Princeton/BaBar/TNDC-97-56
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The Effect of Annealing on Creep of Aluminum Wire

1 Update of Creep Measurements

Most creep measurements were obtained by stretching the wire to a given initial tension in a tube of fixed length, and then determining the tension at later times by observing the natural frequency of the stretched wire with the apparatus described in Princeton/BaBar/TNDC-96-39. The measurements are taken in our clean room which is nominally temperature stabilized to$\pm$2F. Many different wires can be under study at the same time with this technique.

A few measurements (see section 2.1) have been made with a different setup in which the wire is strung vertically with a large weight resting on a balance, and then the wire is stretched to an initial tension indicated by the apparent loss of weight on the balance. The wire position is fixed and the weight observed at various times. A temperature correction is applied to these measurements. Only one setup of this type exists.

1.1 80 μm Wire Delivered in 12/96

All 10 spools measured in our initial survey failed our acceptance criterion that the creep be less than 10% in the first 10 days.

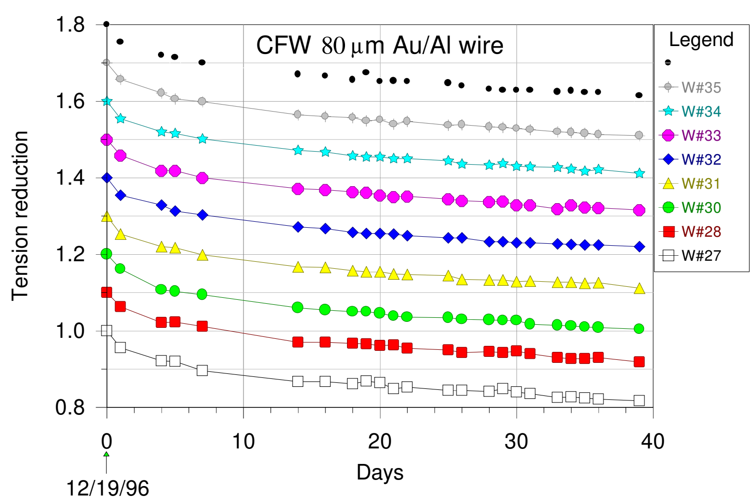

Figure 1: Measured creep of production 80-μm Au/Al wire delivered in 12/96. The initial tension was 100 g.

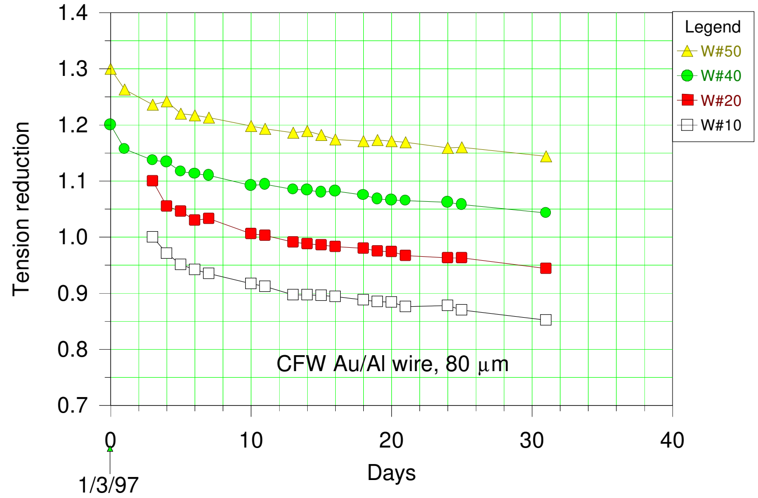

Figure 2: Measured creep of production 80-μm Au/Al wire delivered in 12/96. Four spools sampled throughout the production run all show large creep, and two of the four have creep in excess of 10% in the first 10 days.

1.2 120 μm Wire Delivered in 12/96

All 10 spools measured in our initial survey failed our acceptance criterion that the creep be less than 10% in the first 10 days, although several were very close to passing.

