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June 2003

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INTRODUCTION

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300 to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. For large disks, residual stresses generated during cooling from solution temperature may require a stabilization heat treatment to relieve these stresses. This is probably more critical for higher cooling rates achieved with oil quenching. The reduction in residual stress levels lessens distortion during subsequent machining operations and therefore decreases disk cost. However, the stabilization heat treatments can have a significant impact on mechanical properties.

As part of NASA's Advanced Subsonic Technology Program, Pratt & Whitney Aircraft was selected to study the effect of stabilization heat treatments on residual stresses and mechanical properties of an advanced nickel-base disk alloy, ME-209. To accomplish this task, measurements of the residual stresses as well as creep and tensile properties generated upon cooling from solution temperature were collected. This was followed by similar measurements on material which was solutioned and stabilized using a design of experiments approach to investigate the temperatures, times, and cooling rates of interest for disk applications. Statistical analysis was then used to generate models that describe the data. The experimental methods, data, and the resulting models are completely reviewed in Reference 1. While this statistical approach was quite informative, a second physically based analysis of the mechanical property data was also performed and is the subject of this paper.

MATERIAL & PROCEDURES

The composition of the nickel-base disk alloy, ME-209, is given in Table I. As with most high-strength, nickel-base disk alloys, argon atomization was employed to produce powder which was subsequently compacted and extruded to 3" diameter billet. The billet was then cut into mults and isoforged to produce "pancake" shapes approximately 8" in diameter by 1.1" thick. These forgings were then heat treated according to the conditions outlined in Table II. Both supersolvus and subsolvus solution treatments were employed to produce coarse grain, about ASTM 5, and fine grain, about ASTM 8, microstructures respectively. Three solution cooling rates designated oil quench, air cool, and blanket cool were employed in the study. Thermocoupled forgings were used to measure these cooling rates. Data from the air and blanket cooled forgings were consistent and produced a cooling rate around 100F/minute and 10F/minute respectively between 2100F and 1600F. Data from the oil quenched forgings was erratic, between 100F/minute and 1000F/minute. As a result, a finite element thermal analysis of the oil quenched forgings was performed using the same thermophysical properties in Reference 2. These results produced an average cooling rate of about 500F/minute between 2100F and 1600F which agreed with several of the experimentally determined oil quench rates summarized in Reference 1. Some forgings were given a solution only heat treatment while others were solutioned, stabilized, and aged. The choice of stabilization parameters included three temperatures (1425, 1500 and 1575F), three times (2, 5, and 8 hours), and two post-stabilization cooling rates (air and blanket). All stabilized forgings were subsequently aged at 1400F for 8 hours. After heat treating the forgings, mechanical test specimens for tensile, notch tensile, and creep tests were machined according to the layout shown in Figure 1. To evaluate the effects of heat treatment on monotonic properties relevant to disk applications, tensile tests were run at 1100, 1300, and 1400F, while notch tensile tests with a Kt of 3.5 were run at 1100F. Creep testing was done at 1300F and 100KSI to strains of 0.2% or greater.

Tensile properties analyzed in this paper included 0.2% yield strength, ultimate tensile strength, and elongation, at each of the three temperatures, as well as the notch tensile strength at 1100F. The creep resistance was analyzed using the time to 0.2% strain. The analysis of the data that follows was based on a simple, physically based approach, irrespective of the property, P, being measured. To help illuminate this approach the figures accompanying the analysis of elongation at 1100F will be used in the following description. First, the effect of solution cooling rate was analyzed by plotting the property for the solution-only heat treated data, P_{SOL}, against the common log of the cooling rate, Figure 2. Supersolvus and subsolvus data were analyzed together in this step. As there were three cooling rates studied, oil quench (500F/minute), air cool (100F/minute), and blanket cool (10F/minute), a parabolic fit to the data was employed as significant curvature was present for many of the properties being studied. The resulting regression equation generally took the following form:

$$P_{SOL}=A+B*LOG(CR)+C*LOG(CR)*LOG(CR)$$

Where A, B, and C are regression constants and CR is the solution cooling rate. In the next two steps, the effects of stabilization and solution temperature were extracted from the data as simple multiplicative factors. To analyze stabilization effects, a normalized property, NPS, was computed by dividing the property for a given stabilization treatment by the appropriate solution-only heat treated property. The resulting quantity, NPS, is a dimensionless factor generally between 0 and 2. If stabilization had no impact on the property in question NPS will equal 1. As a given stabilization heat treatment is characterized by a unique set of temperature, time, and cooling rate the following approach was adopted. First the effect of stabilization temperature and time were combined using a Larson-Miller Parameter, LMP=(TEMP+460)*(20+LOG(TIME)), and then NPS was plotted against LMP for each of the three solution cooling rates, Figure 3. The effect of stabilization cooling rates was ignored, i.e. the data was pooled, as their impact was generally found to be negligible in the statistically based analysis employed in Reference 1. The resulting set of curves were then fit using a simple linear regression producing a set of three equations:

$$NPS_{OIL}=A+B*LMP$$
$$NPS_{AIR}=C+D*LMP$$
$$NPS_{BLANKET}=E+F*LMP$$

Where A through F are regression constants. The effect of solution temperature was also analyzed by plotting a normalized property, NPT, against solution temperature for each of the heat treatments in this study, Figure 4. Once again NPT is equal to 1 if solution temperature did not impact the property in question. NPT is calculated by dividing the property at a given solution temperature, P_{ST}, by the averaged value of that property at both solution temperatures (subsolvus and supersolvus) for all of the various heat treatments, $NPT=2*P_{ST}/(P_{SUB}+P_{SUP})$. As there are only two solution temperatures in this study a linear fit of the data is the only alternative and the resulting equation takes on the following form:

$$NPT=A+B*TEMP$$

Where A and B are regression constants and TEMP is the solution temperature. The final step of the analysis involves a comparison between predicted and observed data for a given property, Figure 5. The predicted property is computed as follows:

$$P=P_{SOL}*NPS_{CR}*NPT$$

Where P_{SOL} and NPT are as previously defined and NPS_{CR} is the appropriate value of NPS for the three cooling rates, oil, air, or blanket. If the predicted and observed property are in perfect agreement their plot will result in all data points lying on a line with a zero intercept and a slope of one. As seen in Figure 5 there are two sources of error in this analysis. The first is random and is characterized by the R^2 value. The second is systematic and is characterized by the slope and intercept of the regressed line in Figure 5, which approach unity and zero respectively when all systematic error is eliminated. Significant systematic error is generated when the model does not adequately describe the "physics of the process".

RESULTS & DISCUSSION

The results of the tensile, notch tensile, and creep tests, and the analysis of the data can be found in appendices at the end of this paper. Each appendix contains a spreadsheet with the heat treatment parameters and test data for a given property as well as the four analysis plots described in the preceding section.

<u>Analysis of Yield Strength.</u> The data and analysis for yield strength at 1100F, 1300F, and 1400F are presented in Appendix 1, 4, and 7 respectively. Examination of these results

reveals several trends common to all three test temperatures. First, the data consistently shows higher cooling rates produce higher yield strength. Oil quenching produces yield strengths around 140 to 150KSI while blanket cooling produces yield strengths around 100 to 110KSI before stabilization. Second, stabilization tends to increase strength (NPS values exceed 1.0), however, increasing stabilization temperature and time, i.e. higher LMP values, tends to diminish this effect. Further, the impact of stabilization is more pronounced at higher solution cooling rates. Stabilization factors, NPS, run as high as 1.2 for oil quenching while that for blanket cooling tends to run around 1.0. Finally, the effect of increasing solution temperature was found to decrease yield strength. This later effect is undoubtedly related to grain size effects, while cooling rate and stabilization would tend to affect strength by impacting nucleation and growth of gamma prime. Predictions of yield strength using the equations developed in this analysis resulted in good agreement with experiment. This is to be expected as the analysis utilizes the data as input, but the high R^2 values (R^2>0.9) indicate the utility of this approach for estimating yield strength as heat treat parameters change. While no attempt was made to model temperature dependence, examination of the data does show increasing temperature between 1100 and 1400F does tend to decrease yield strength.

Analysis of Ultimate Tensile Strength. The data and analysis for ultimate tensile strength at the three test temperatures are presented in Appendix 2, 5, and 8. Unlike yield strength, tensile strength did not increase monotonically with increasing cooling rate. In fact, the air cool data generally produced the highest tensile strength before stabilization. This result may be related to low elongation for oil quenched material. Stabilization tended to increase tensile strength. For oil quenching, stabilization factors tended to run between 1.1 and 1.4, while the lower cooling rates showed less of an effect. The degree of scatter in the stabilization data made it difficult to discern any convincing trends with LMP values. Finally, the effect of solution temperature was much less for tensile strength than yield strength. At 1100F tensile strength exhibited a substantial increase with decreasing solution temperature, while at 1400F there was little if any relation between solution temperature and tensile strength. The model predictions for tensile strength were, in general, less accurate than that observed for yield strength, with R^2 values of 0.95, 0.82, and 0.72 at 1100, 1300, and 1400F respectively. Further, the slope of the regressed lines, for observed versus predicted, tended to deviate from unity to a much greater extent as test temperature increased. Examination of the data also revealed a significant drop in tensile strength with increasing test temperature.

Analysis of Elongation. The data and analysis for tensile elongation at the three test temperatures are presented in Appendix 3, 6, and 9. Lower solution cooling rates were found to increase elongation. In general, oil quenching resulted in elongation values less than 10% while blanket quenching resulted in elongation values greater than 20% before stabilization. The effect of cooling rate on elongation was also found to become more pronounced as test temperature increased. Stabilization heat treatments improved elongation, especially for material with higher solution cooling rates. Stabilization factors, NPS, approached 2 to 3 for oil quenching, whereas NPS remained near 1 for blanket cooled materials. The effect of stabilization temperature and time, as measured by LMP values, showed an inverse relation between LMP and elongation at 1100F.

However, at 1300 and 1400F increasing LMP values generally resulted in higher elongation numbers. Solution temperature was also found to produce a divergence in elongation behavior as test temperature increased. At 1100F increasing solution temperature tended to lower elongation, while increasing solution temperature improved elongation at 1300 and 1400F. The agreement between prediction and experiment for elongation were reasonable at all temperatures with R^2 values running about 0.9, although significant systematic errors were apparent on the slopes and intercepts of the predicted-observed plots in Appendix 3, 6, and 9.

Analysis of Notch Tensile Strength. The data and analysis for notch tensile strength are presented in Appendix 10. Solution cooling rate was found to increase notch tensile strength, however, at higher cooling rates the change in notch tensile strength was minimal. Stabilization also tended to improve notch tensile strength. Stabilization factors, NPS, reached 1.1 for oil quenching with the greatest increases occurring at lower LMP values. As with most other properties, NPS values stayed near 1 for blanket cooling. Higher solution temperatures were found to produce a substantial decrease in notch tensile strength. Overall agreement between observed and predicted values were quite good as R^2 exceeded 0.9 and the slope/intercept of the regressed line were reasonable.

Analysis of 1300F Creep. The data and analysis of 1300F/100KSI creep rate, which was characterized by the time to 0.2% strain, are presented in Appendix 11. Changing heat treatment parameters were found to produce very significant changes in creep rate. Increasing solution cooling rate produced a dramatic improvement in creep. Before stabilization, the time to 0.2% strain went from 10 hours at low cooling rates to nearly 500 hours for oil quenching. Unlike tensile properties, stabilization caused a significant loss in creep resistance. Stabilization factors tended to start at 1, for low LMP values, and reached levels as low as 0.2, at higher LMP values. Recall higher LMP values imply higher stabilization temperatures and times. As one might expect, the impact of stabilization on creep was much more pronounced for material with higher solution cooling rates. Solution temperature also produced significant changes in creep resistance. For every heat treatment, raising the solution temperature improved creep resistance. On average this produced a 1.5X increase in creep resistance and is undoubtedly related to differences in grain size. The accuracy of the predicted creep data is remarkable considering the range of the data encountered in this study. The regressed line of the observed versus predicted plot had a slope close to unity and an intercept near zero, indicating little if any systematic error, while the R^2 value was very good at 0.95.

SUMMARY & CONCLUSIONS

As part of NASA's Advanced Subsonic Technology Program, a study of stabilization heat treatment options for an advanced nickel-base disk alloy, ME-209, was performed. Using a simple, physically based approach, the effect of stabilization heat treatments on tensile and creep properties was analyzed in this paper. Solution temperature, solution cooling rate, and stabilization temperature/time were found to have a significant impact on tensile and creep properties. These effects were readily quantified using the following methodology. First, the effect of solution cooling rate was assessed to determine its impact on a given property. The as-cooled property was then modified by using two multiplicative factors which assess the impact of solution temperature and stabilization parameters. Comparison of experimental data with predicted values showed this physically based analysis produced good results that rivaled the statistical analysis employed in Reference 1, which required numerous changes in the form of the regression equation depending on the property and temperature in question.

As this physically based analysis uses the data for input, it should be noted that predictions which attempt to extrapolate beyond the bounds of the data must be viewed with skepticism. Future work aimed at expanding the range of the stabilization/aging parameters explored in this study would be highly desirable, especially at the higher solution cooling rates.

REFERENCES

1. P. L. Reynolds, Effects of Residual Stress Heat Treatments (Sub-AoI 4.2.6), NASA AST Report FR-25331, December 1999.
2. J. Gayda, P. L. Reynolds, and S. Mayers, The Effect of Solution Cooling Rate on Residual Stresses in an Advanced Nickel-Base Disk Alloy, NASA AST 031, September 1999.

				COMPOSITION OF DISK ALLOY IN W/O							
Co	Cr	Mo	W	Nb	Ta	Al	Ti	B	C	Zr	Ni
20	13.1	3.8	1.9	1.1	2.25	3.45	3.6	0.03	0.04	0.05	BAL

TABLE I. ALLOY COMPOSITION.

Heat Treat S/N	Solution Cycle	Solution Quench Rate	Stress Relief Cycle	Stress Relief Quench Rate	Age Cycle
1	2060F / 1 Hr + 2155 / 3 Hr	Oil quench	NONE	NONE	NONE
2	2060F / 1 Hr + 2155 / 3 Hr	Air cool	"	"	"
3	2060F / 1 Hr + 2155 / 3 Hr	Blanket cool	"	"	"
4	2080F / 1 Hr	Oil quench	"	"	"
5	2080F / 1 Hr	Air cool	"	"	"
6	2080F / 1 Hr	Blanket cool	"	"	"
7	2080F / 1 Hr	Blanket cool	1425F / 2 Hr	Air Cool	1400F / 8 Hr / Air Cool
8	2060F / 1 Hr + 2155 / 3 Hr	Blanket cool	1425F / 2 Hr	Blanket Cool	"
9	2080F / 1 Hr	Oil quench	1425F / 2 Hr	Blanket Cool	"
10	2060F / 1 Hr + 2155 / 3 Hr	Oil quench	1425F / 2 Hr	Air Cool	"
11	2080F / 1 Hr	Blanket cool	1575F / 2 Hr	Blanket Cool	"
12	2060F / 1 Hr + 2155 / 3 Hr	Blanket cool	1575F / 2 Hr	Air Cool	"
13	2080F / 1 Hr	Oil quench	1575F / 2 Hr	Air Cool	"
14	2060F / 1 Hr + 2155 / 3 Hr	Oil quench	1575F / 2 Hr	Blanket Cool	"
15	2080F / 1 Hr	Blanket cool	1425F / 8 Hr	Blanket Cool	"
16	2060F / 1 Hr + 2155 / 3 Hr	Blanket cool	1425F / 8 Hr	Air Cool	"
17	2080F / 1 Hr	Oil quench	1425F / 8 Hr	Air Cool	"
18	2060F / 1 Hr + 2155 / 3 Hr	Oil quench	1425F / 8 Hr	Blanket Cool	"
19	2080F / 1 Hr	Blanket cool	1575F / 8 Hr	Air Cool	"
20	2060F / 1 Hr + 2155 / 3 Hr	Blanket cool	1575F / 8 Hr	Blanket Cool	"
21	2080F / 1 Hr	Oil quench	1575F / 8 Hr	Blanket Cool	"
22	2060F / 1 Hr + 2155 / 3 Hr	Oil quench	1575F / 8 Hr	Air Cool	"
23	2080F / 1 Hr	Air cool	1500F / 5 Hr	Air Cool	"
24	2060F / 1 Hr + 2155 / 3 Hr	Air cool	1500F / 5 Hr	Air Cool	"
25	2060F / 1 Hr + 2155 / 3 Hr	Air cool	1500F / 5 Hr	Blanket Cool	"
26	2080F / 1 Hr	Air cool	1500F / 5 Hr	Blanket Cool	"

TABLE II. HEAT TREATMENT MATRIX.

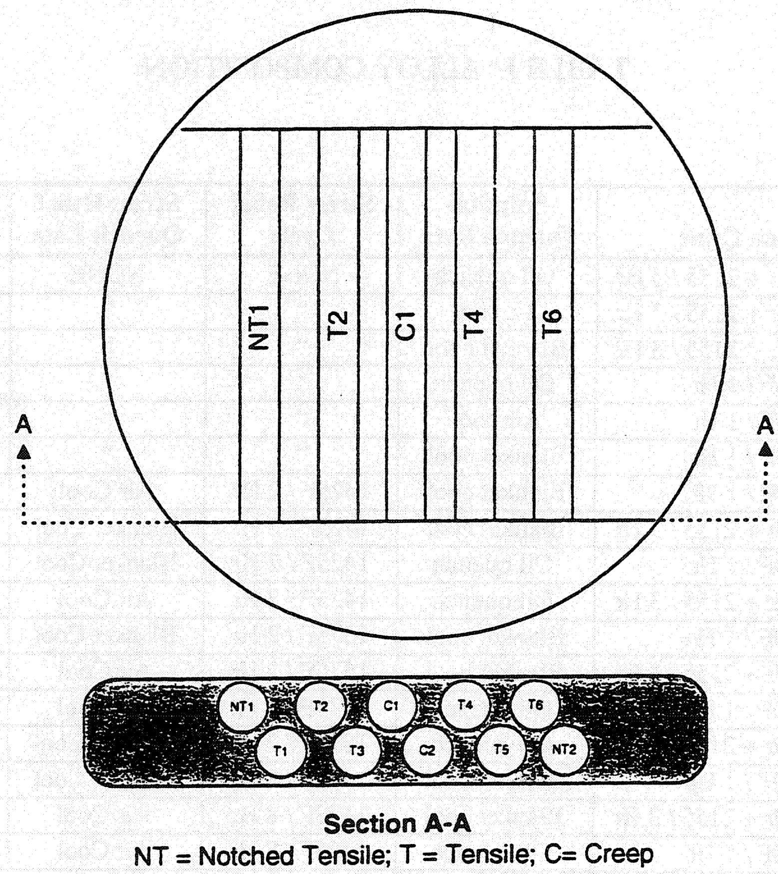


FIGURE 1. SPECIMEN CUT-UP PLAN.

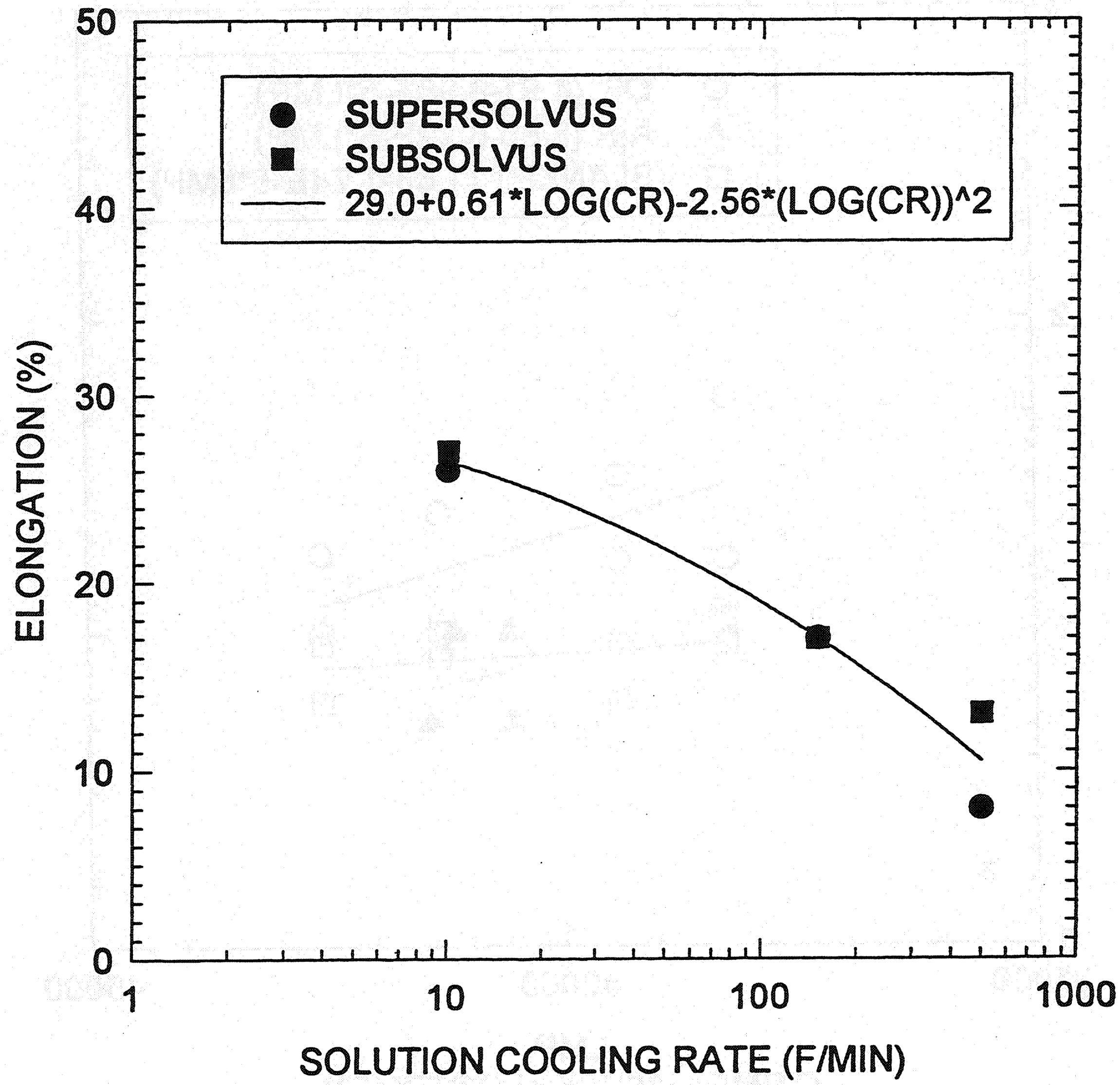


FIGURE 2. SOLUTION COOLING RATE ANALYSIS.

