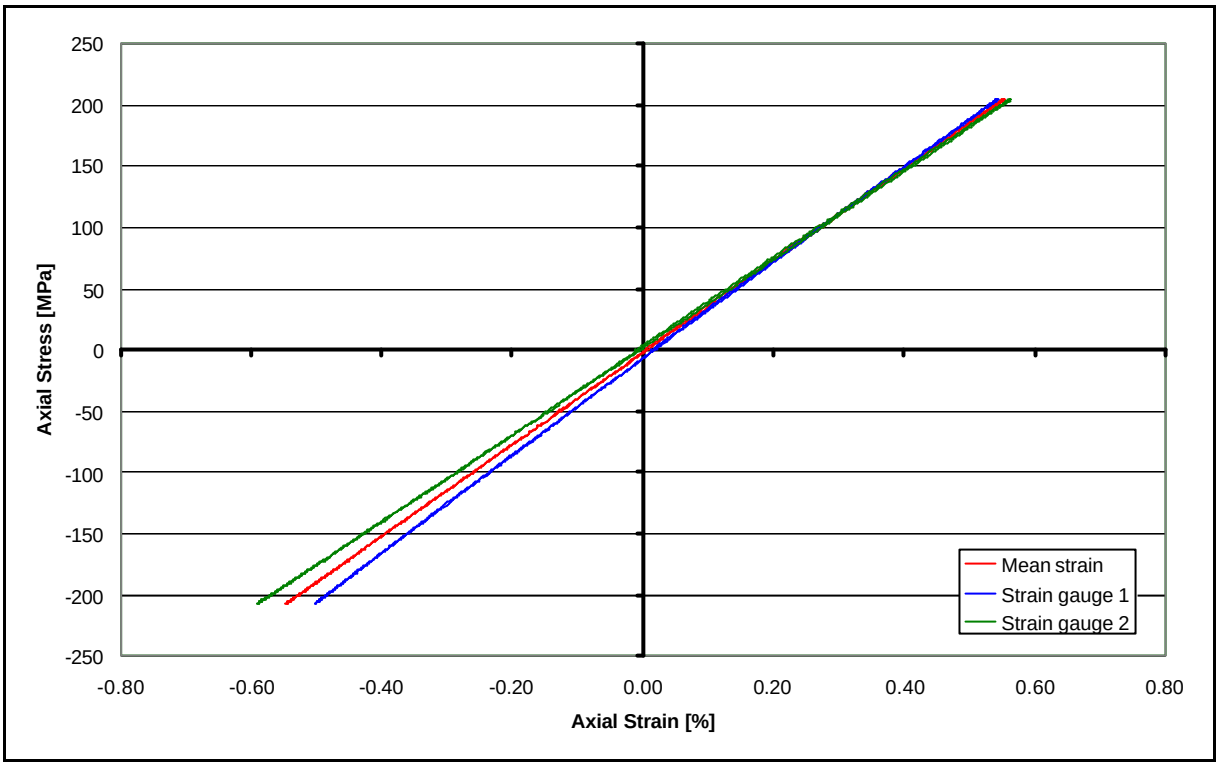

Figure 14: Stress-strain loops of coupon GEV0206-R0300-0122

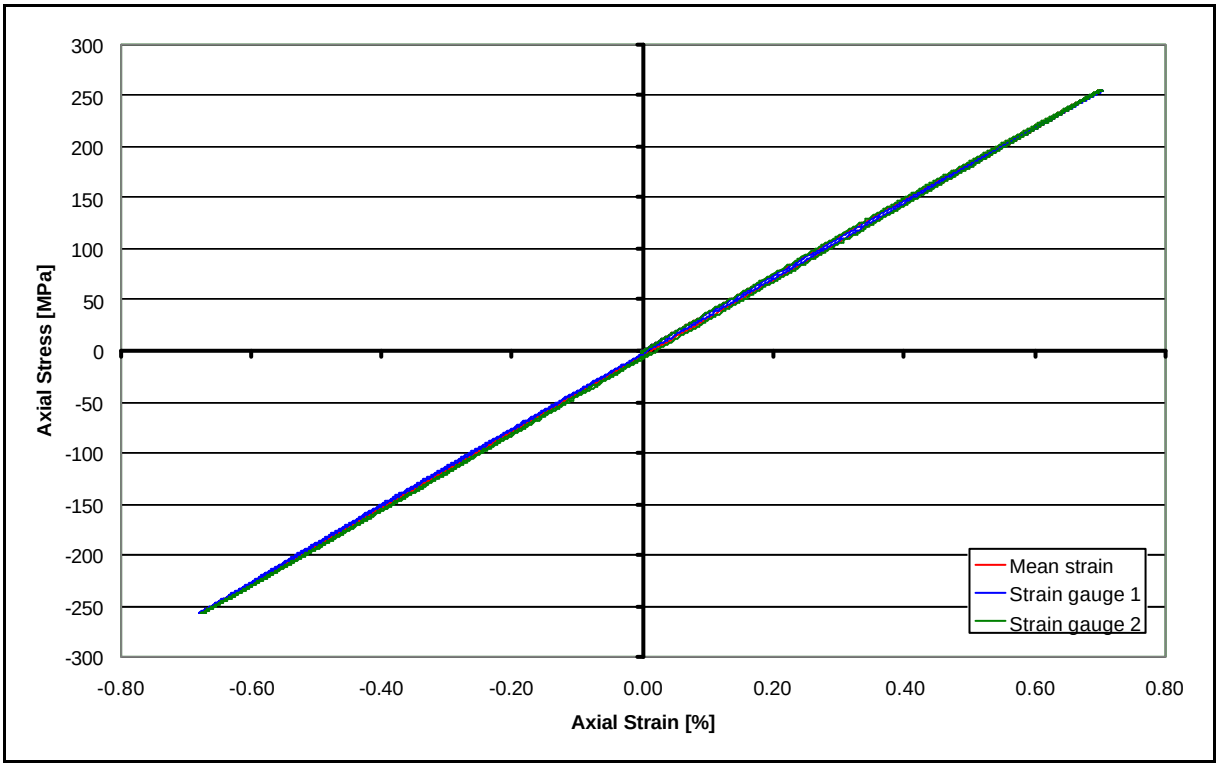