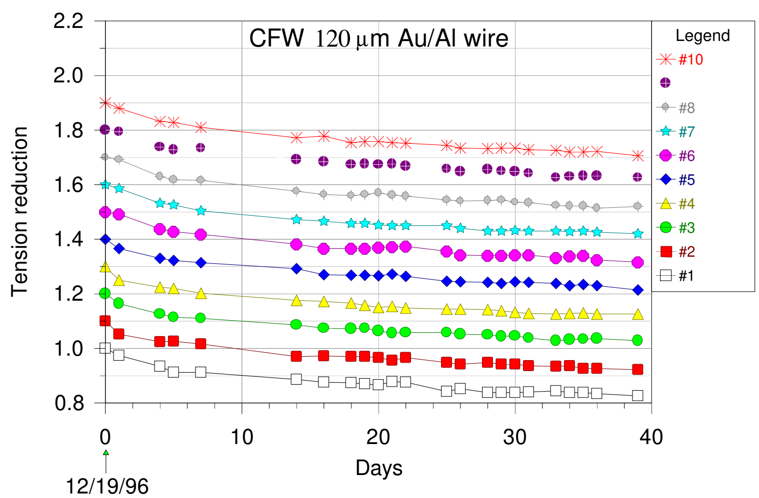

Figure 3: Measured creep of production 120-μm Au/Al wire delivered in 12/96. The initial tension was 200 g.

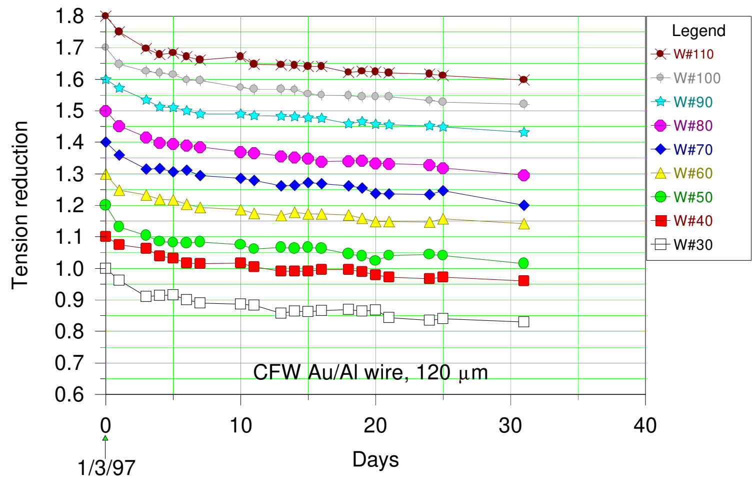

Figure 4: Measured creep of production 120-μm Au/Al wire delivered in 12/96. Ten spools sampled throughout the production run all show large creep, and nine of the ten have creep in excess of 10% in the first 10 days.

1.3 Wire Obtained in Summer 1995

These samples took 40 days to accumulate 10% creep. There is a suggestion of a flattening at 16% loss after 95 days, but the creep appeared to start up again around 150 days.

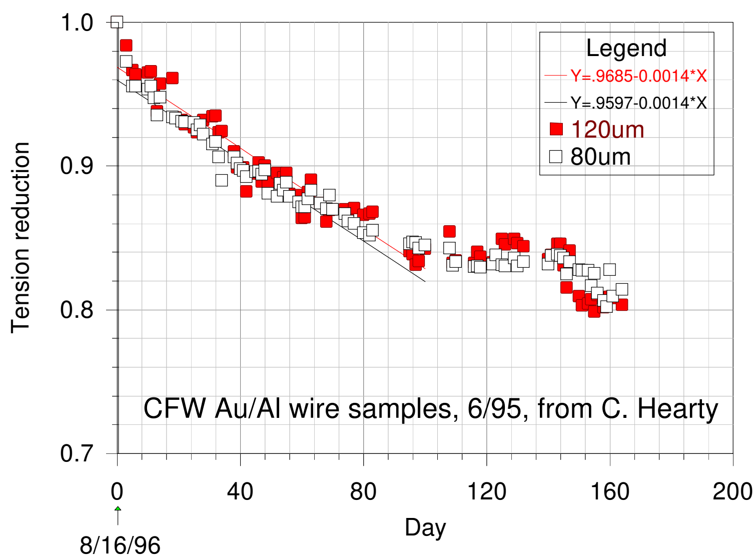

Figure 5: Measured creep of 120-μm Au/Al wire delivered in Summer '96. The initial tension was 200 g.

1.4 Wire Obtained in April 1996

These samples took 70-90 days to accumulate 10% creep, and show a hint of flattening at about 16% loss after 140 days.