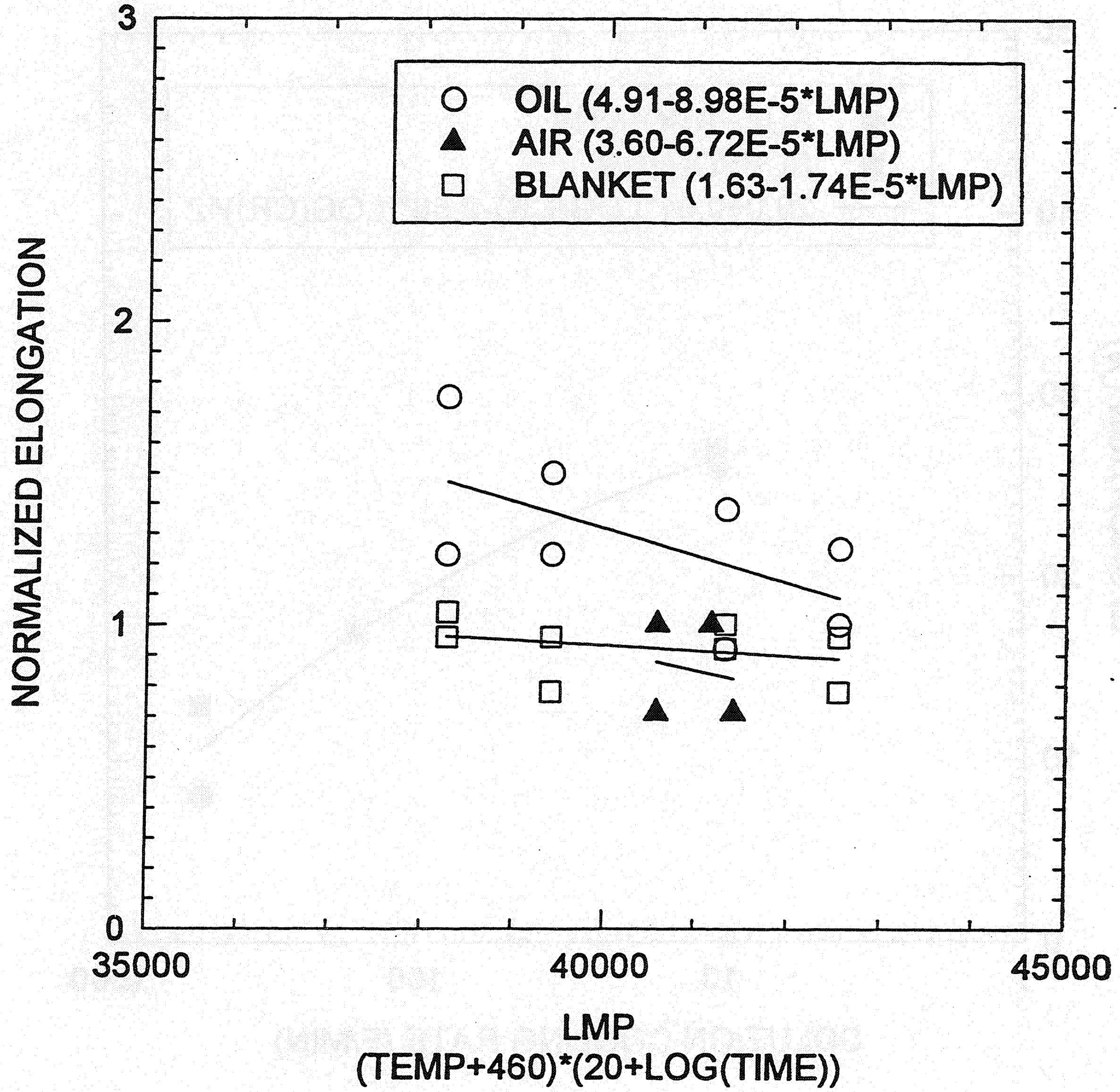


FIGURE 3. STABILIZATION FACTOR ANALYSIS.

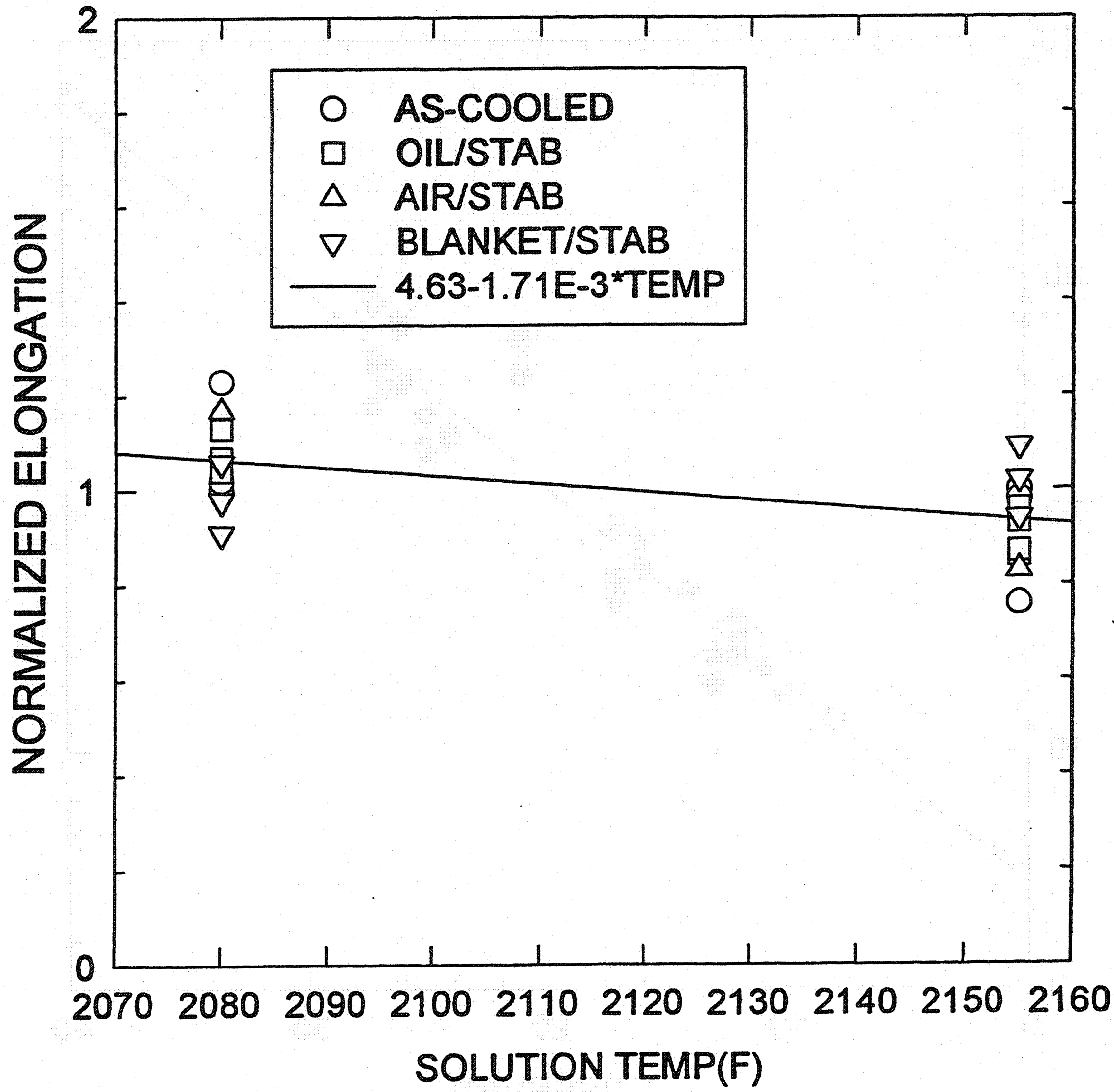


FIGURE 4. SOLUTION TEMPERATURE FACTOR ANALYSIS.

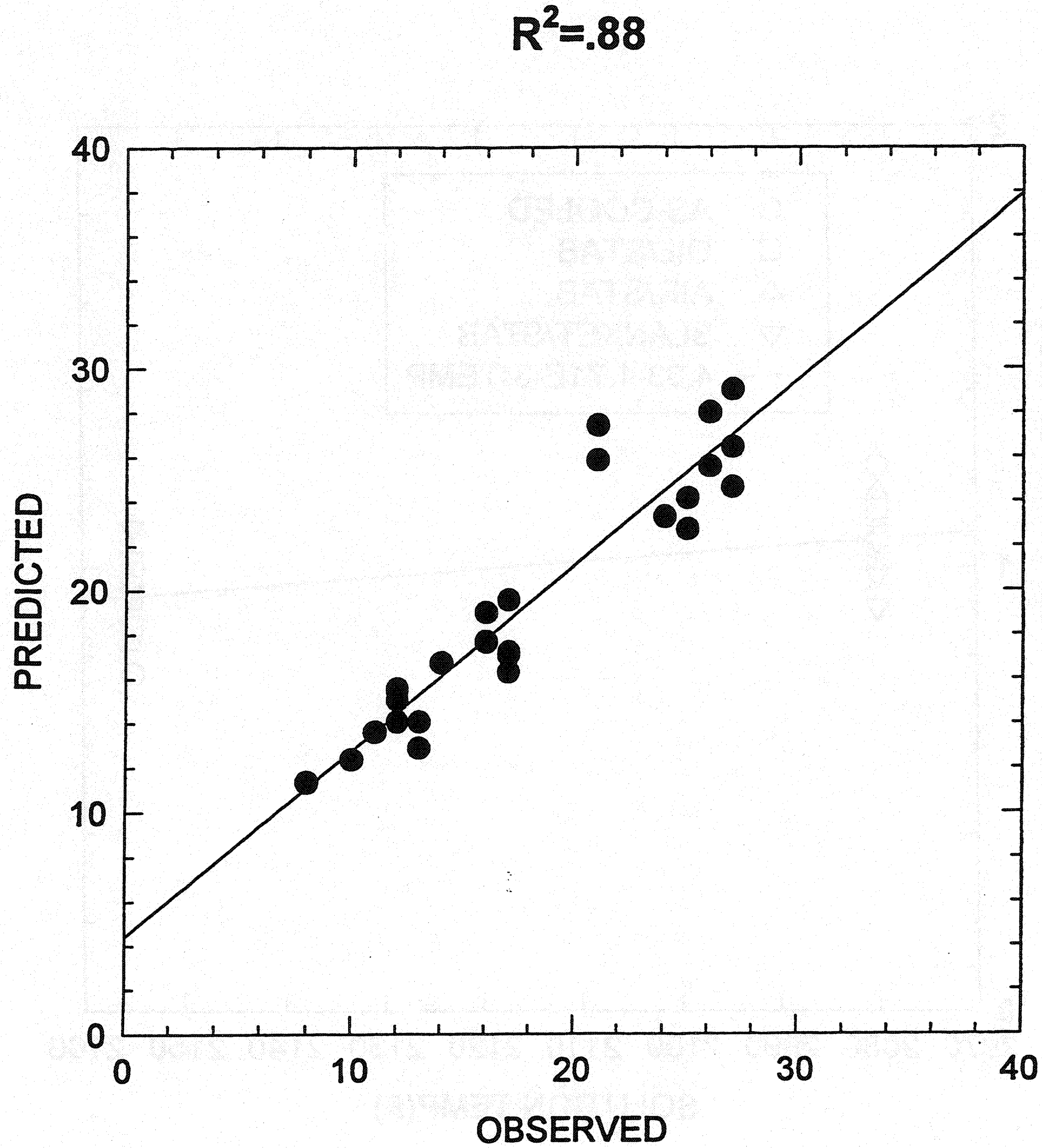


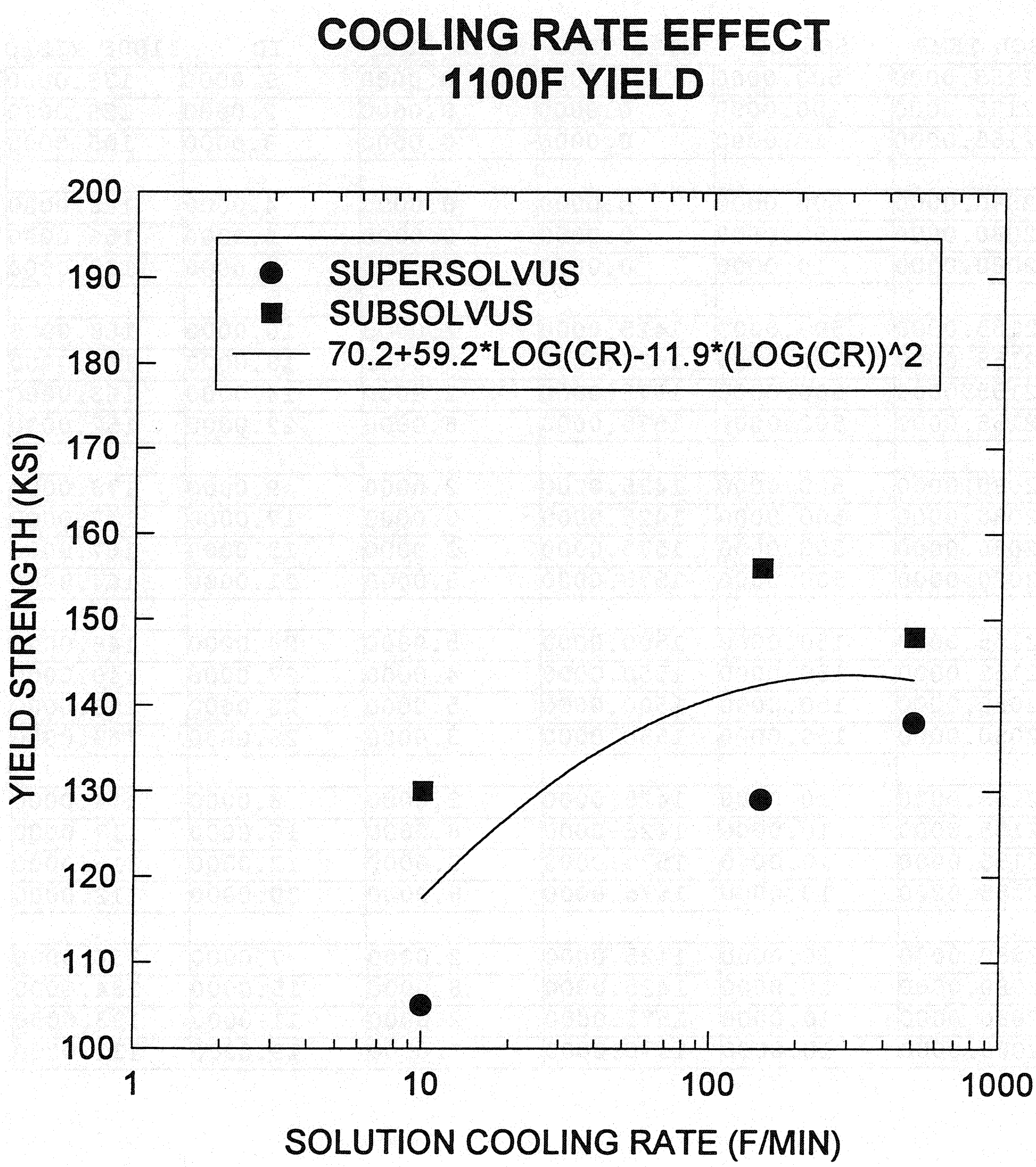
FIGURE 5. COMPARISON OF PREDICTED VERSUS OBSERVED PROPERTY.

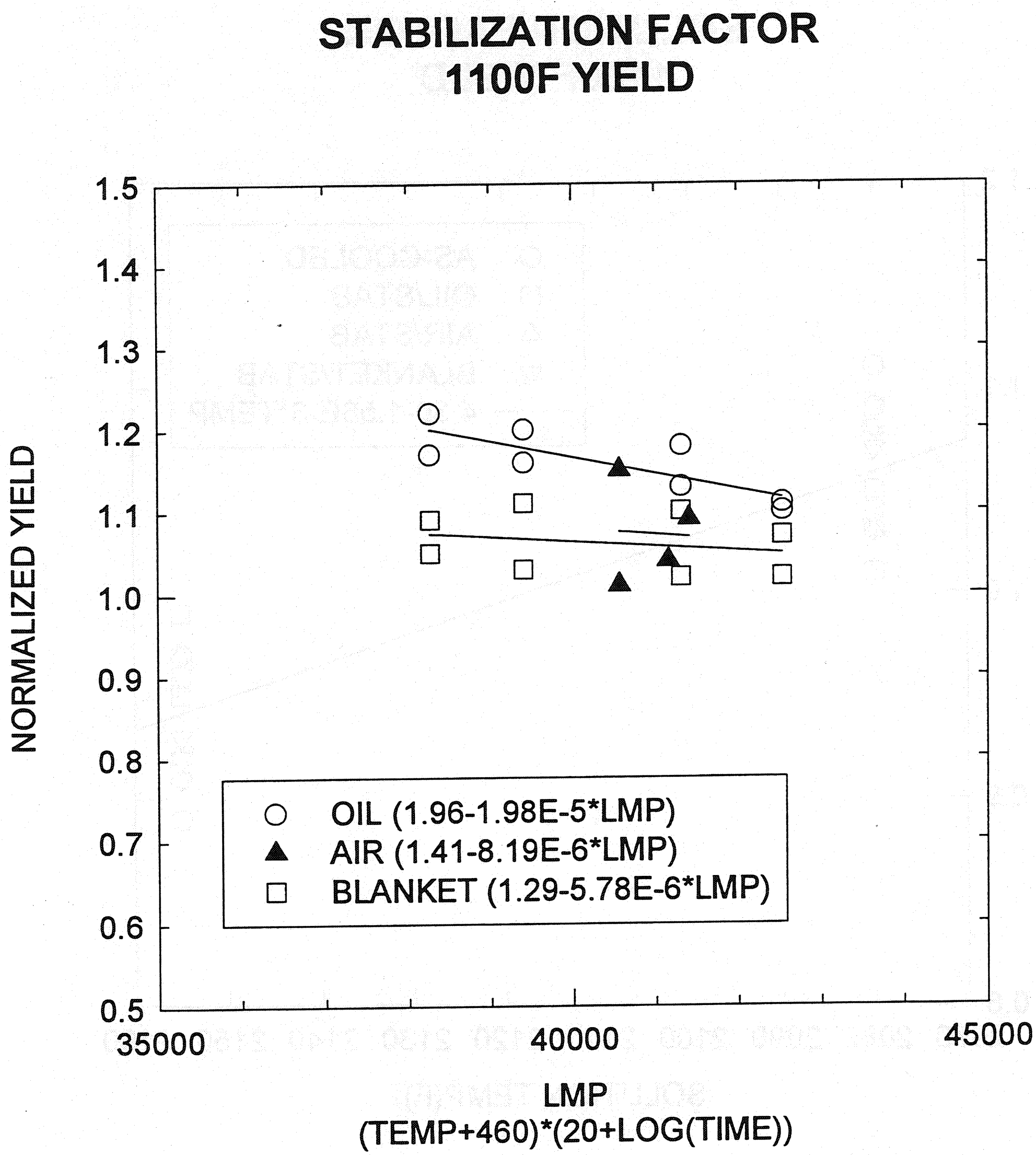
LIST OF APPENDICES

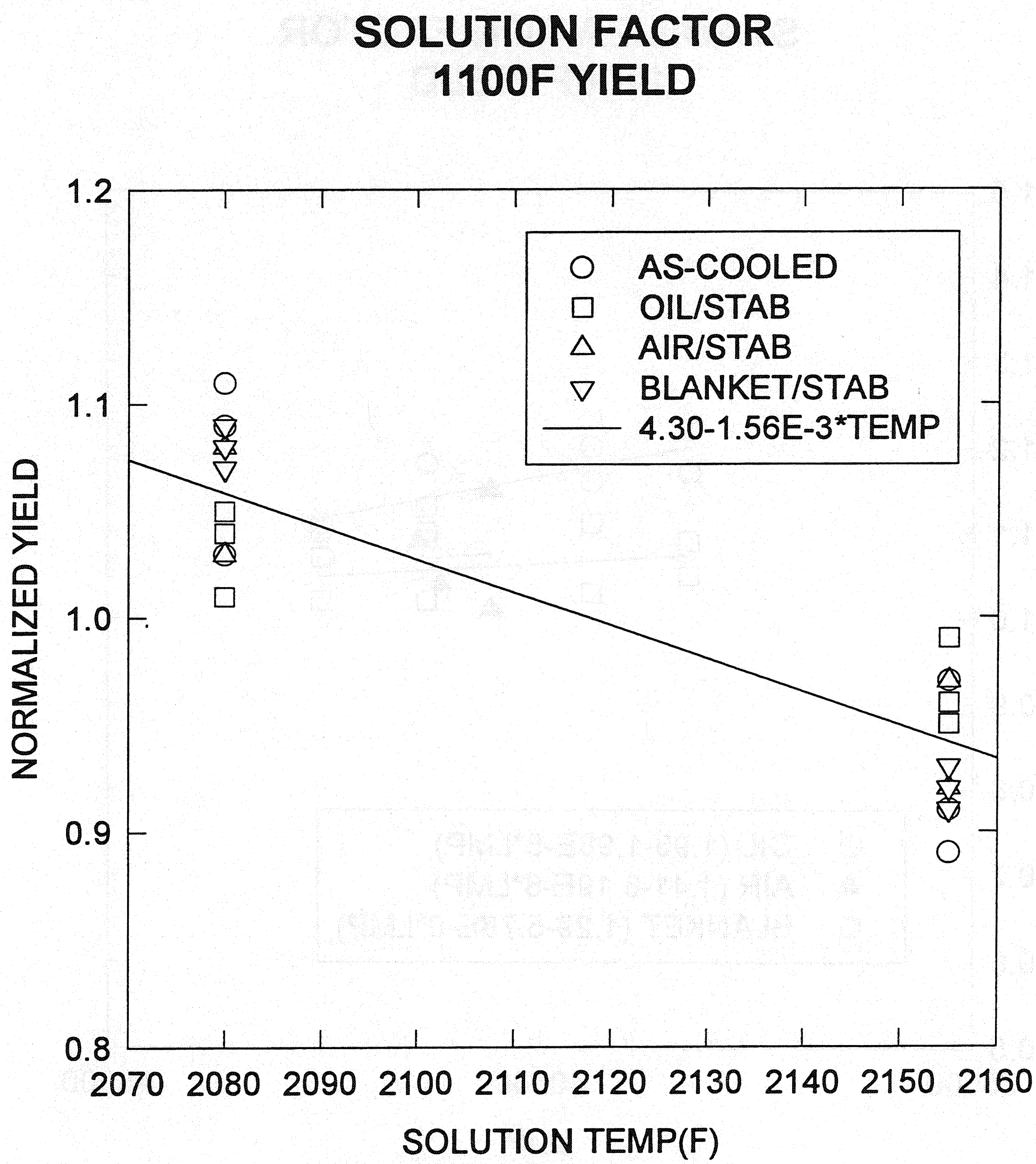
APPENDIX I

1100F YIELD STRENGTH ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1100F YIELD
2155.0000	500.0000	0.0000	0.0000	1.0000	138.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	129.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	105.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	148.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	156.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	130.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	168.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	160.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	163.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	152.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	173.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	177.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	167.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	164.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	148.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	140.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	158.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	163.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	114.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	117.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	116.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	112.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	136.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	134.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	133.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	132.0000