Figure 15: Stress-strain loops of coupon GEV0206-R0300-0123

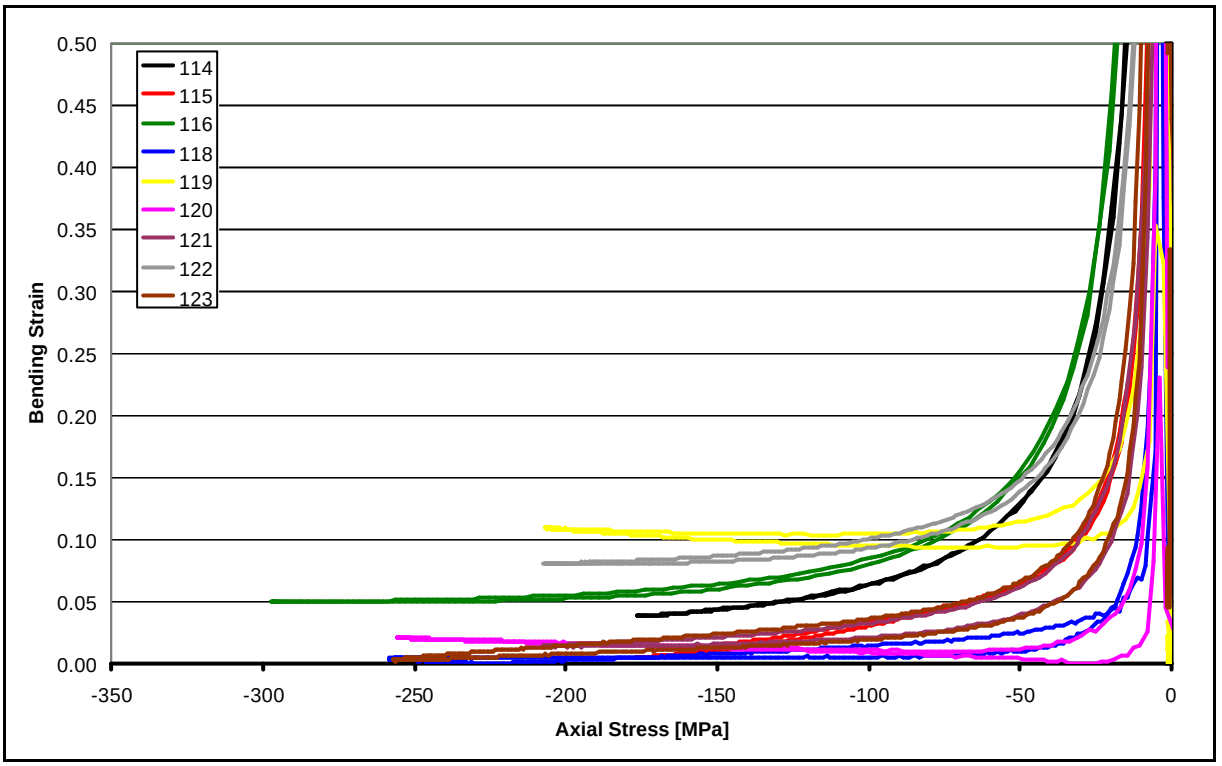