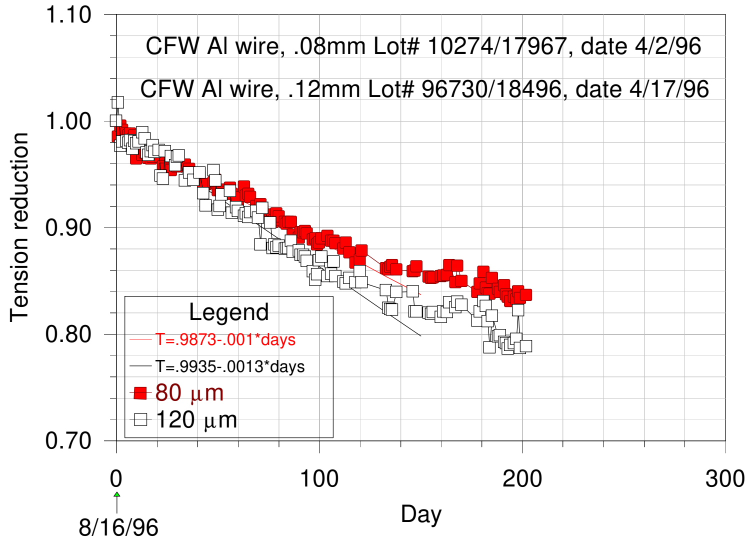

Figure 6: Measured creep of 120-μm Au/Al wire delivered in April '96. The initial tension was 200 g.

1.5 Wire Obtained in September 1996

These samples took only 15-20 days to accumulate 10% creep.

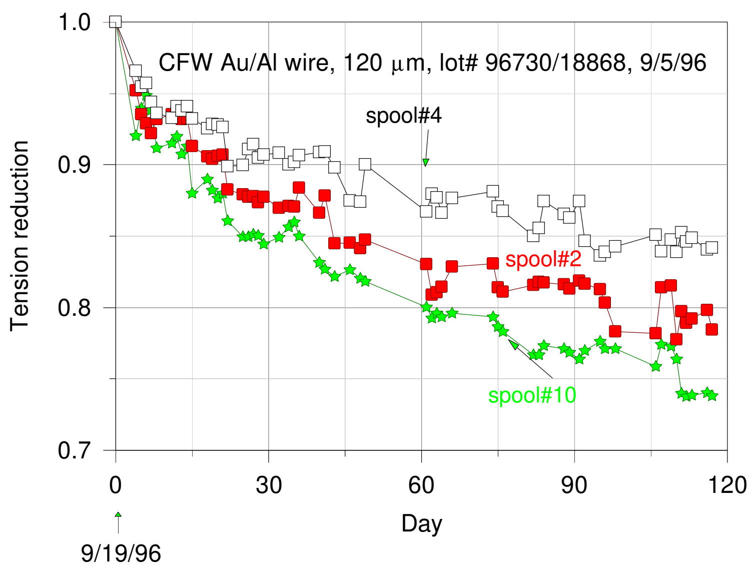

Figure 7: Measured creep of 120-μm Au/Al wire delivered in September '96. The initial tension was 200 g.

1.6 KEK Wire

This wire appears to take about 175 days to accumulate 10% creep.

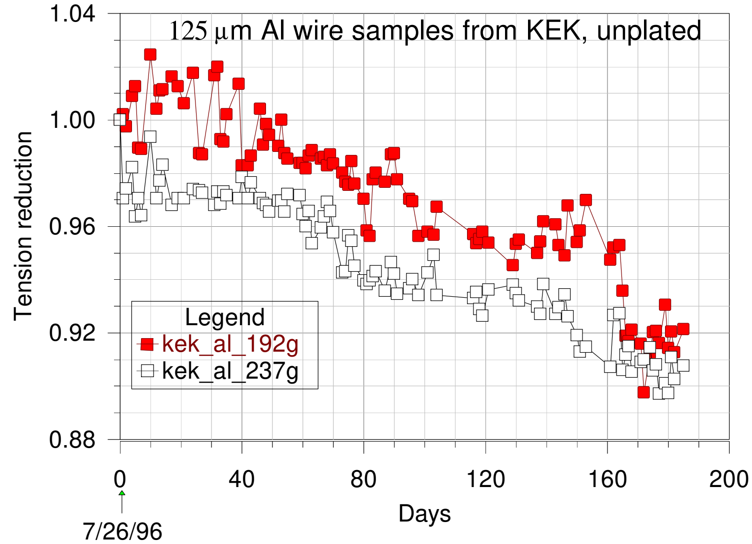

Figure 8: Measured creep of 125-μm bare Al wire obtained from KEK.