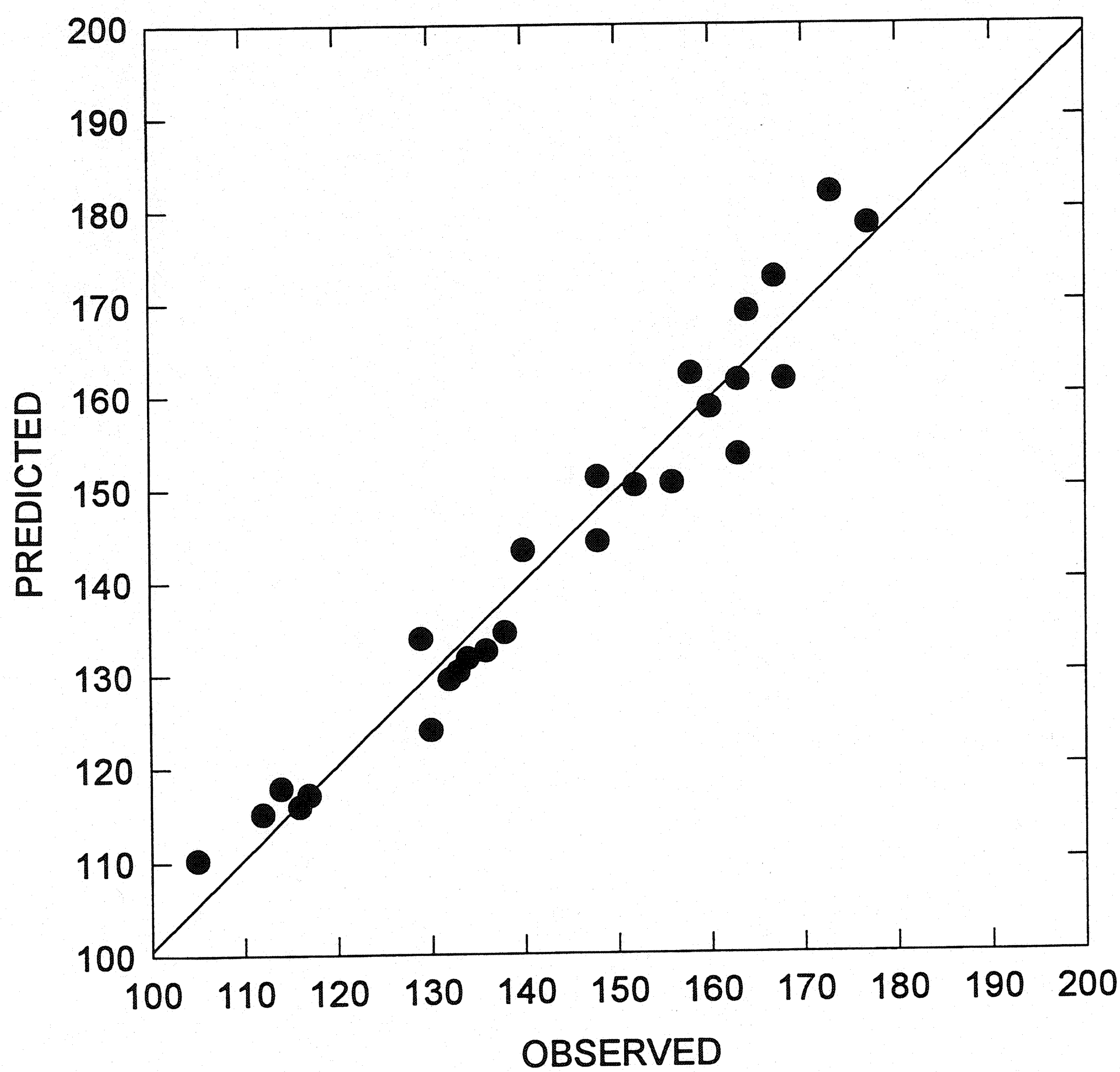

COOLING RATE EFFECT
1100F YIELD
SUPERSOLVUS
SUBSOLVUS
70.2+59.2*LOG(CR)-11.9*(LOG(CR))^2
YIELD STRENGTH (KSI)
200
190
180
170
160
150
140
130
120
110
100
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1100F YIELD
NORMALIZED YIELD
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (1.96-1.98E-5*LMP)
AIR (1.41-8.19E-6*LMP)
BLANKET (1.29-5.78E-6*LMP)



SOLUTION FACTOR
1100F YIELD
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
4.30-1.56E-3*TEMP
NORMALIZED YIELD
1.2
1.1
1.0
0.9
0.8
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)

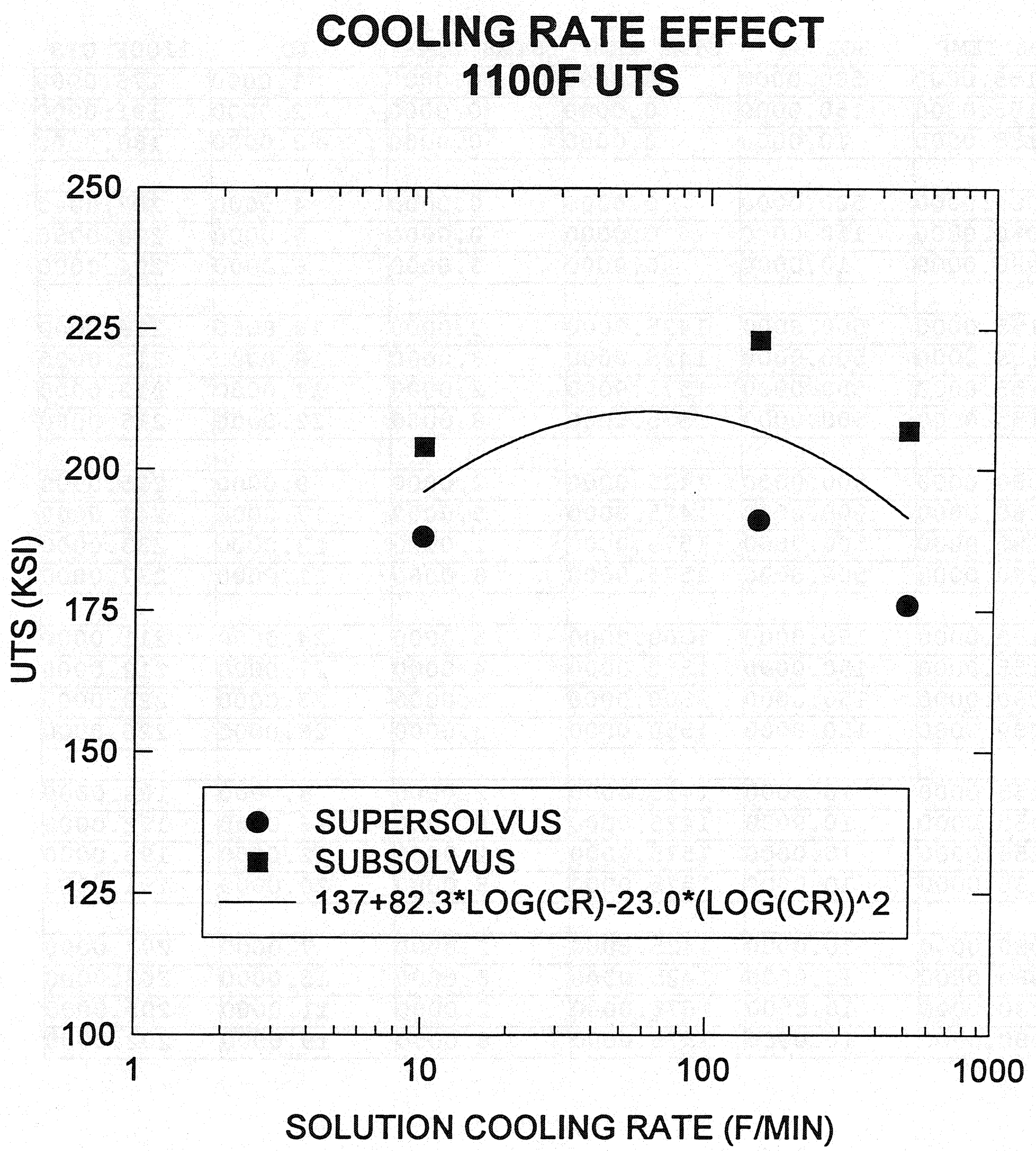
1100F YIELD PREDICTIONS FOR ALLOY 2
R^2=.95

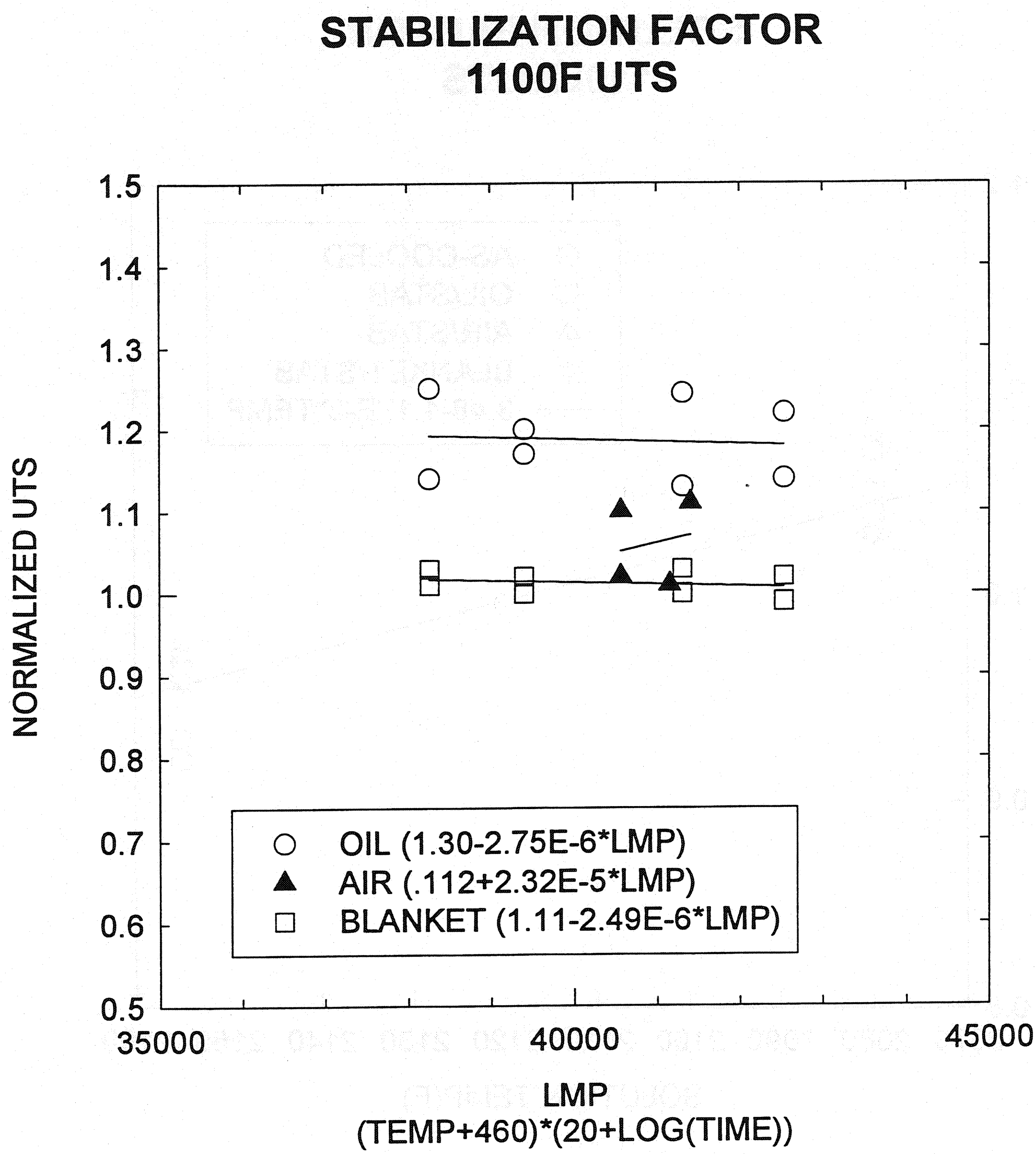


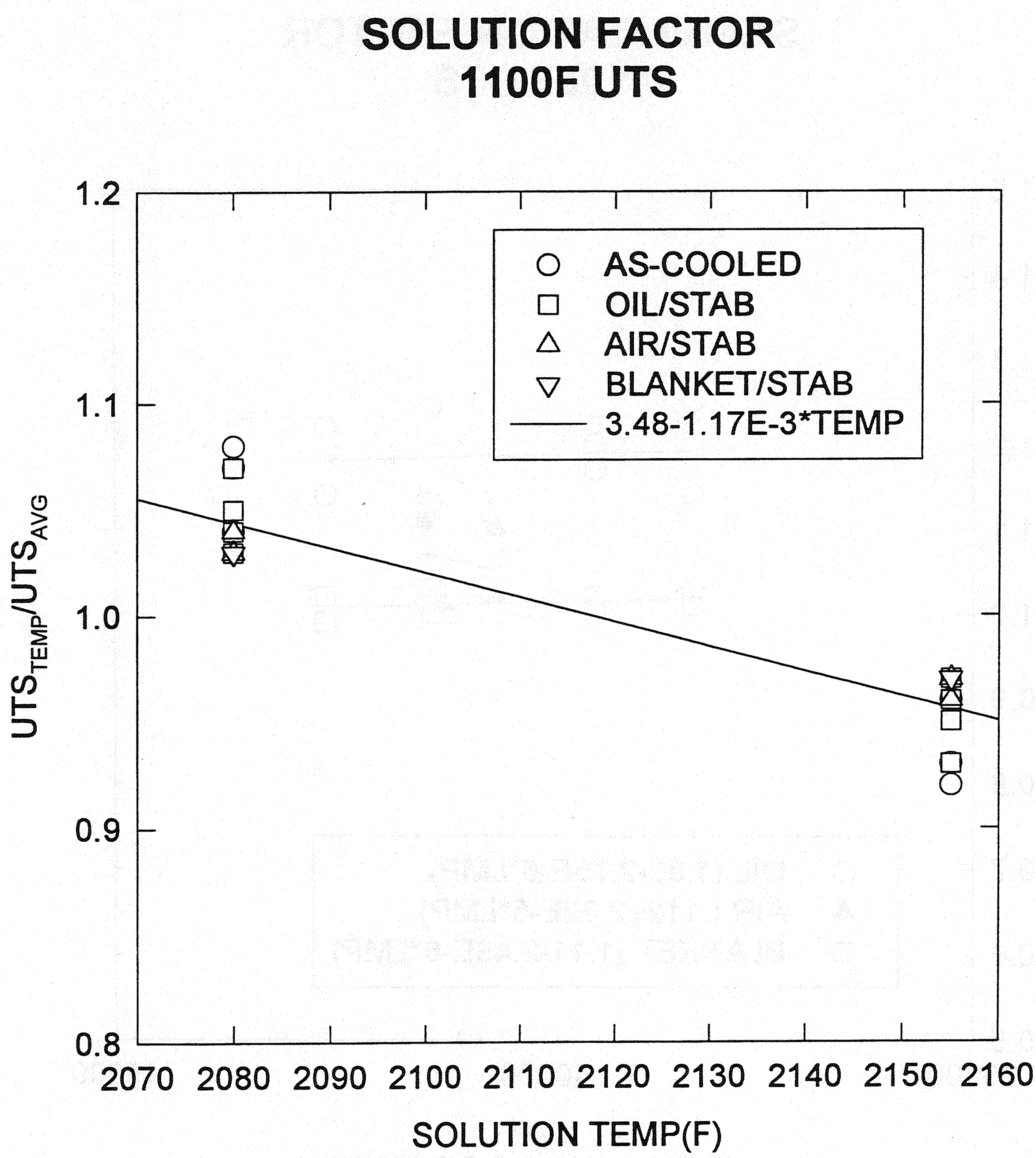
APPENDIX 2

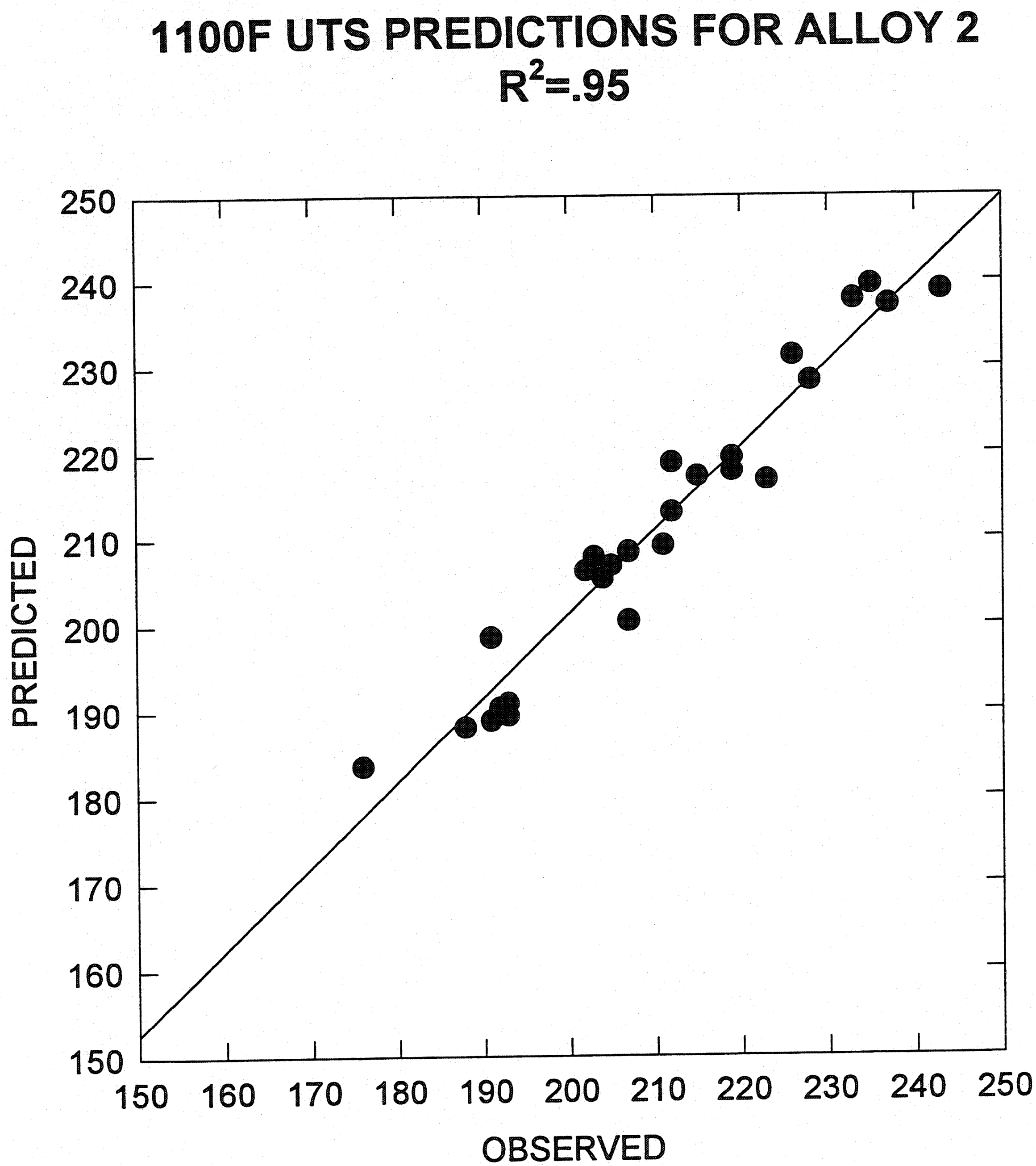
1100F ULTIMATE TENSILE STRENGTH ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1100F UTS
2155.0000	500.0000	0.0000	0.0000	1.0000	176.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	191.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	188.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	207.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	223.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	204.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	219.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	212.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	219.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	215.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	235.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	243.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	233.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	237.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	211.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	212.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	228.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	226.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	193.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	192.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	193.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	191.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	207.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	203.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	205.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	202.0000


COOLING RATE EFFECT
1100F UTS
250
225
200
175
150
125
100
UTS (KSI)
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)
SUPERSOLVUS
SUBSOLVUS
137+82.3*LOG(CR)-23.0*(LOG(CR))^2


STABILIZATION FACTOR
1100F UTS
NORMALIZED UTS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (1.30-2.75E-6*LMP)
AIR (.112+2.32E-5*LMP)
BLANKET (1.11-2.49E-6*LMP)