Figure 16: Stress-strain loops (compression) of each coupon

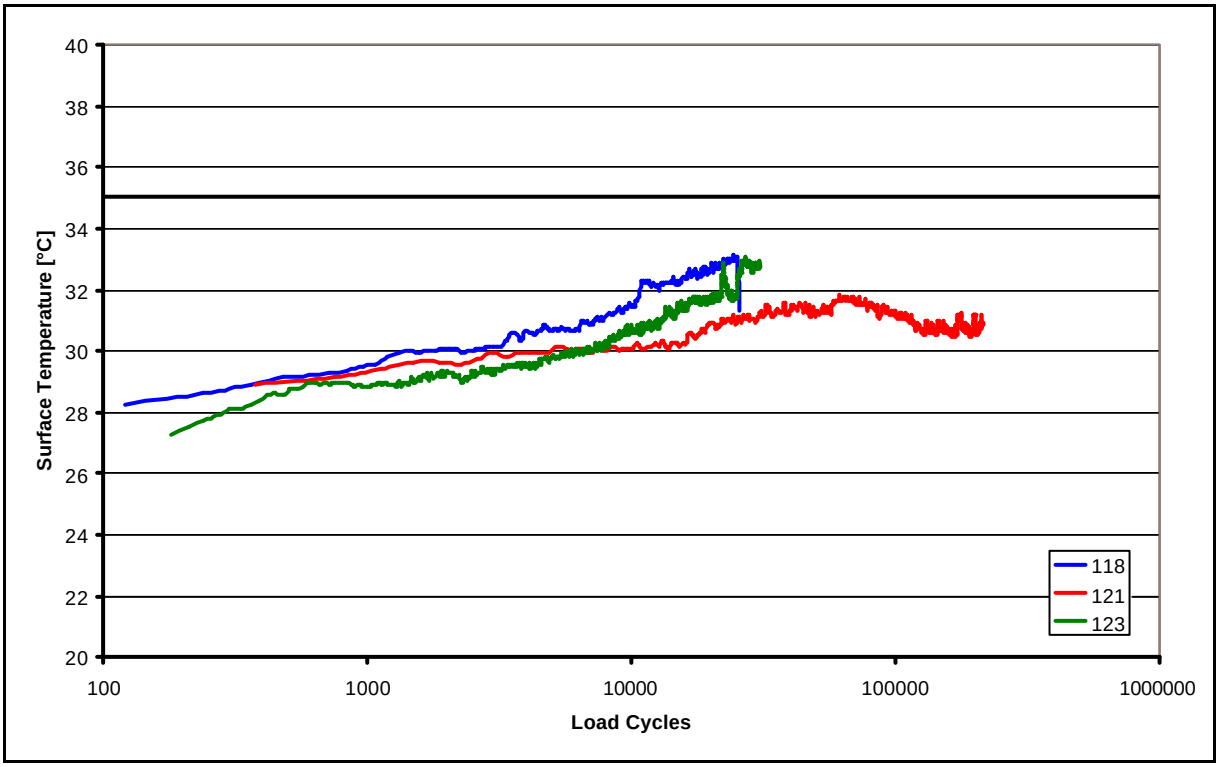

Figure 17: Temperature measurements