1.7 CLEO Wire Delivered from CFW at Various Times

Five samples of wire purchased by CLEO show varying rates of creep. Their samples obtained in 4/96 and 10/96 have creep rates close to ours obtained in 4/96 and 9/96, respectively.

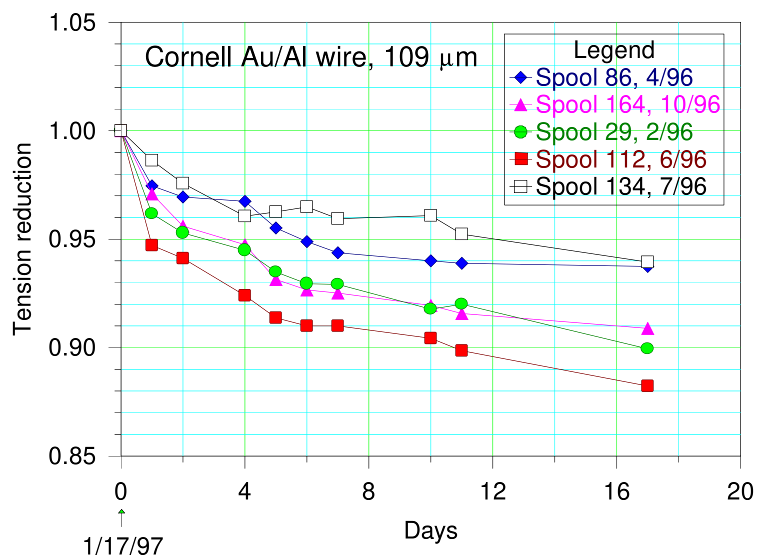

Figure 9: Measured creep of 109-μm Au/Al wire obtained from Dan Peterson.

2 Annealing

In discussions with Frank Castellano and Mike Greenelsh of California Fine Wire we learned that although the wire we obtained in '95 and '96 had been 'stress relieved' this was due to a mechanical process at room temperature. The wire had not been 'annealed', the process of relieving internal stresses by heat treatment.

The effect of annealing is of interest in that it can be done on the existing batch of wire.

Frank Castellano has provided us with four samples of annealed wire, and we have made one annealing ourselves at Princeton. The annealed samples generally show a lower rate of creep, although a fully systematic picture has not yet emerged.

All annealed samples are of 80-μm wire.

1. Castellano: Au/Al wire annealed at 250C for 3 hours. Date of manufacture not known.

2. Castellano: Au/Al wire annealed at 350C for 3 hours. Date of manufacture not known.

3. Castellano: Bare Al wire annealed at about 550C for about 5 min. This sample was from CFW stock, and was characterized by them as having 5% elongation = fractional stretch before breaking.

4. Castellano: Bare Al wire annealed at about 550C for about 10 min. This was characterized by CFW as having 10% elongation.

5. Princeton: Au/Al wire from spool #28 of the 12/96 production run, annealed at 350C for about 1 hour. The wire appeared to relax visibly during the first few seconds of heating!

We have consulted two books on aluminum metallurgy published by the American Society for Metals: *Aluminum and Aluminum Alloys*, ed. by J.R. Davis, and *Aluminum, Properties and Physical Metallurgy*, ed. by J.E. Hatch. These references indicate that the effect of annealing depends on the temperature, but only a few minutes are required at a given temperature to achieve the main effect. Note that the melting temperature of aluminum is 660C.

Many aluminum alloys show nearly complete annealing at temperatures as low as 350C, due to 'recrystallization'. However, it appears that some alloys must be brought closer to the melting point before recrystallization occurs.

Annealing to typically associated with significant lowering of the tensile strength (yield strength) and increase in the fractional elongation prior to breaking. The Young's modulus is largely unaffected.