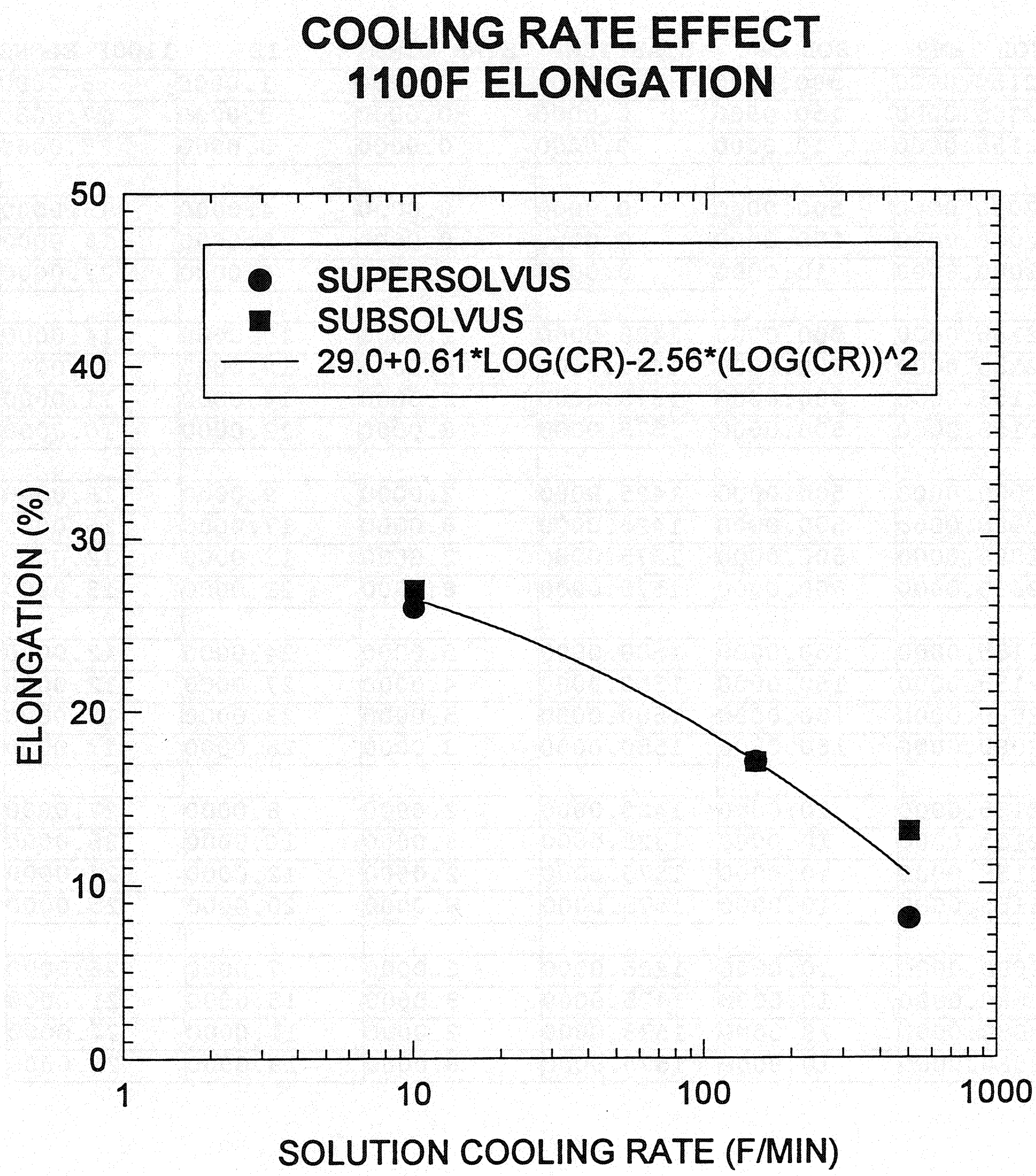

SOLUTION FACTOR
1100F UTS
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
3.48-1.17E-3*TEMP
1.2
1.1
1.0
0.9
0.8
UTS$_{TEMP}$/UTS$_{AVG}$
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)

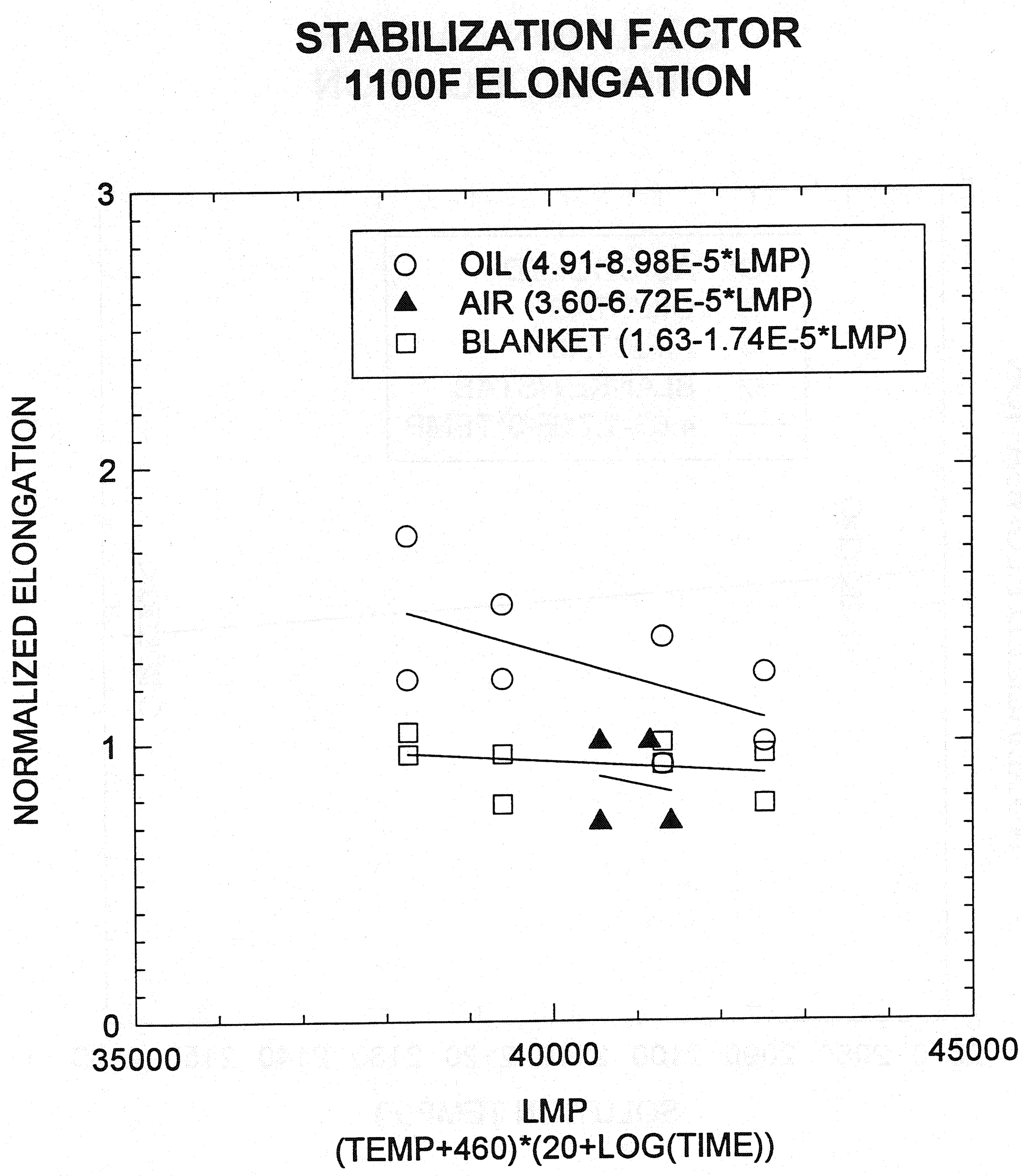

1100F UTS PREDICTIONS FOR ALLOY 2
R2=.95
PREDICTED
OBSERVED
150
160
170
180
190
200
210
220
230
240
250

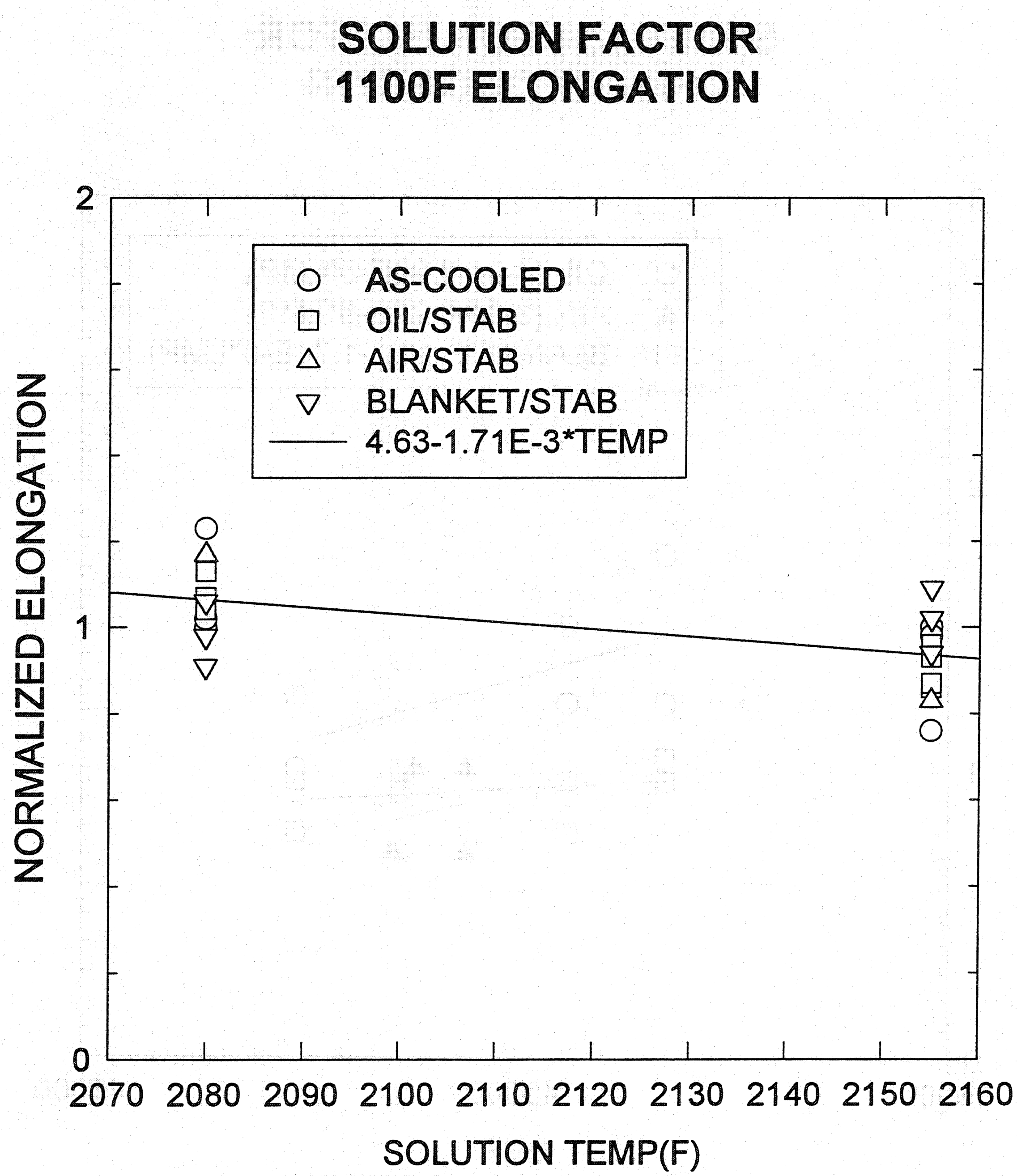
APPENDIX 3

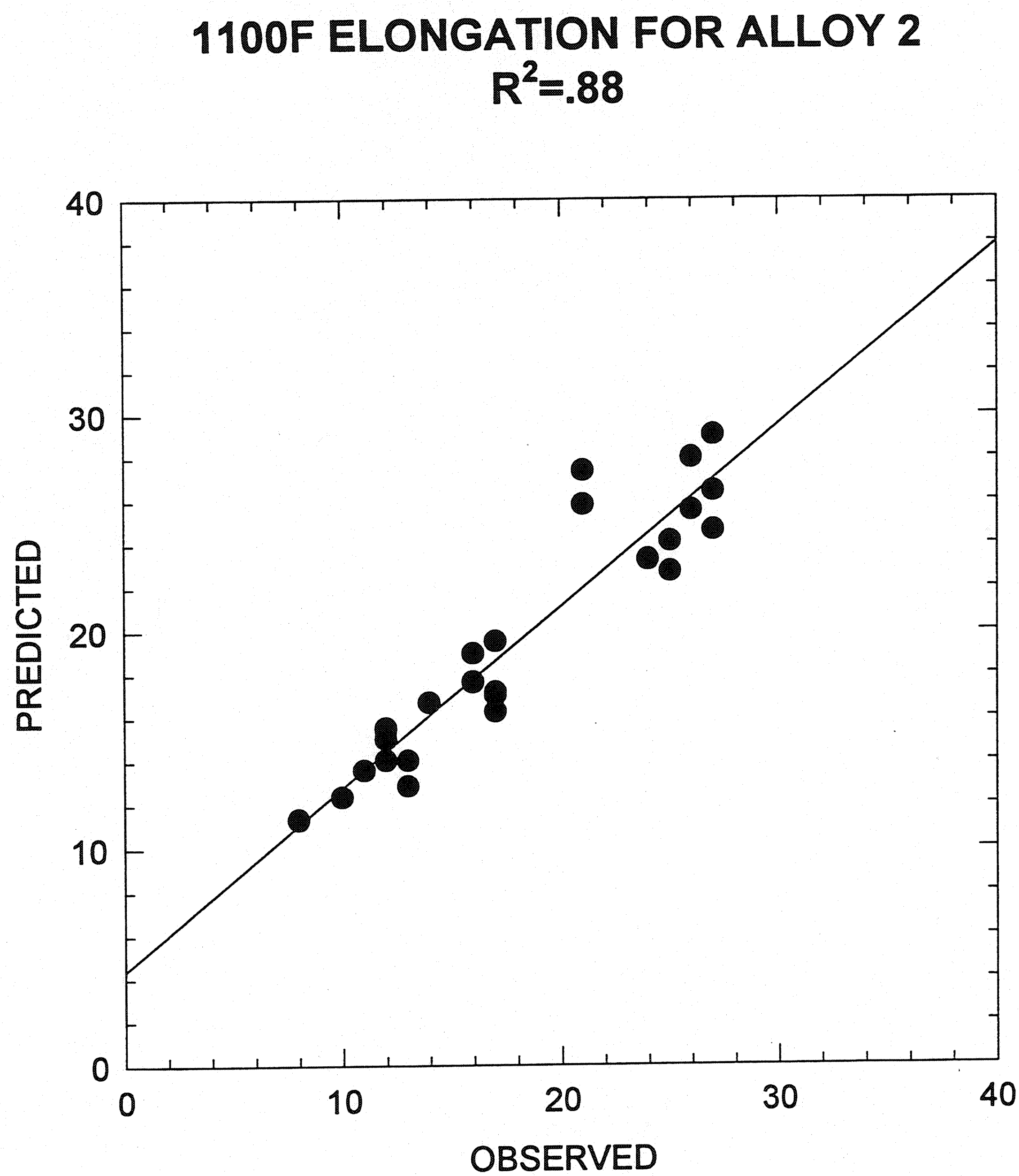
1100F TENSILE ELONGATION ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1100F ELONG
2155.0000	500.0000	0.0000	0.0000	1.0000	8.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	17.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	26.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	13.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	17.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	27.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	14.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	12.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	11.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	10.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	16.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	16.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	12.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	13.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	12.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	12.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	17.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	17.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	27.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	25.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	24.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	25.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	26.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	21.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	27.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	21.0000


COOLING RATE EFFECT
1100F ELONGATION
SUPERSOLVUS
SUBSOLVUS
29.0+0.61*LOG(CR)-2.56*(LOG(CR))^2
ELONGATION (%)
SOLUTION COOLING RATE (F/MIN)
0
10
20
30
40
50
1
10
100
1000


STABILIZATION FACTOR
1100F ELONGATION
OIL (4.91-8.98E-5*LMP)
AIR (3.60-6.72E-5*LMP)
BLANKET (1.63-1.74E-5*LMP)
NORMALIZED ELONGATION
3
2
1
0
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))

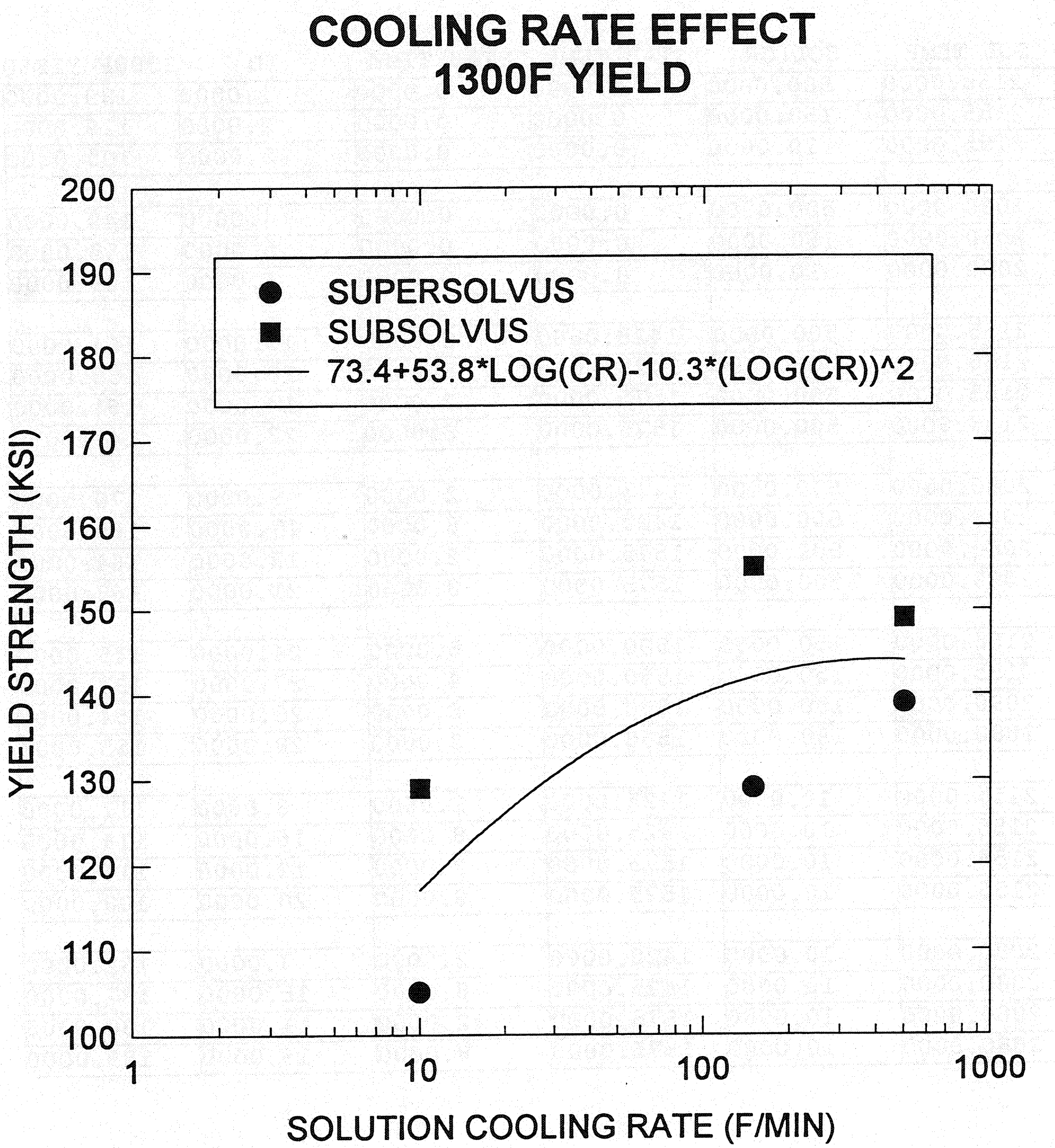

SOLUTION FACTOR
1100F ELONGATION
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
4.63-1.71E-3*TEMP
NORMALIZED ELONGATION
0
1
2
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)