2.1 Creep Measurements of Annealed Wire

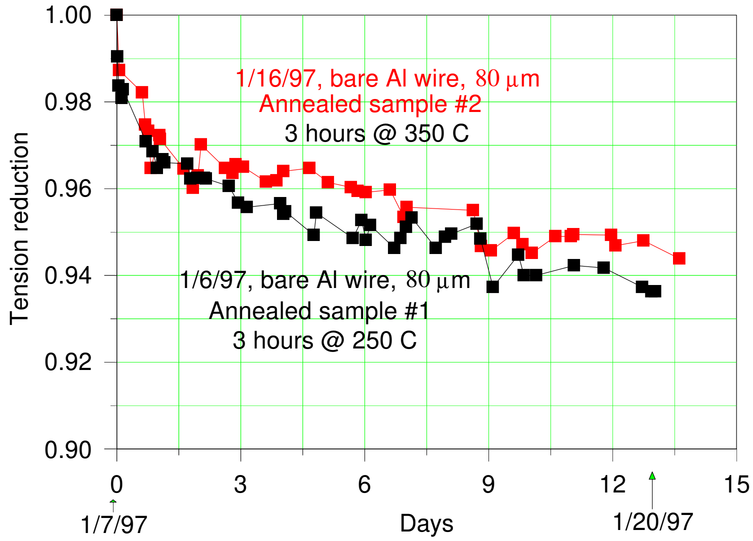

Figure 10: Measured creep of samples 1 and 2 of Au/Al wire. These results were obtained using the second technique described in sec. 1.

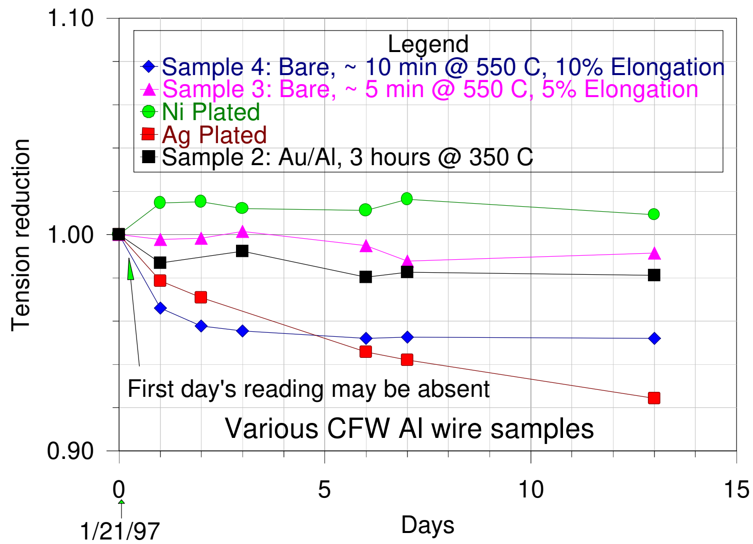

Figure 11: Measured creep of various samples/Al wire. These results were obtained using the first technique described in sec. 1. It is not unlikely that the large creep in the first few hours was not recorded in some of these measurements. Sample 2 appears in both Figs. 8 and 9, which suggests that the results in Fig. 9 should be lowered by about 3%. The silver-plated sample may be from the KLOE run. The nickel-plated sample was obtained from a recent run just prior to the gold-plating step.

2.2 Yield and Elongation

The method for measuring the yield strength of wire was described in the note Princeton/BaBar/TNDC-96-46. Wire samples 56 cm long were used. Data for tension *vs.* elongation were collected until the wire broke. The fractional elongation is then the ratio of the stretch at breaking to 56 cm.

The Table summarizes the results obtained to date. Figures 12-19 show the results of the various measurements.

CFW Samples 2 and 5 had nominally similar heat treatment and so may be expected to have similar properties. Sample 2 was prepared by CFW while Sample 5 was annealed by us using spool #28 of the 80-μm CFW production wire delivered in 12/96.

There is some ambiguity in the measurement of the creep rate of Sample 3; the higher value is more likely correct. Also, there is some doubt as to the processing of sample 3. CFW claimed it had been annealed at a very high temperature and should have 5% elongation. However, we measure only 2% elongation, and a relatively high yield strength of 184 g. Perhaps Sample 3 had only a modest anneal at around 300C.

Table 1: Summary of yield, elongation and creep rate for various samples of aluminum wire. The yield strength is normalized to 80-μm wire by assuming the yield scales as the area.