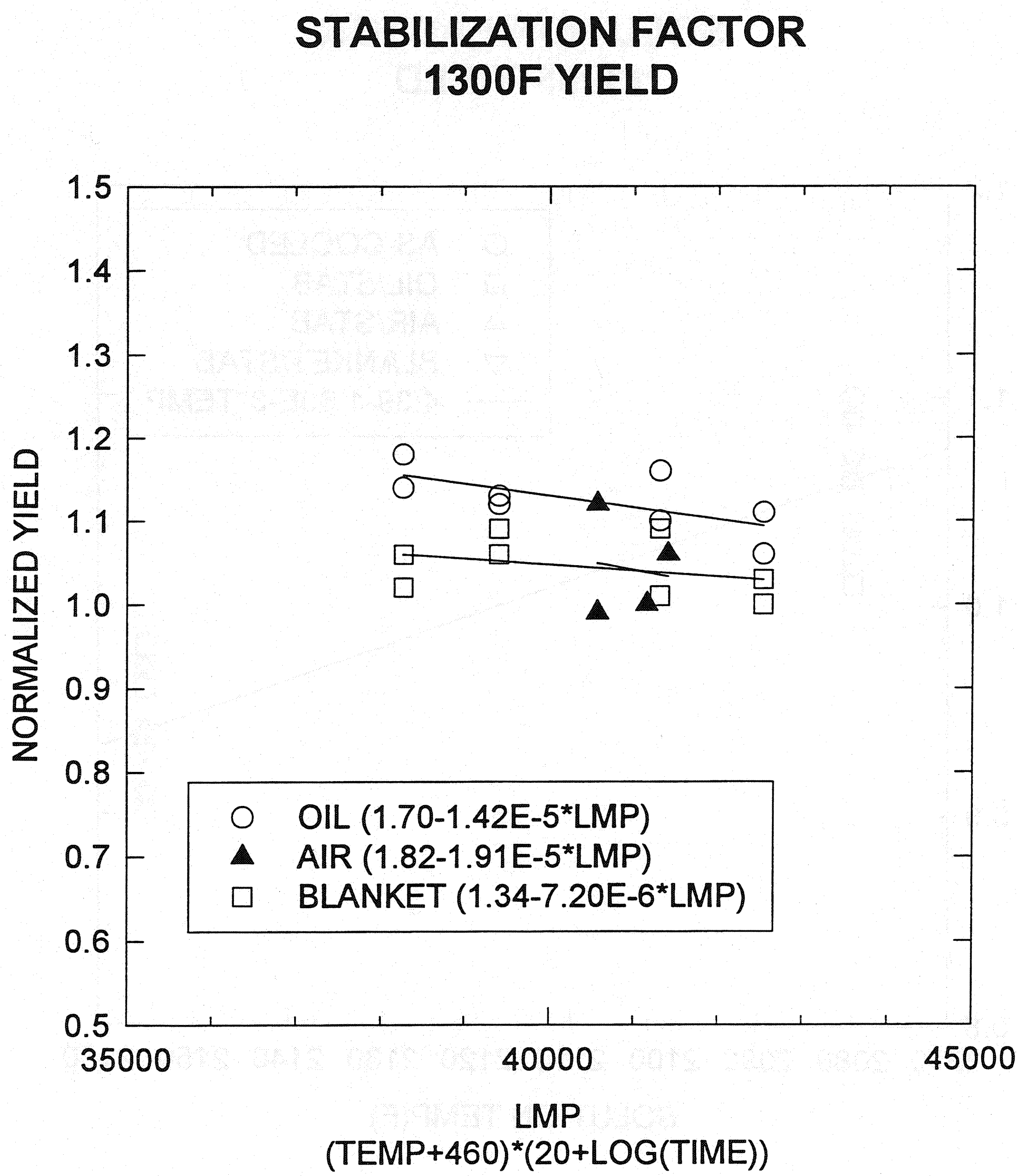

1100F ELONGATION FOR ALLOY 2
R2=.88
PREDICTED
OBSERVED
0
10
20
30
40

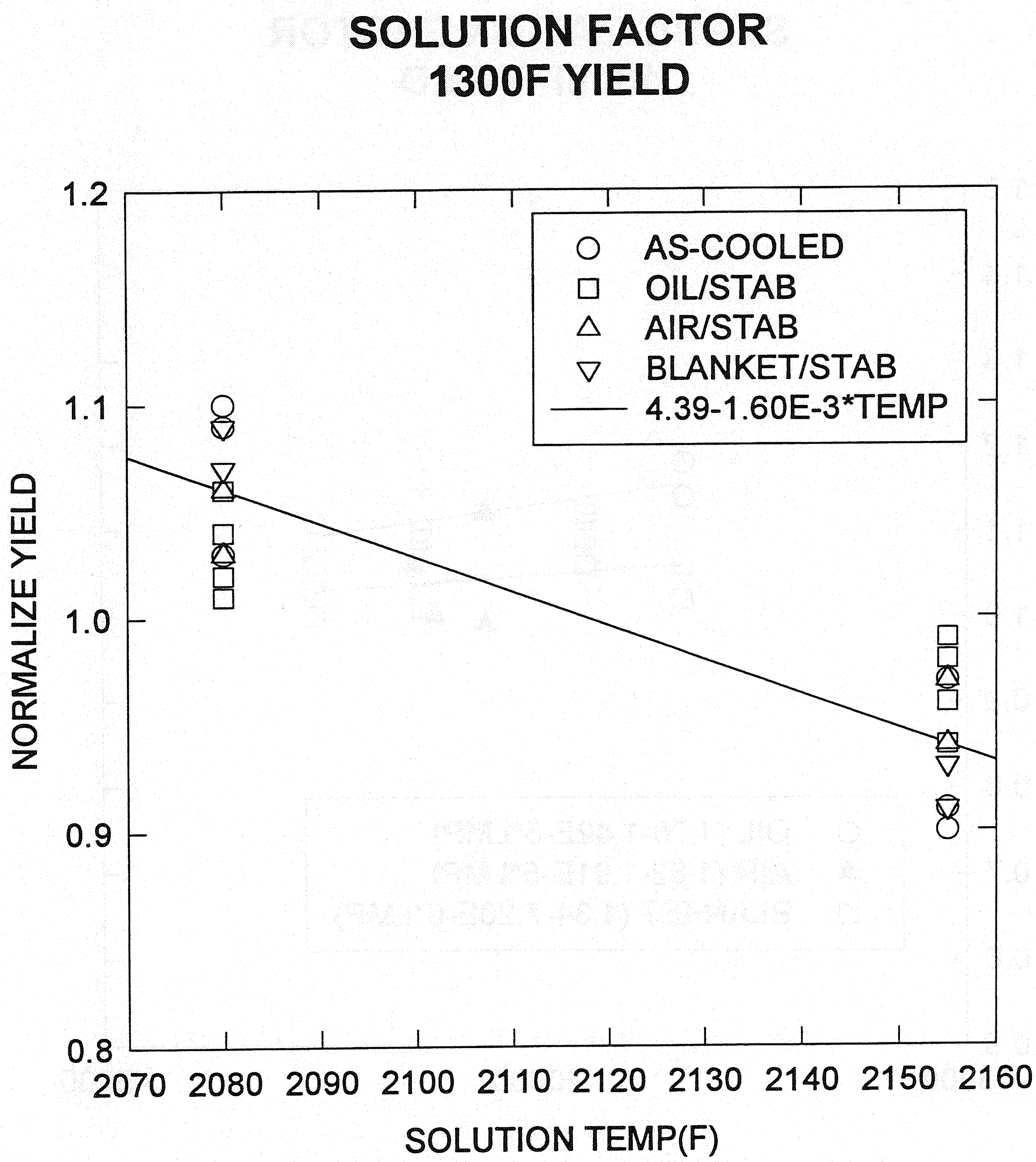
APPENDIX 4

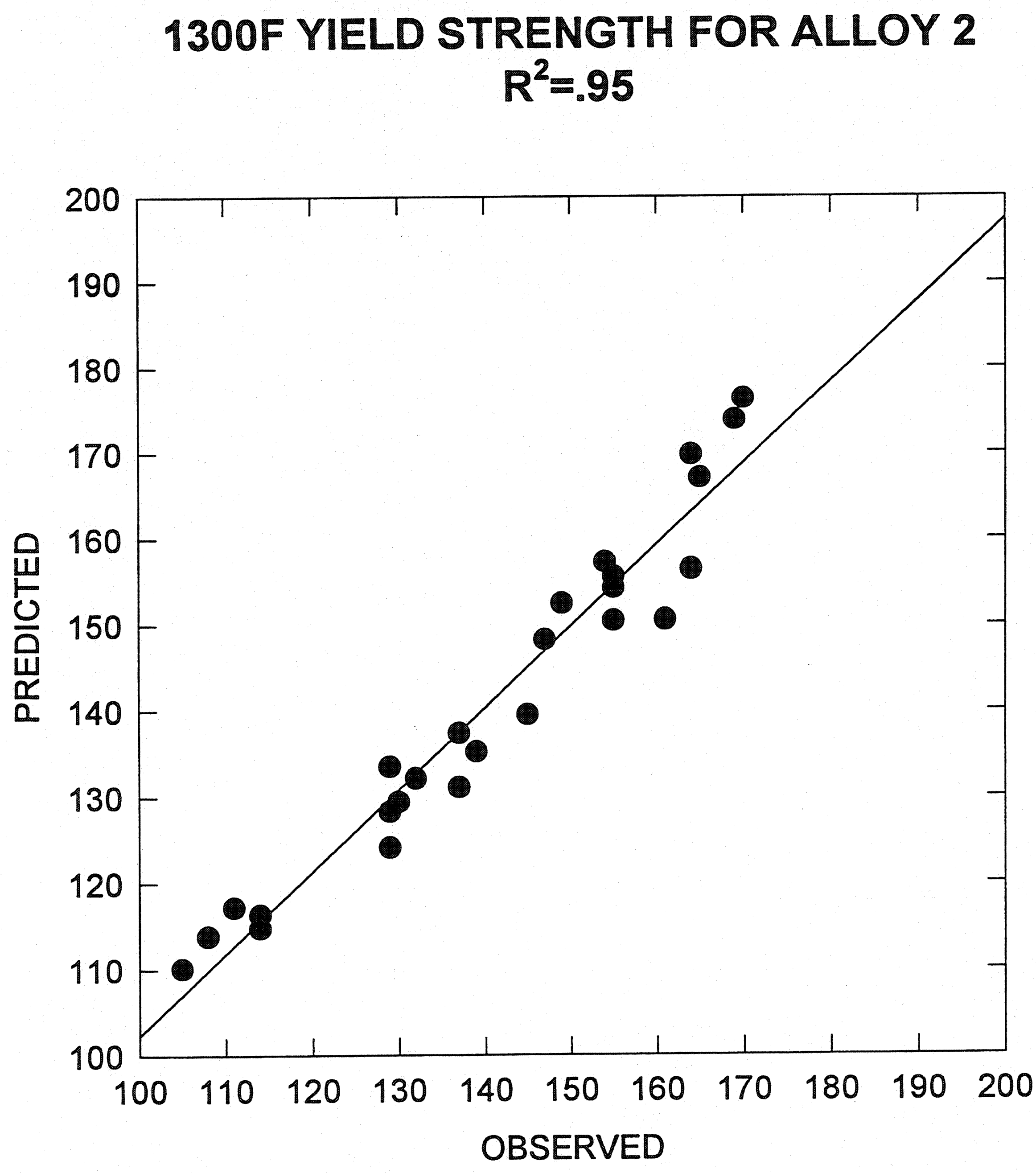
1300F YIELD STRENGTH ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1300F YIELD
2155.0000	500.0000	0.0000	0.0000	1.0000	139.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	129.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	105.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	149.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	155.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	129.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	164.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	155.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	161.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	147.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	170.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	169.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	164.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	165.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	145.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	137.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	154.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	155.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	111.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	114.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	114.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	108.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	132.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	137.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	130.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	129.0000


COOLING RATE EFFECT
1300F YIELD
SUPERSOLVUS
SUBSOLVUS
73.4+53.8*LOG(CR)-10.3*(LOG(CR))^2
YIELD STRENGTH (KSI)
200
190
180
170
160
150
140
130
120
110
100
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1300F YIELD
NORMALIZED YIELD
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (1.70-1.42E-5*LMP)
AIR (1.82-1.91E-5*LMP)
BLANKET (1.34-7.20E-6*LMP)

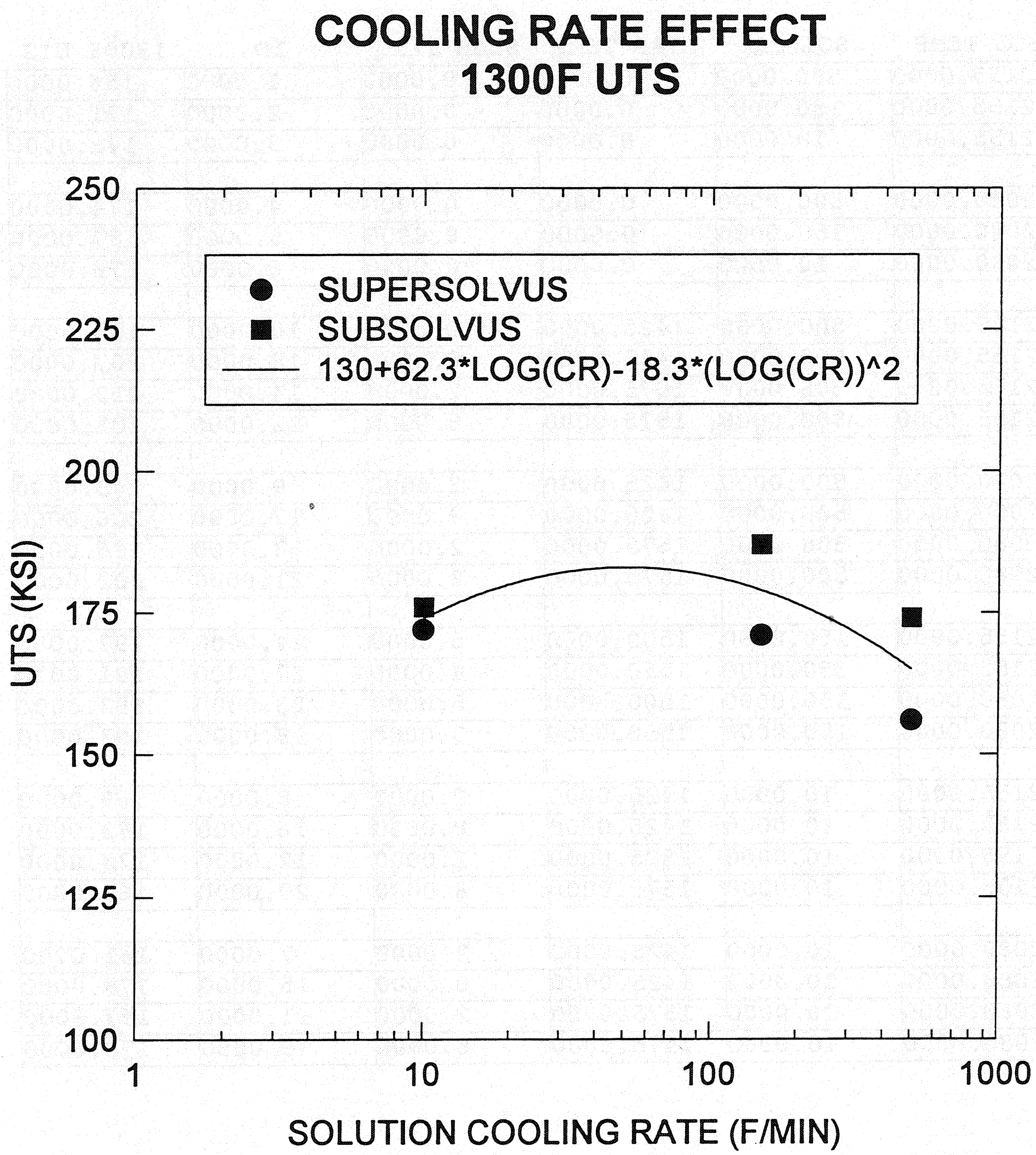

SOLUTION FACTOR
1300F YIELD
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
4.39-1.60E-3*TEMP
NORMALIZE YIELD
SOLUTION TEMP(F)
1.2
1.1
1.0
0.9
0.8
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160

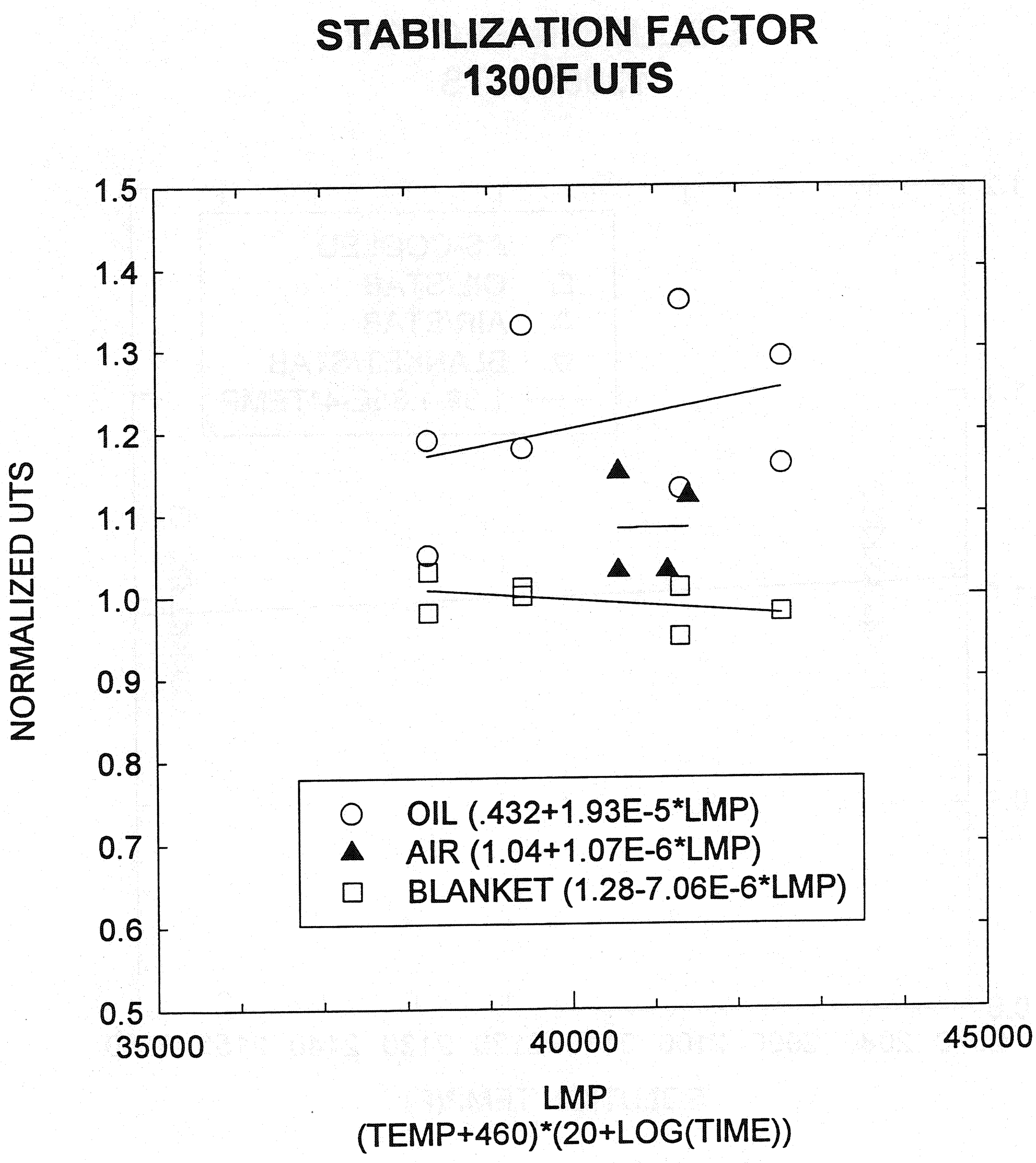

1300F YIELD STRENGTH FOR ALLOY 2
R^2=.95
PREDICTED
OBSERVED
100
110
120
130
140
150
160
170
180
190
200

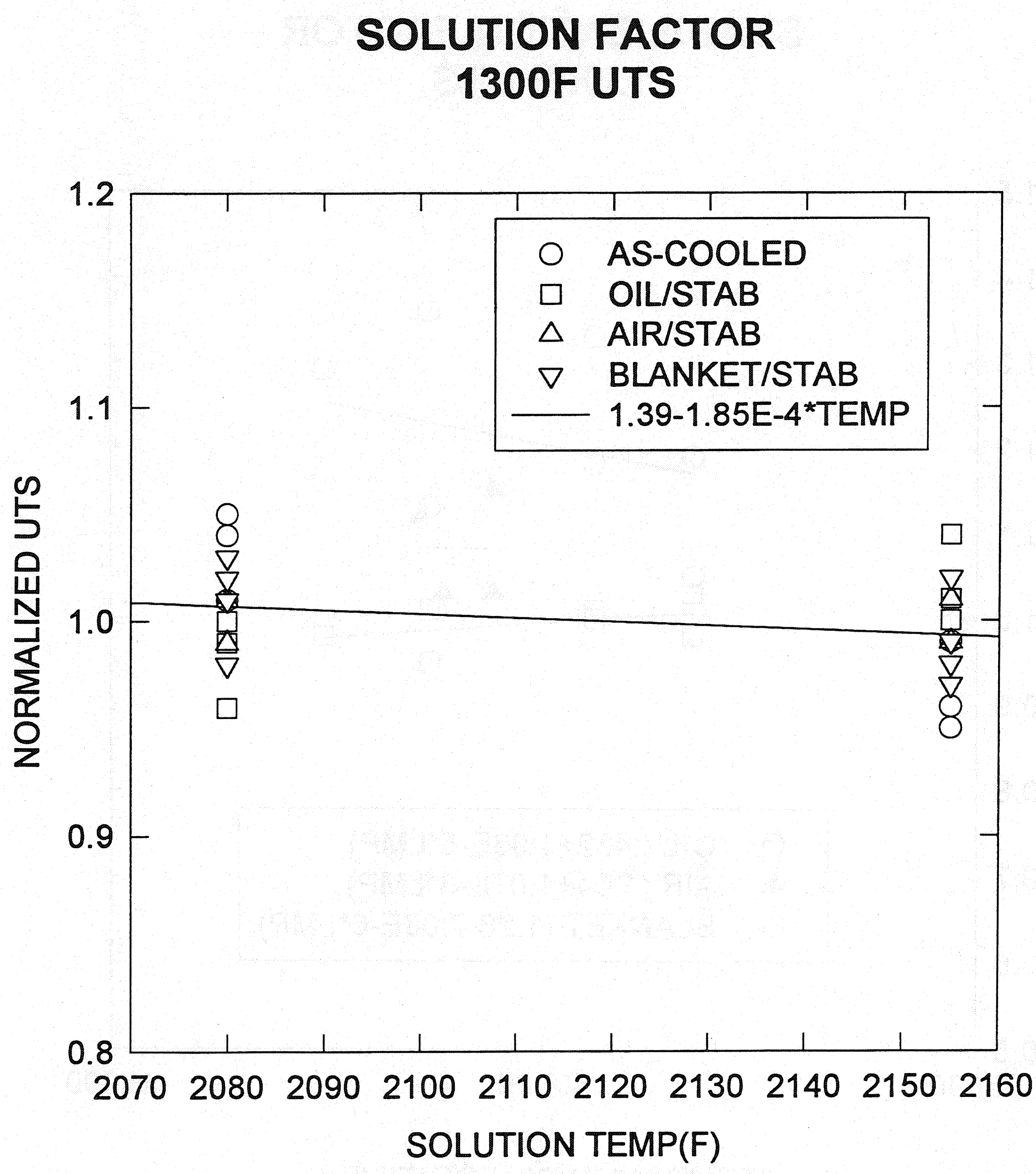
APPENDIX 5

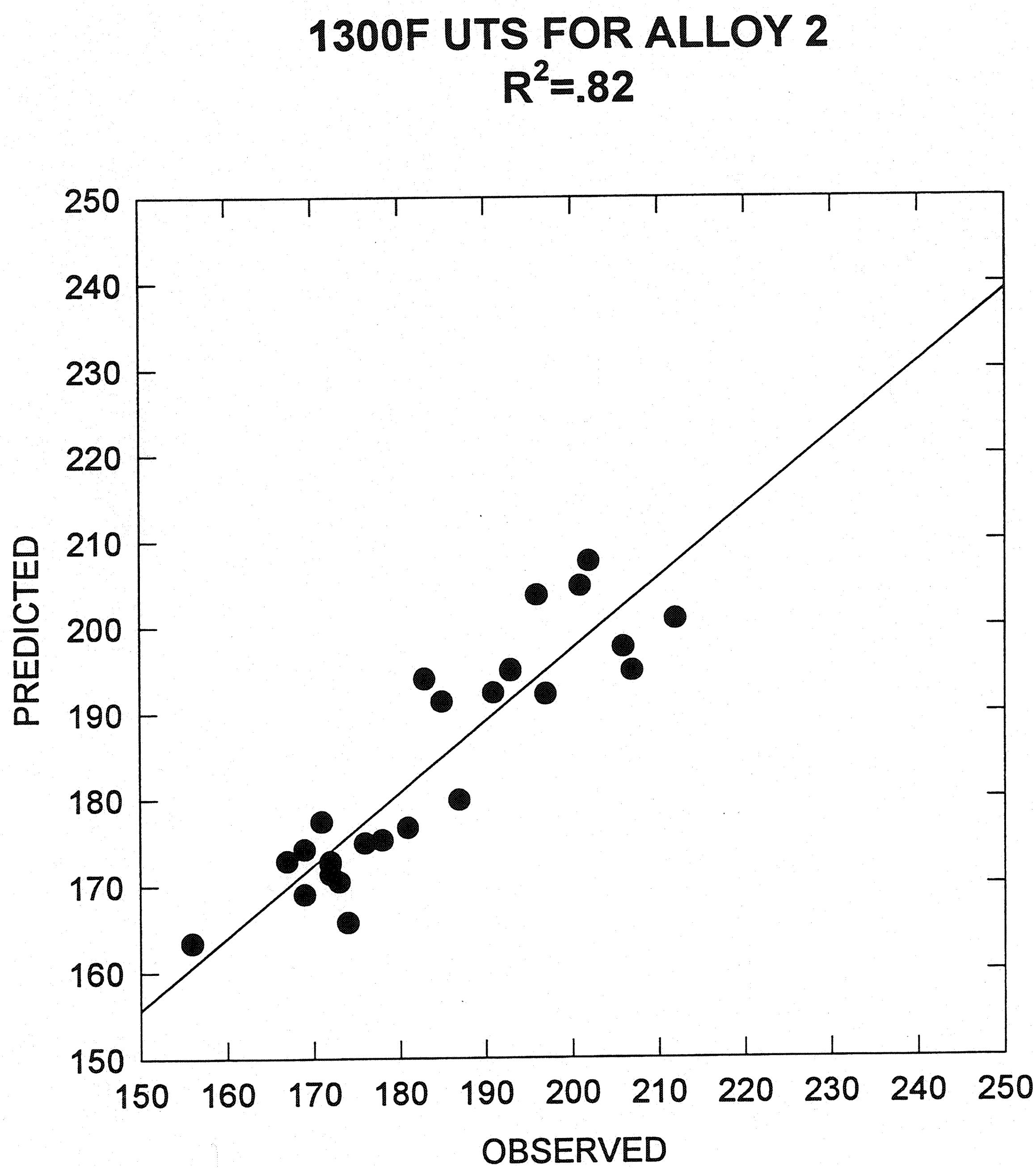
1300F ULTIMATE TENSILE STRENGTH ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1300F UTS
2155.0000	500.0000	0.0000	0.0000	1.0000	156.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	171.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	172.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	174.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	187.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	176.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	185.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	207.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	212.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	201.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	183.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	206.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	196.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	202.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	197.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	191.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	193.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	193.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	169.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	172.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	173.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	169.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	181.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	178.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	167.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	172.0000


COOLING RATE EFFECT
1300F UTS
SUPERSOLVUS
SUBSOLVUS
130+62.3*LOG(CR)-18.3*(LOG(CR))^2
UTS (KSI)
250
225
200
175
150
125
100
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1300F UTS
NORMALIZED UTS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (.432+1.93E-5*LMP)
AIR (1.04+1.07E-6*LMP)
BLANKET (1.28-7.06E-6*LMP)

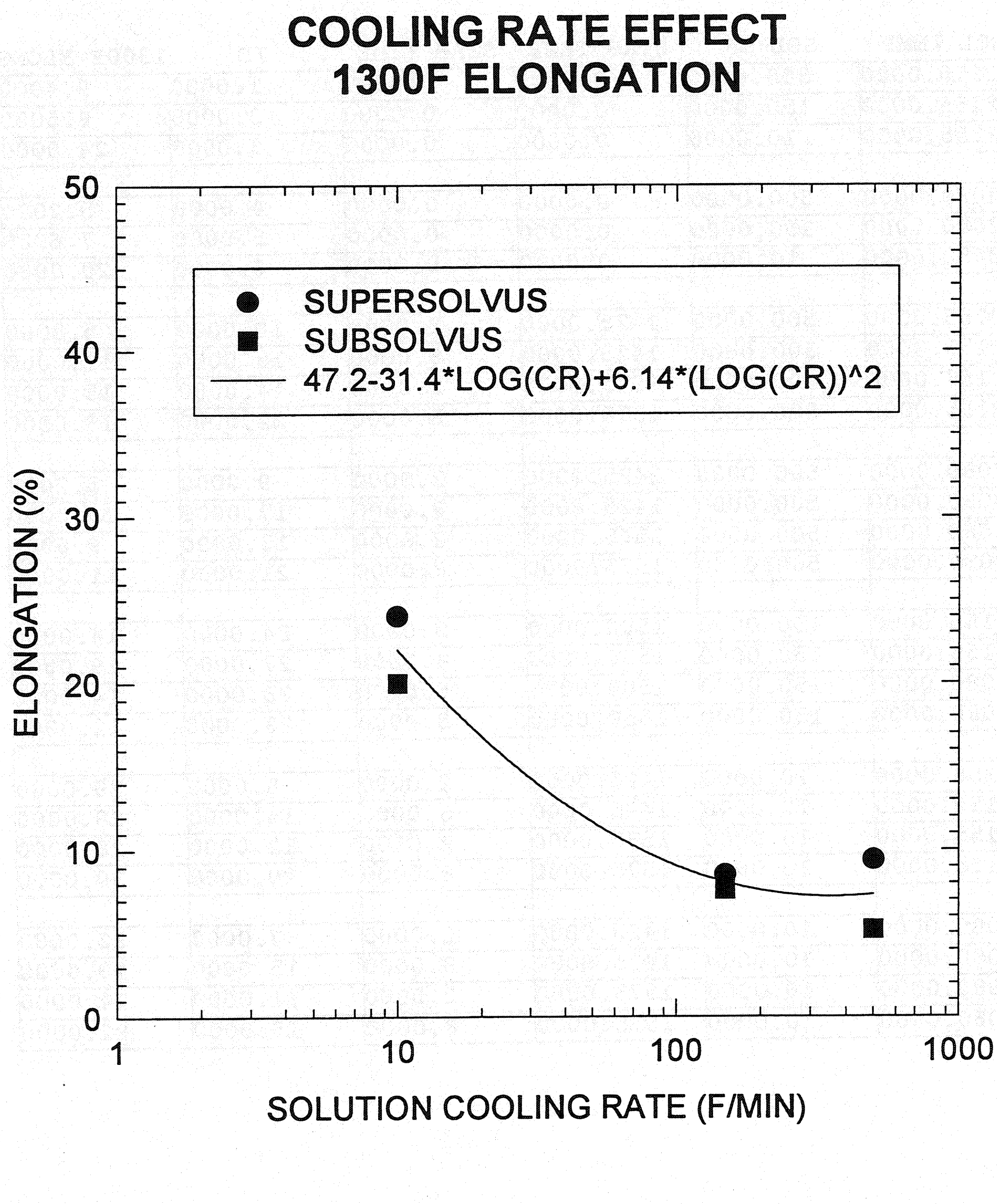

SOLUTION FACTOR
1300F UTS
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
1.39-1.85E-4*TEMP
NORMALIZED UTS
1.2
1.1
1.0
0.9
0.8
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)

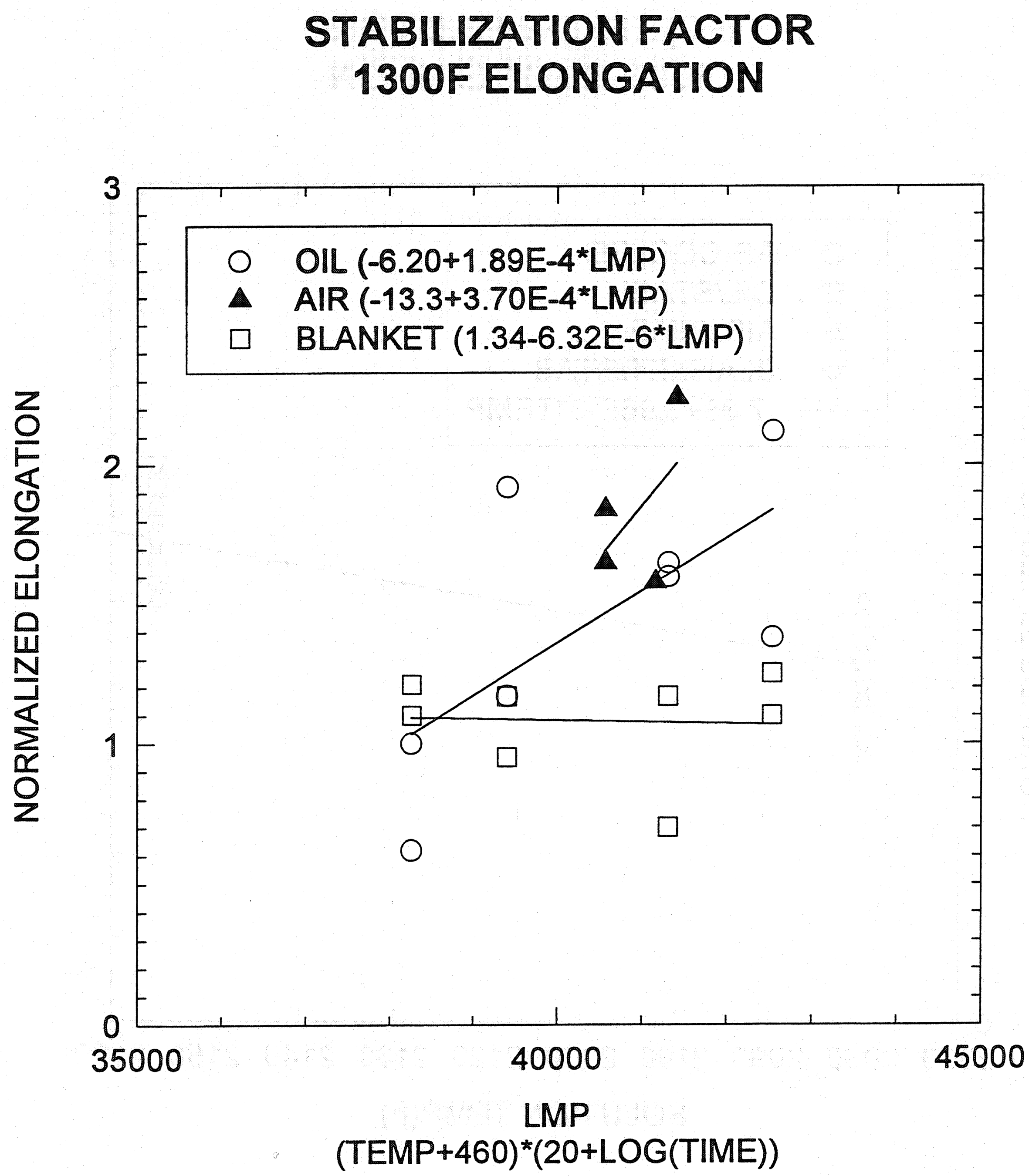

1300F UTS FOR ALLOY 2
R2=.82
PREDICTED
OBSERVED
250
240
230
220
210
200
190
180
170
160
150
150
160
170
180
190
200
210
220
230
240
250

APPENDIX 6

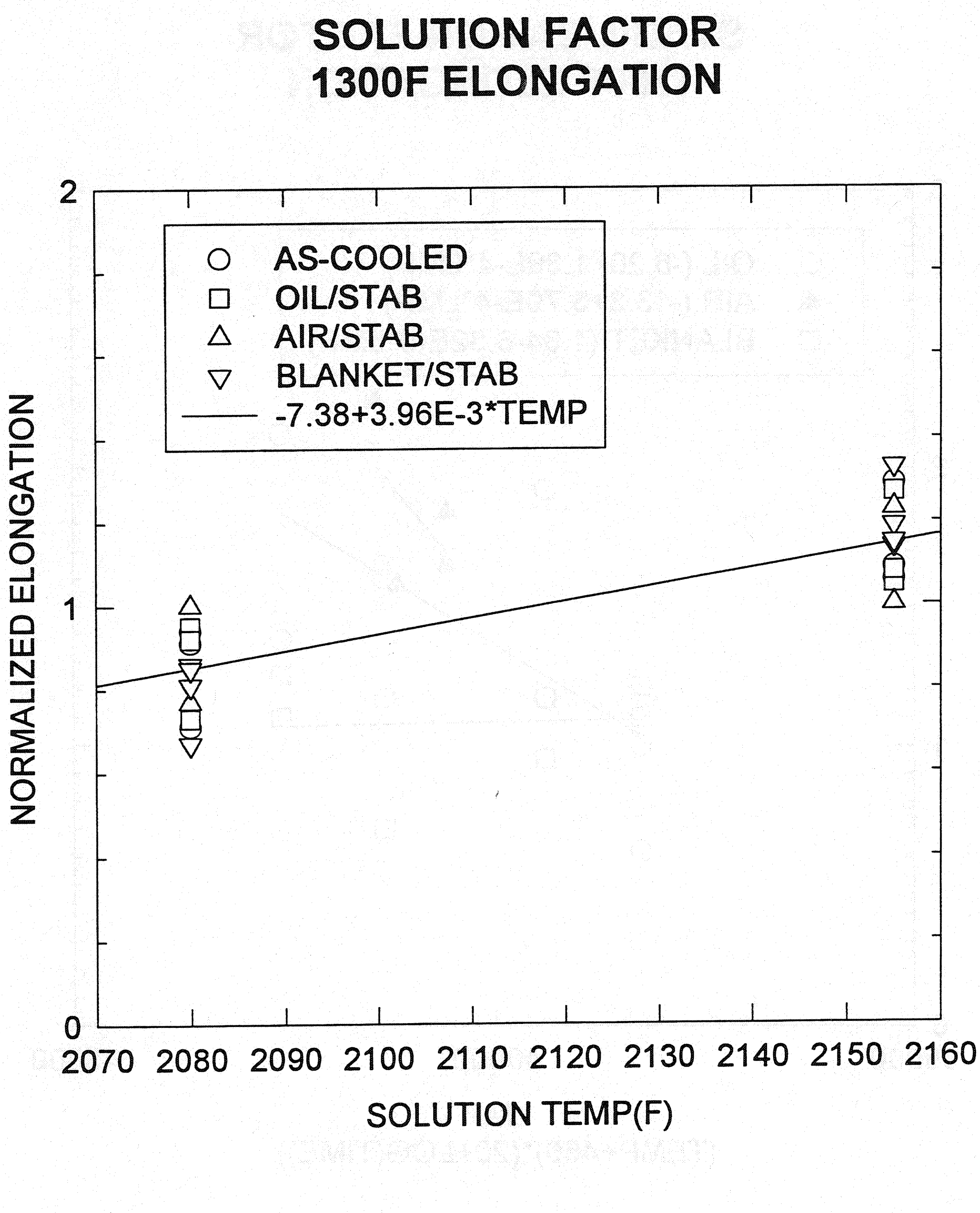
1300F TENSILE ELONGATION ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1300F ELONG
2155.0000	500.0000	0.0000	0.0000	1.0000	9.4000
2155.0000	150.0000	0.0000	0.0000	2.0000	8.5000
2155.0000	10.0000	0.0000	0.0000	3.0000	24.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	5.2000
2080.0000	150.0000	0.0000	0.0000	5.0000	7.6000
2080.0000	10.0000	0.0000	0.0000	6.0000	20.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	5.8000
2155.0000	500.0000	1425.0000	8.0000	18.0000	11.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	15.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	13.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	5.2000
2080.0000	500.0000	1425.0000	8.0000	17.0000	10.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	8.6000
2080.0000	500.0000	1575.0000	8.0000	21.0000	11.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	14.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	19.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	14.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	12.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	29.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	28.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	28.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	30.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	22.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	19.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	14.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	22.0000

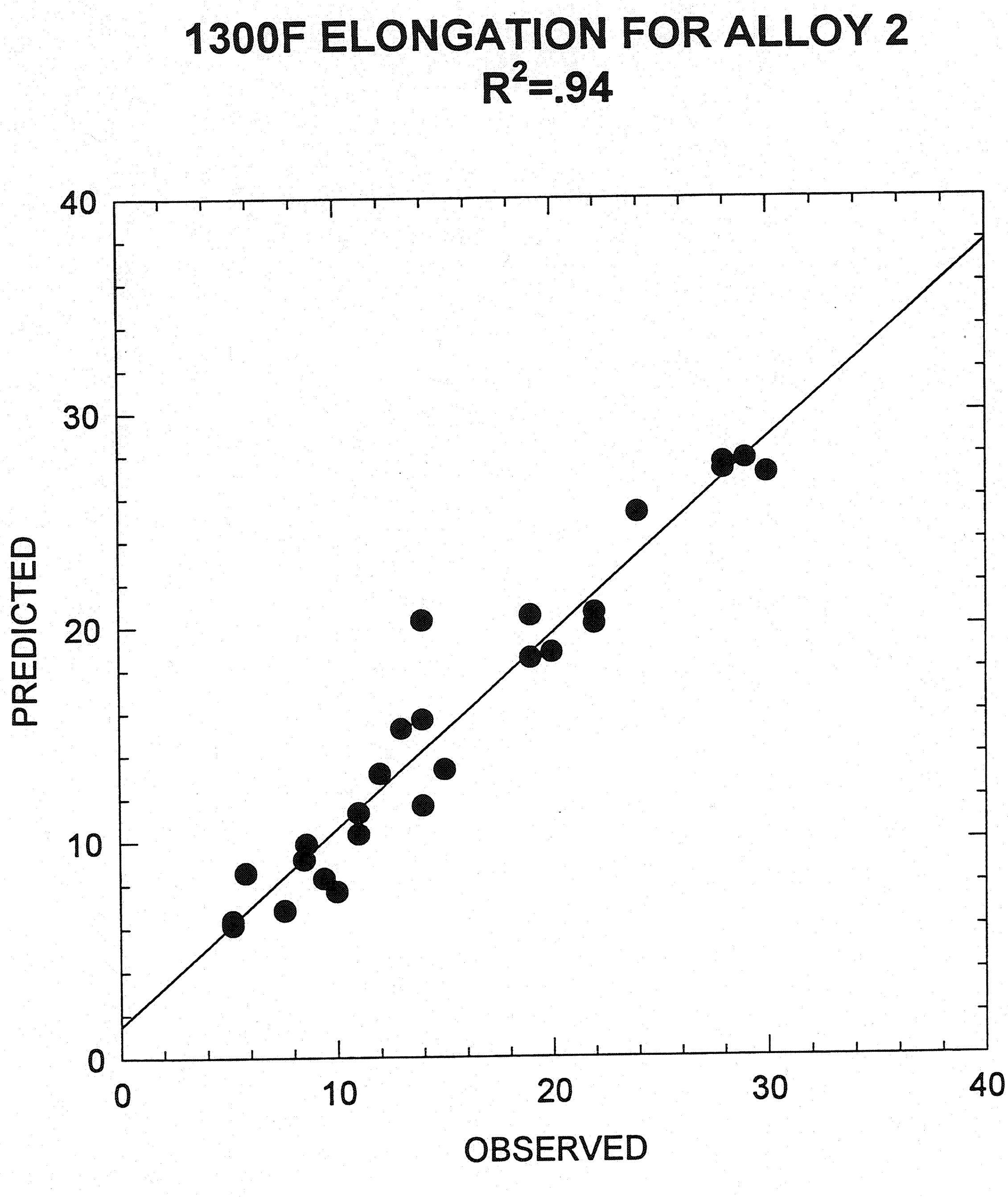

COOLING RATE EFFECT
1300F ELONGATION
SUPERSOLVUS
SUBSOLVUS
47.2-31.4*LOG(CR)+6.14*(LOG(CR))^2
ELONGATION (%)
0
10
20
30
40
50
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)



STABILIZATION FACTOR
1300F ELONGATION
OIL (-6.20+1.89E-4*LMP)
AIR (-13.3+3.70E-4*LMP)
BLANKET (1.34-6.32E-6*LMP)
NORMALIZED ELONGATION
0
1
2
3
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))



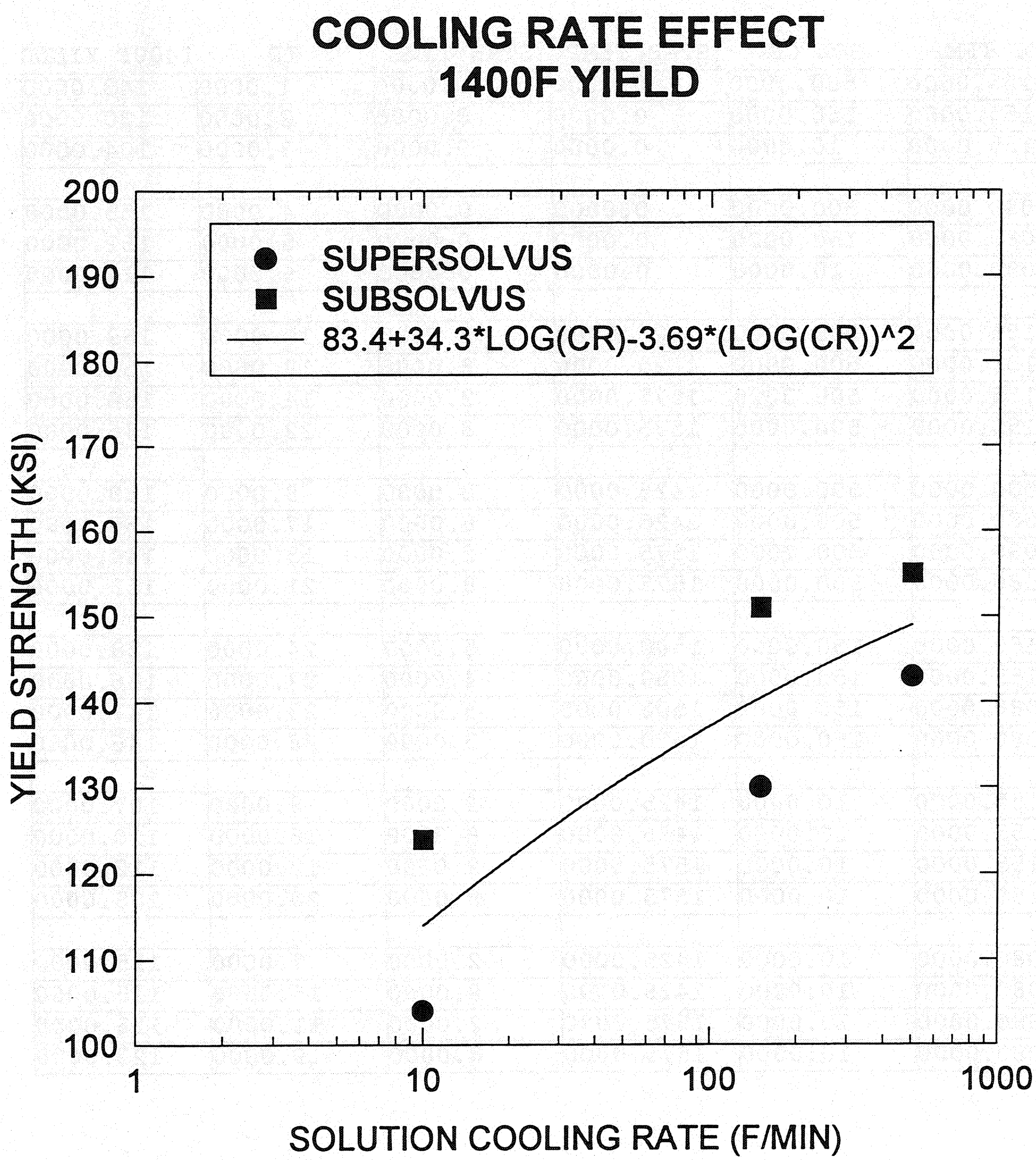
SOLUTION FACTOR
1300F ELONGATION
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
-7.38+3.96E-3*TEMP
NORMALIZED ELONGATION
2
1
0
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)