Sample	Yield Strength (g)	Elongation (%)	Creep in 1st 10 days (%)	Anneal Temp. (°C)	Anneal Time (min)
CFW Production	280	1.3	10	–	–
KEK	110	12.7	1	?	?
CFW Sample 1	270	1.3	6	250	180
CFW Sample 2	?	?	5	350	180
CFW Sample 3	184	2.0	2-5	550(?)	5(?)
CFW Sample 4	142	9.6	5	550	10
CFW Sample 5	123	7.3	?	350	60

We will repeat and extend the ambiguous measurements reported in Fig. 11. We will make a more systematic study of the effect of annealing temperature and time on spool #28 of 12/96 80-μm wire.

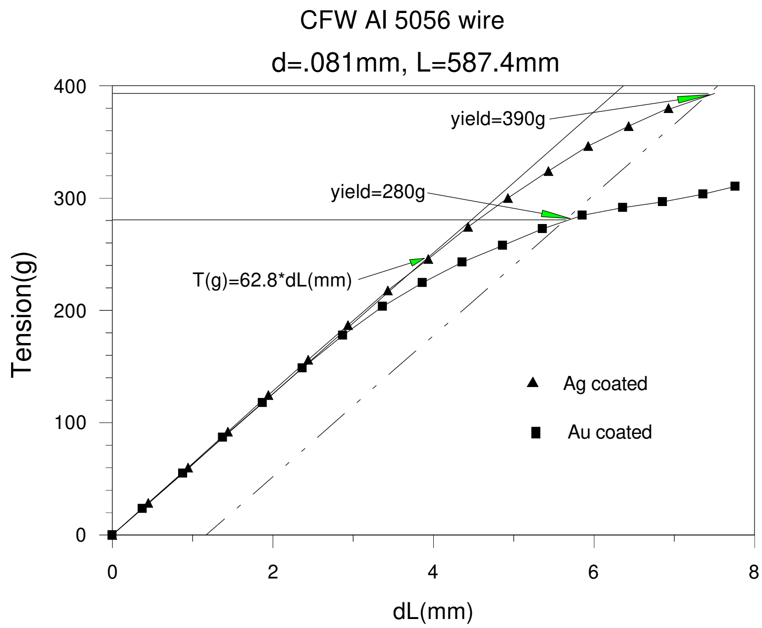

Figure 12: Yield measurement of 80-μm CFW wire. The elongation of the Au-plated sample is measured by us as 1.3%, a typical value as reported by CFW for our production wire.

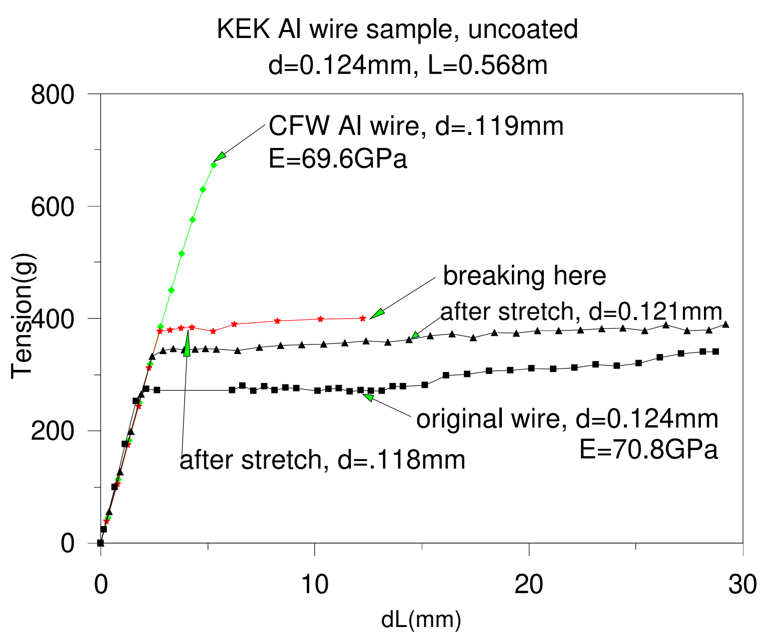

Figure 13: Yield measurement of 124-μm KEK bare aluminum wire. The elongation is 12.7%.

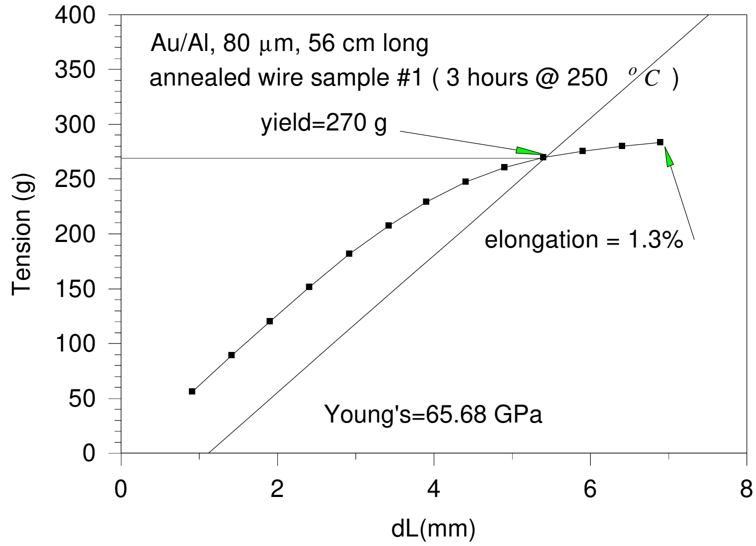

Figure 14: Yield measurement of annealed CFW 80-μm wire, Sample 1. The elongation is 1.3%.

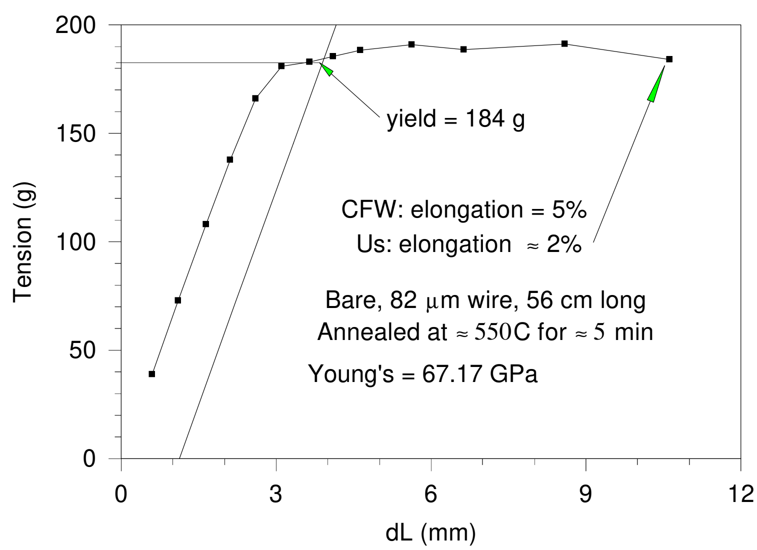

Figure 15: Yield measurement of annealed CFW 80-μm wire, Sample 3. The elongation as measured by us is 2%, although the sample was labelled as 5% elongation by CFW.

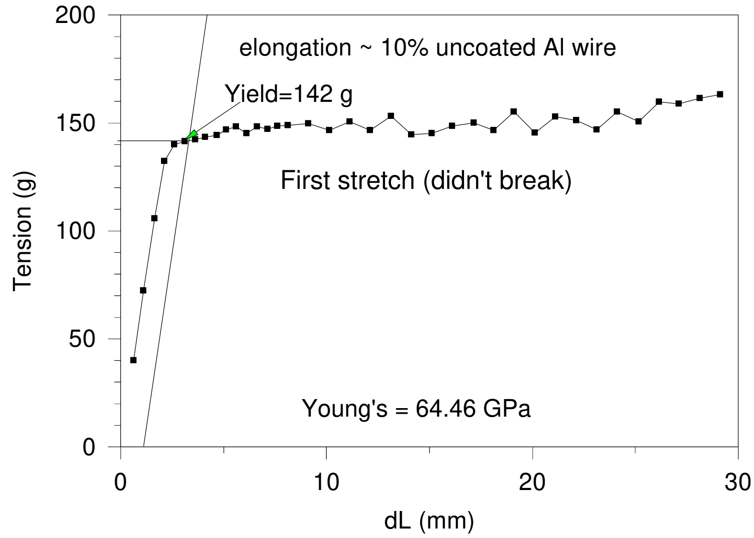

Figure 16: Yield measurement of annealed CFW 80-μm wire, Sample 4; first stretch. The elongation was larger than 3 cm, the maximum stretch at one time in our setup.