1300F ELONGATION FOR ALLOY 2
R^2=.94
PREDICTED
OBSERVED
0
10
20
30
40
0
10
20
30
40

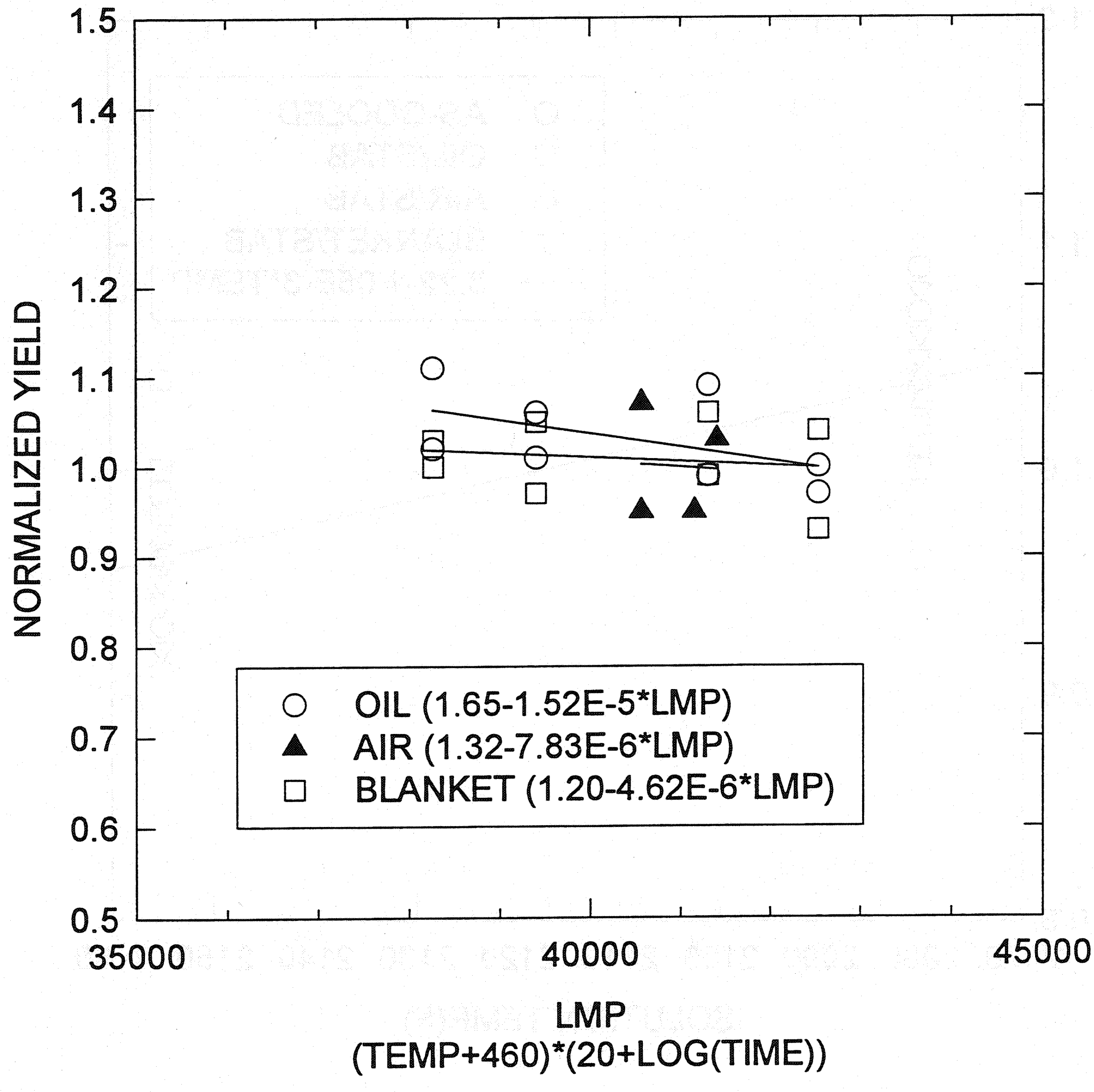
APPENDIX 7

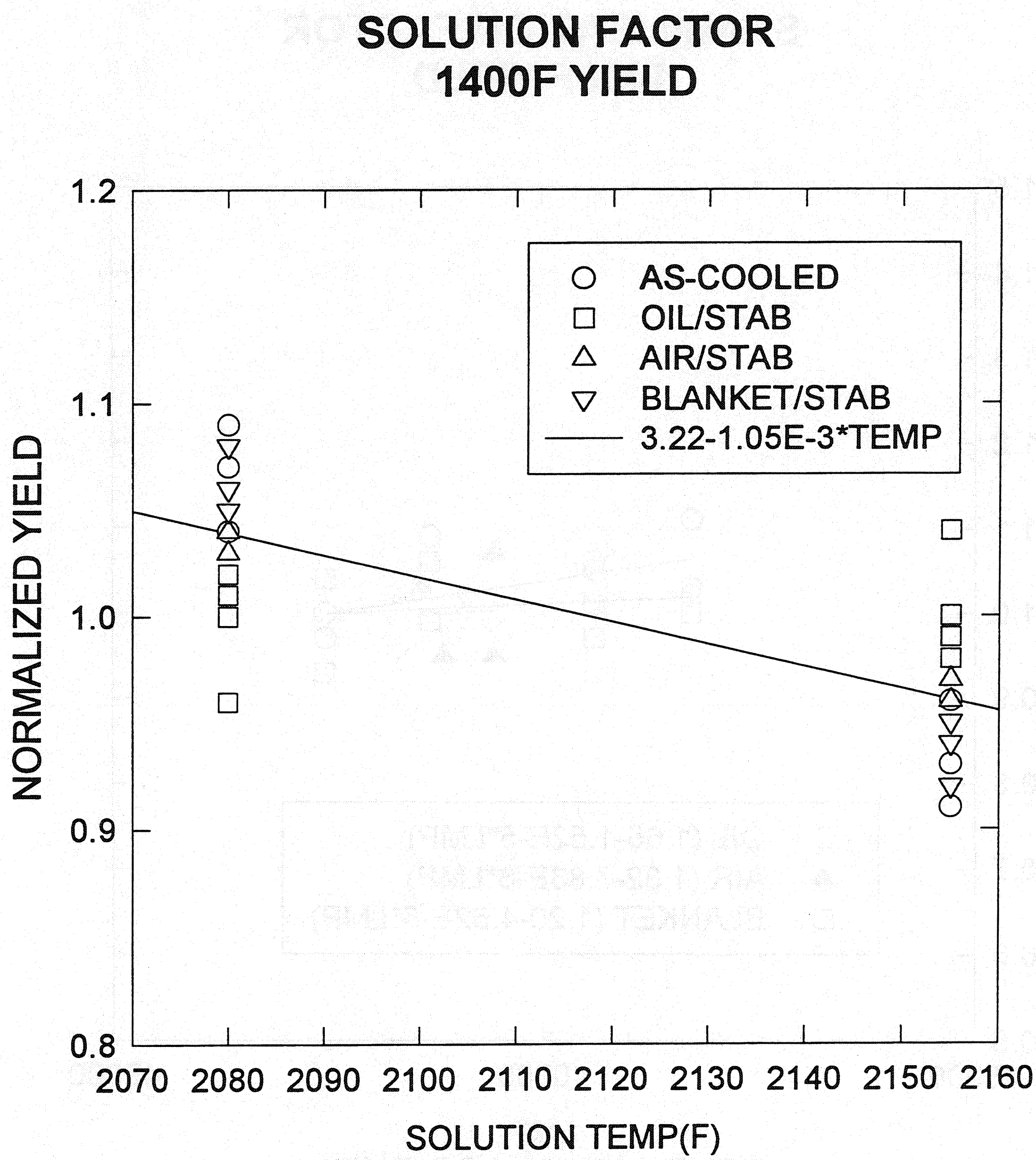
1400F YIELD STRENGTH ANALYSIS

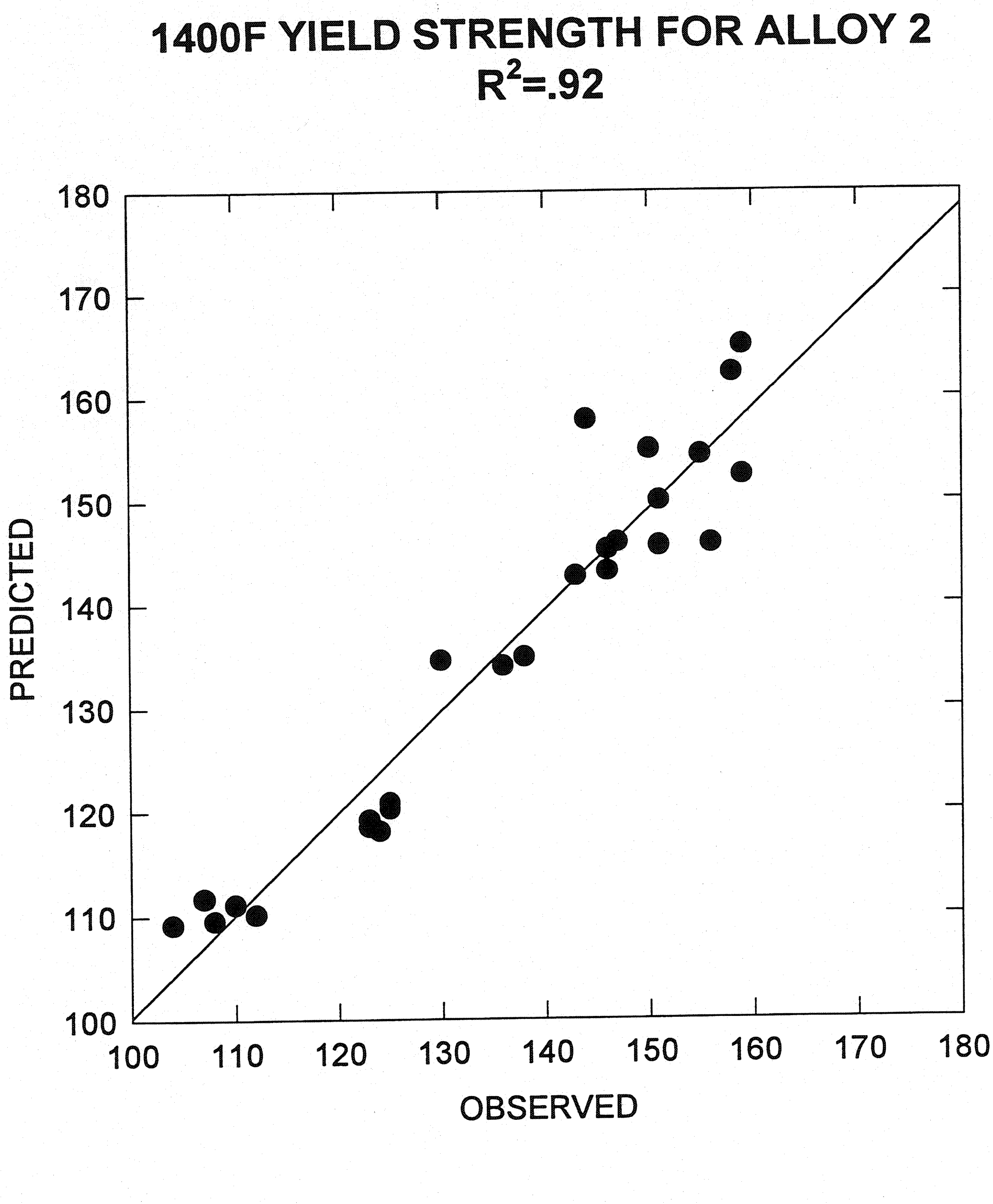
SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1400F YIELD
2155.0000	500.0000	0.0000	0.0000	1.0000	143.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	130.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	104.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	155.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	151.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	124.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	159.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	151.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	156.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	146.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	159.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	158.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	144.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	150.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	138.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	136.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	147.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	146.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	107.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	110.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	112.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	108.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	125.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	125.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	123.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	123.0000


COOLING RATE EFFECT
1400F YIELD
SUPERSOLVUS
SUBSOLVUS
83.4+34.3*LOG(CR)-3.69*(LOG(CR))^2
YIELD STRENGTH (KSI)
SOLUTION COOLING RATE (F/MIN)
200
190
180
170
160
150
140
130
120
110
100
1
10
100
1000

STABILIZATION FACTOR
1400F YIELD



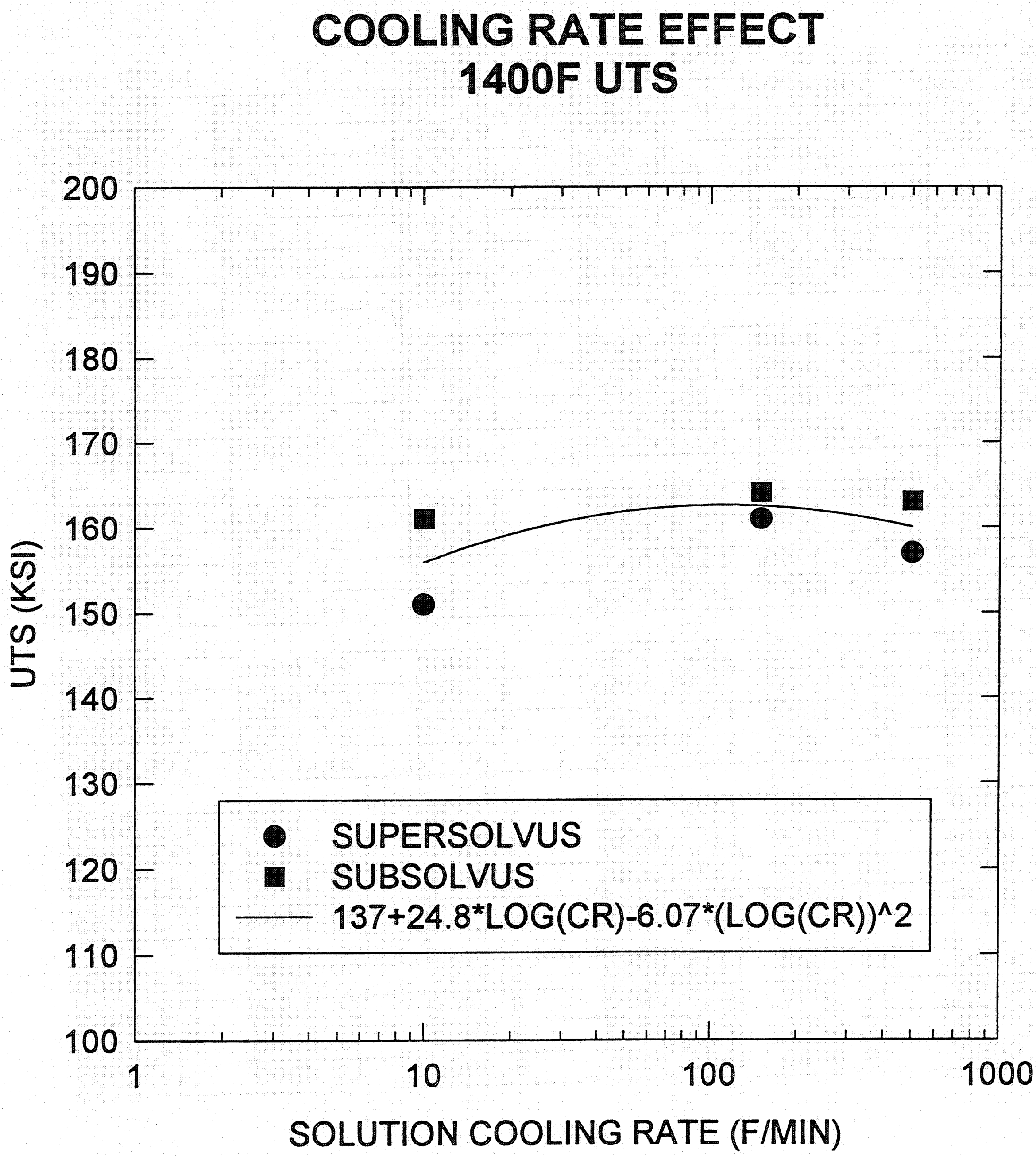

SOLUTION FACTOR
1400F YIELD
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
3.22-1.05E-3*TEMP
NORMALIZED YIELD
SOLUTION TEMP(F)
1.2
1.1
1.0
0.9
0.8
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160