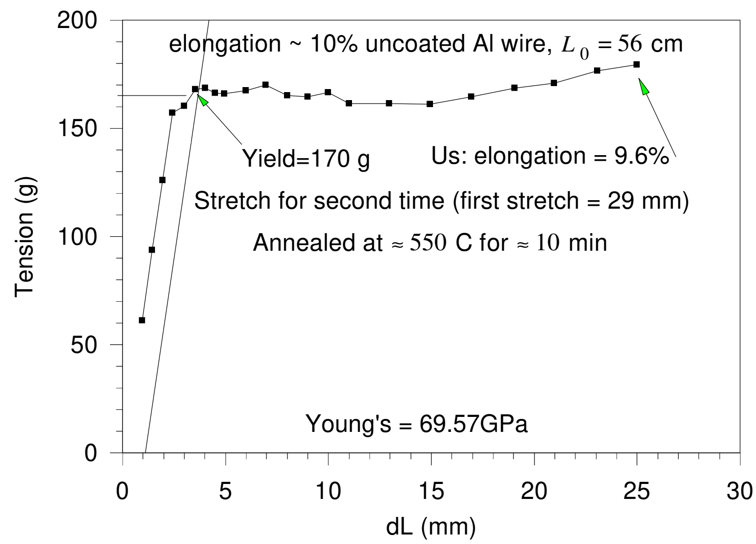

Figure 17: Yield measurement of annealed CFW 80-μm wire, Sample 4; second stretch. The elongation was measured by us as 9.6%, and labelled as 10% elongation by CFW.

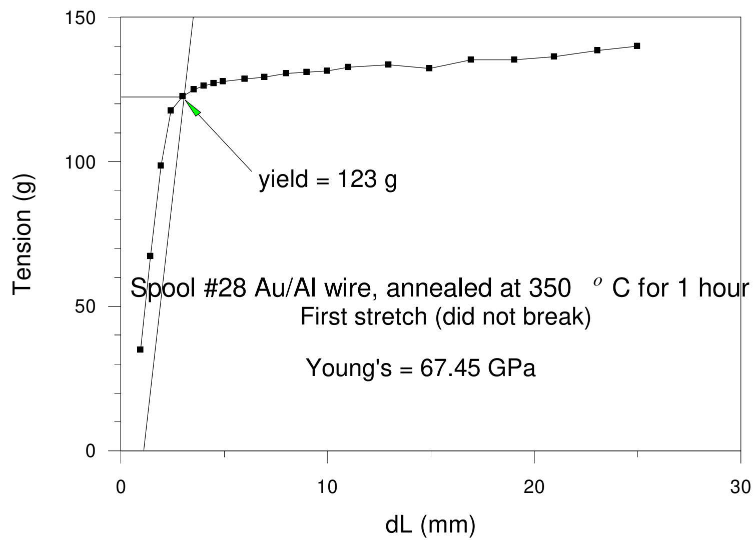

Figure 18: Yield measurement of annealed CFW 80-μm wire, Sample 5; first stretch.

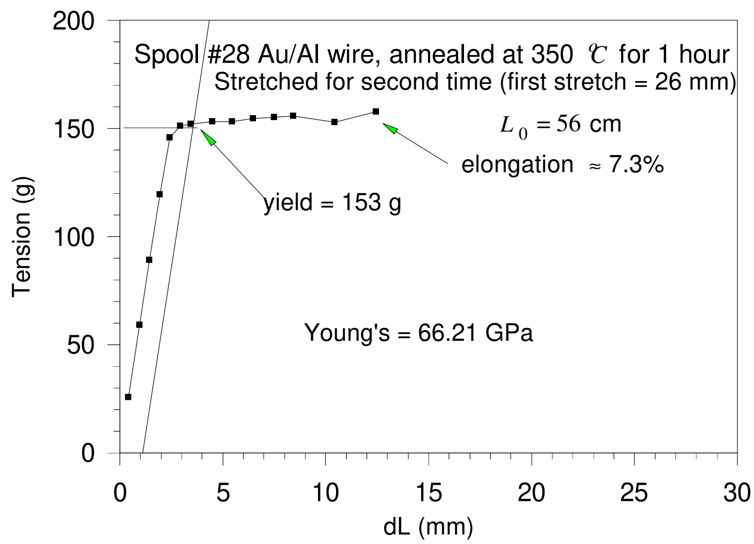

Figure 19: Yield measurement of annealed CFW 80-μm wire, Sample 5; second stretch. The elongation is %.