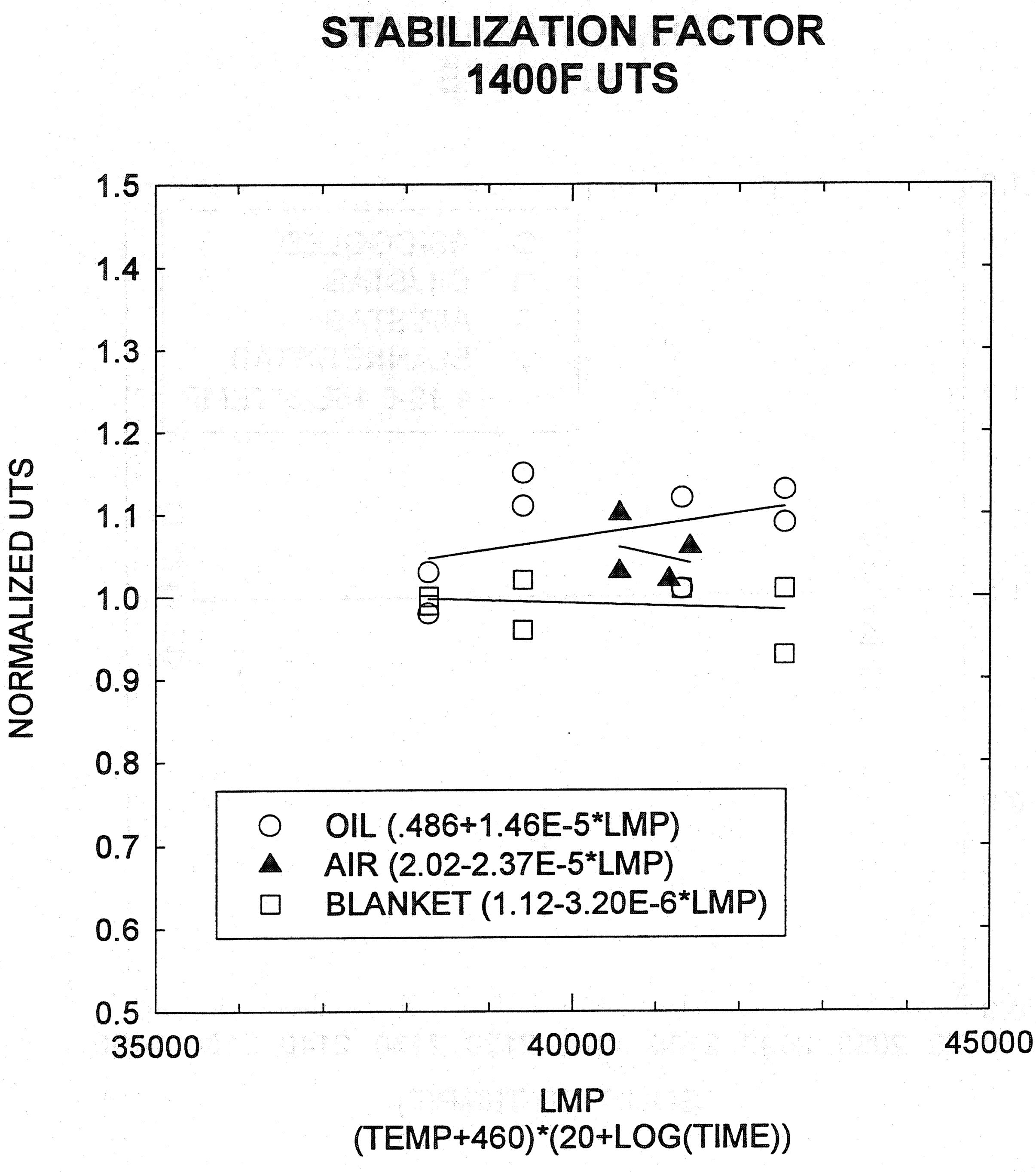

1400F YIELD STRENGTH FOR ALLOY 2
R2=.92
PREDICTED
OBSERVED
100
110
120
130
140
150
160
170
180

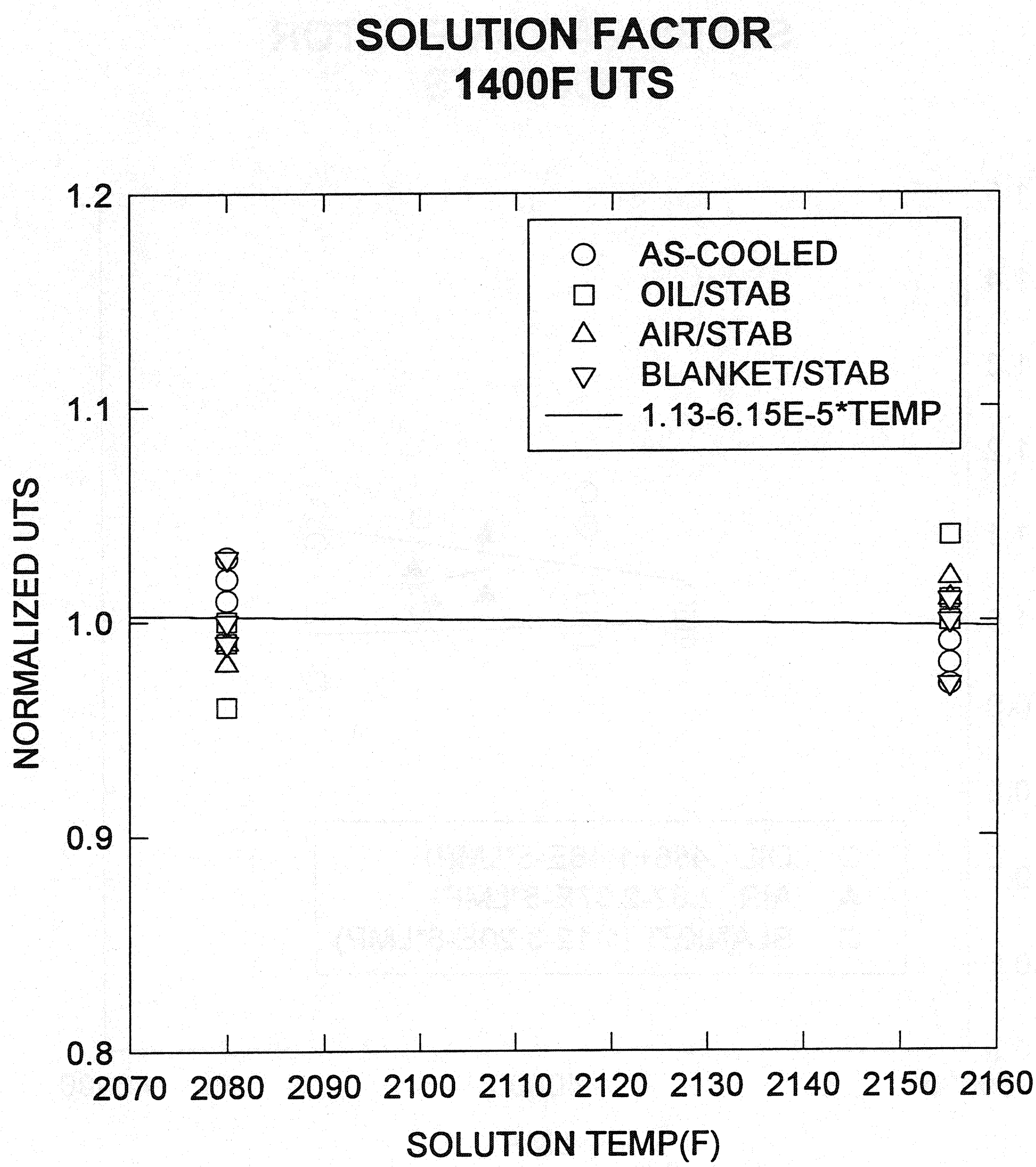
APPENDIX 8

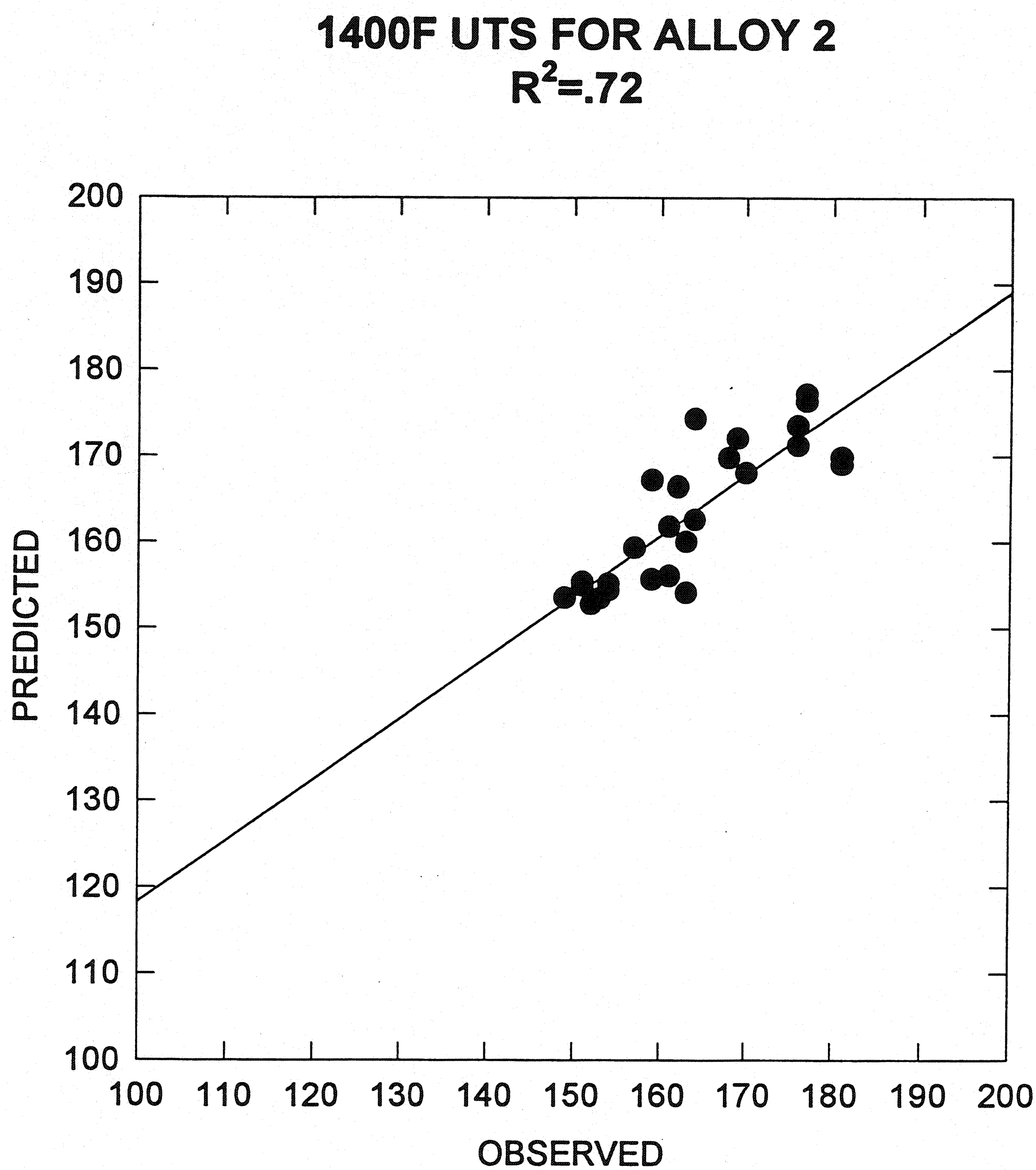
1400F ULTIMATE TENSILE STRENGTH ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1400F UTS
2155.0000	500.0000	0.0000	0.0000	1.0000	157.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	161.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	151.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	163.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	164.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	161.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	162.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	181.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	176.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	177.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	159.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	181.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	164.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	177.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	176.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	170.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	169.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	168.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	151.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	154.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	153.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	152.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	159.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	154.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	163.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	149.0000


COOLING RATE EFFECT
1400F UTS
200
190
180
170
160
150
140
130
120
110
100
1
10
100
1000
UTS (KSI)
SOLUTION COOLING RATE (F/MIN)
SUPERSOLVUS
SUBSOLVUS
137+24.8*LOG(CR)-6.07*(LOG(CR))^2


STABILIZATION FACTOR
1400F UTS
NORMALIZED UTS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (.486+1.46E-5*LMP)
AIR (2.02-2.37E-5*LMP)
BLANKET (1.12-3.20E-6*LMP)

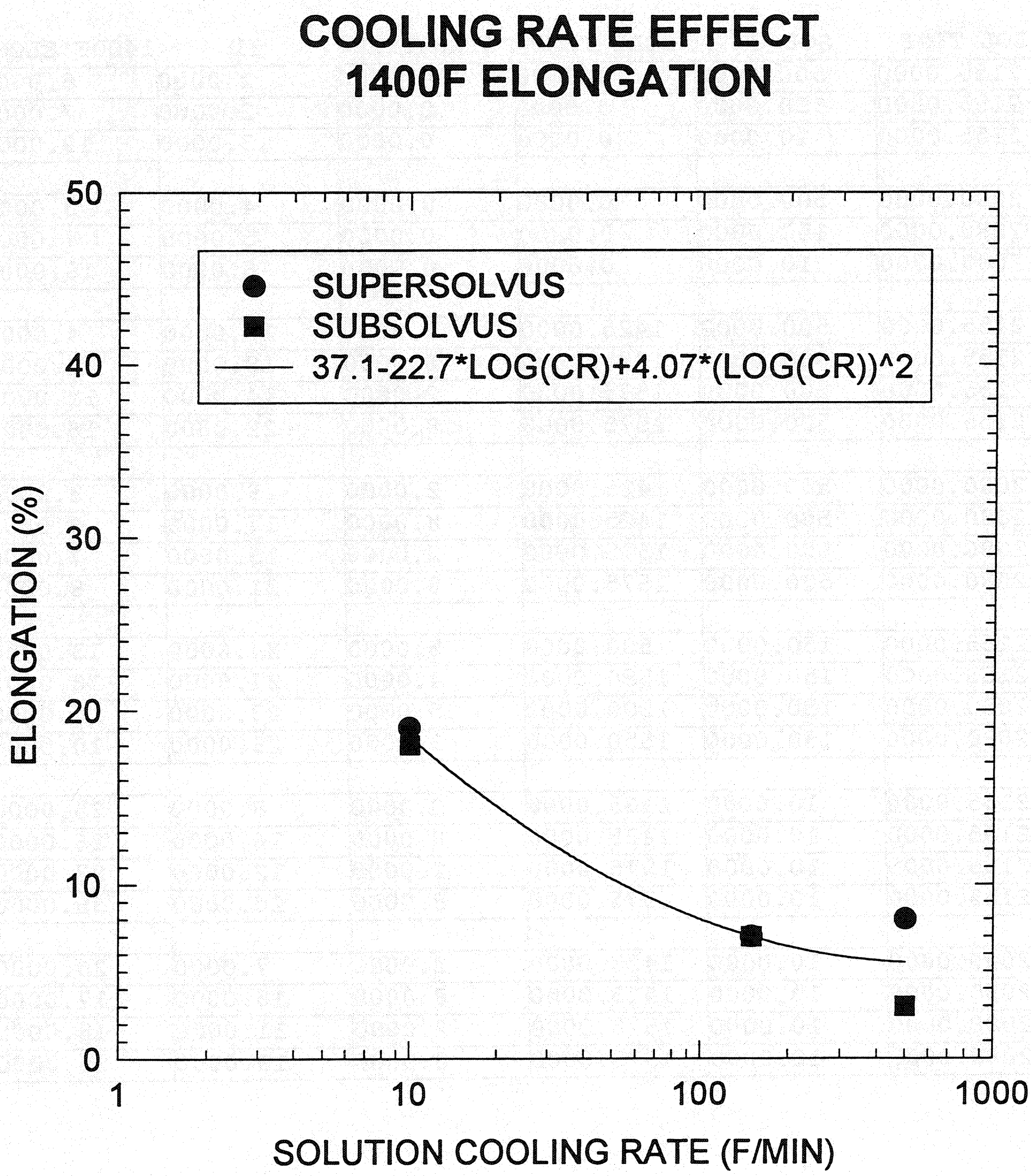

SOLUTION FACTOR
1400F UTS
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
1.13-6.15E-5*TEMP
NORMALIZED UTS
1.2
1.1
1.0
0.9
0.8
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)


1400F UTS FOR ALLOY 2
R^2=.72
PREDICTED
OBSERVED
200
190
180
170
160
150
140
130
120
110
100
100 110 120 130 140 150 160 170 180 190 200

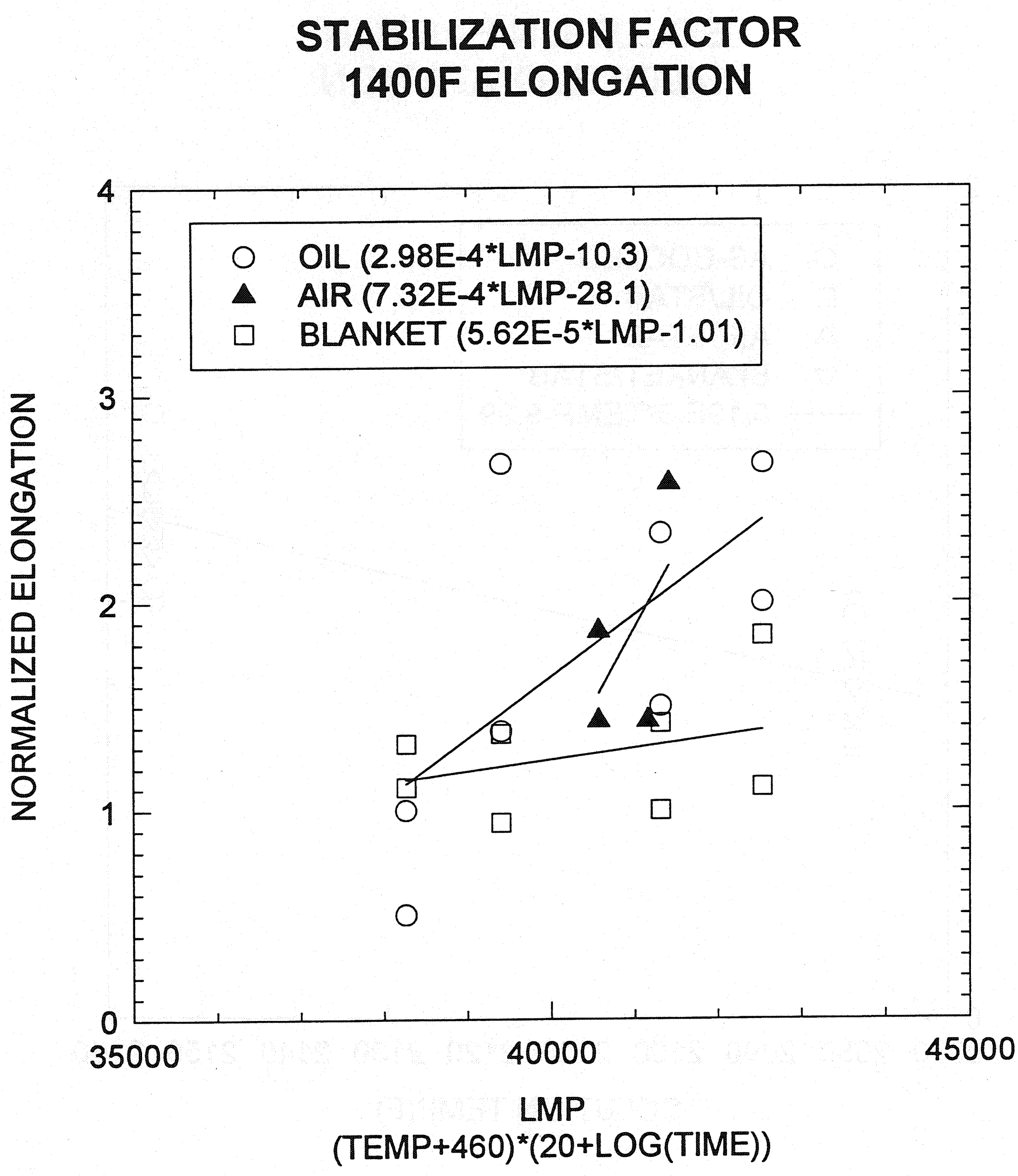
APPENDIX 9

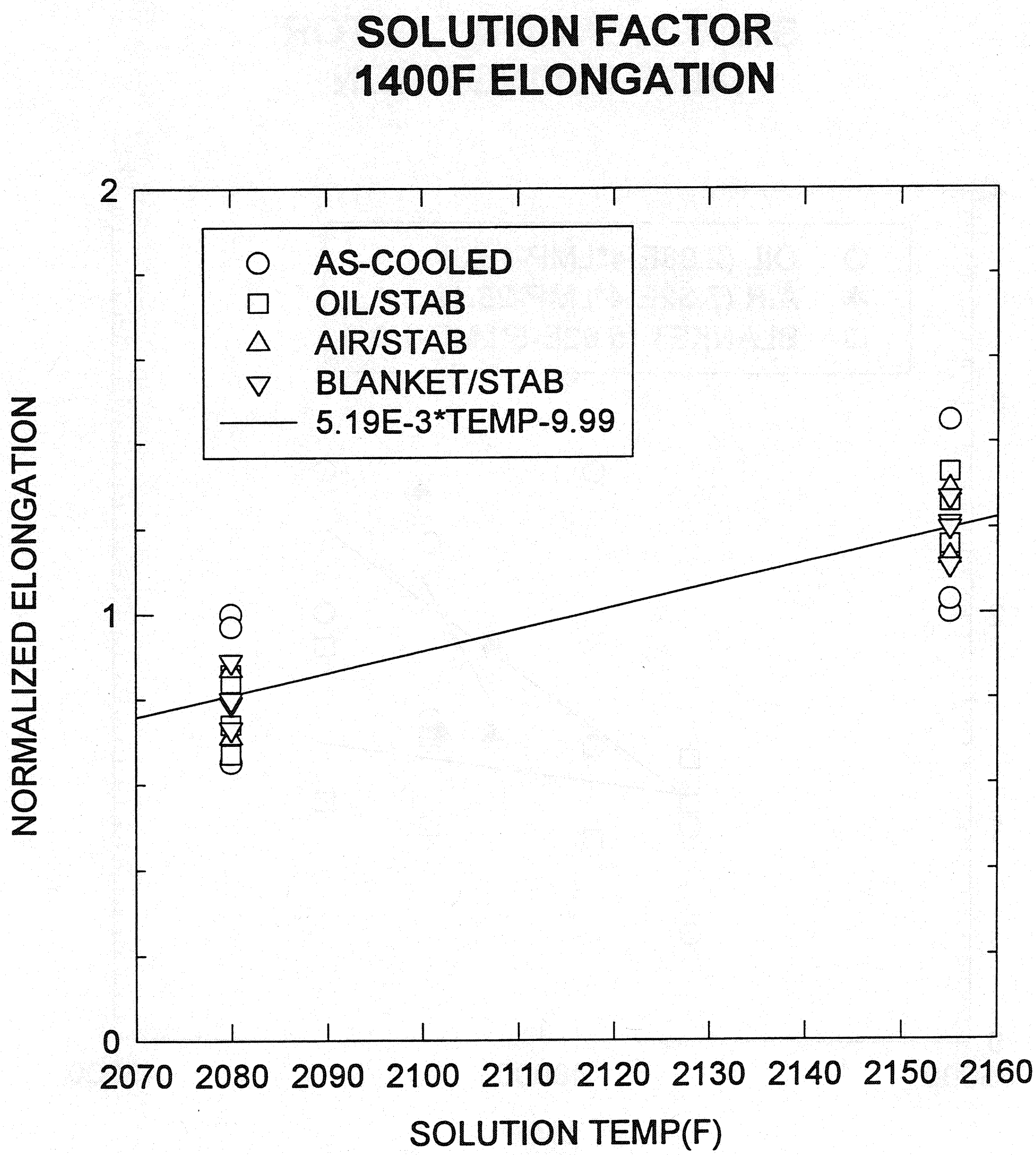
1400F TENSILE ELONGATION ANALYSIS

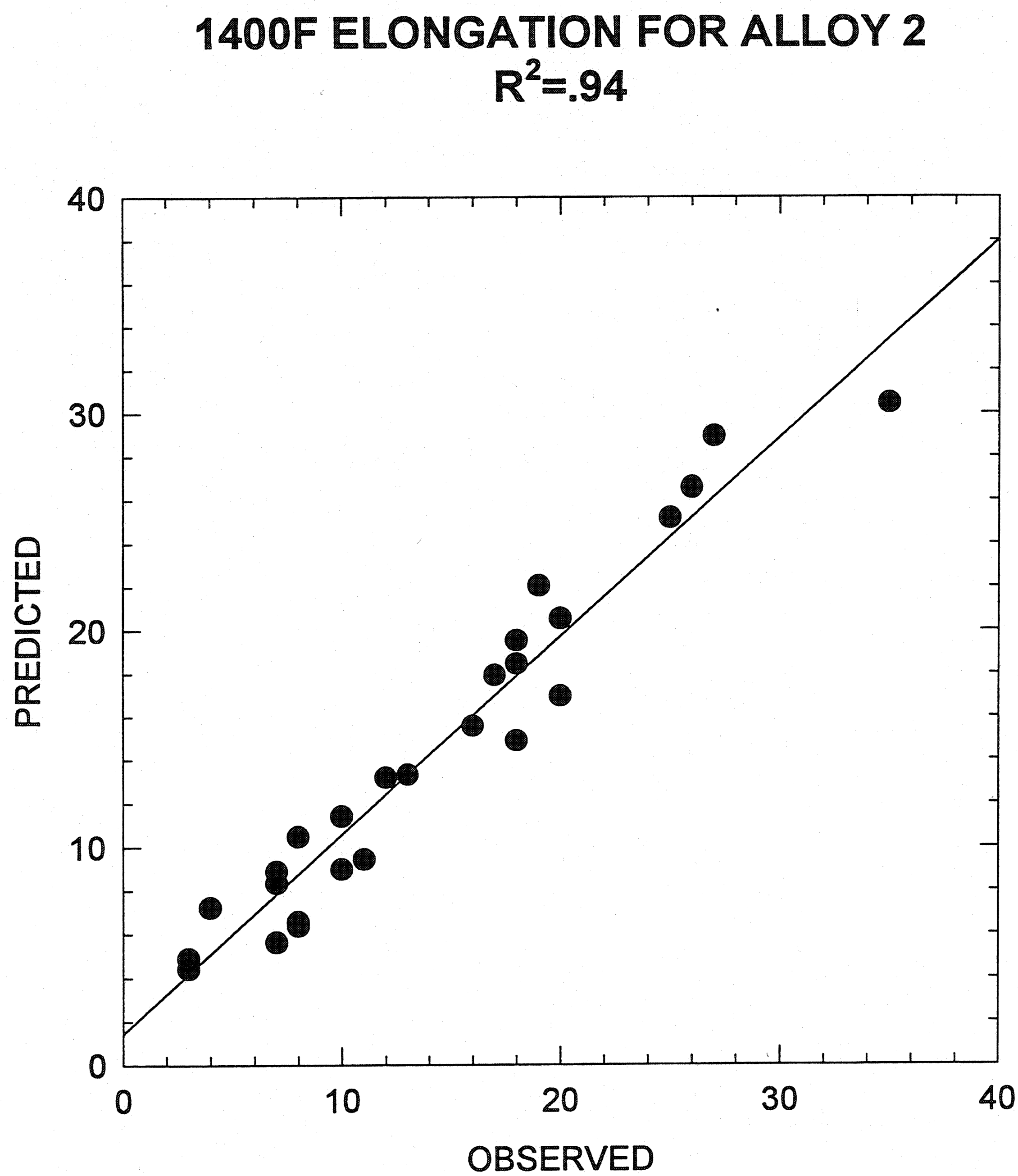
SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	1400F ELONG
2155.0000	500.0000	0.0000	0.0000	1.0000	8.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	7.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	19.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	3.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	7.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	18.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	4.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	11.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	12.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	16.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	3.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	8.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	7.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	8.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	13.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	18.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	10.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	10.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	25.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	26.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	27.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	35.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	20.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	17.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	18.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	20.0000



COOLING RATE EFFECT
1400F ELONGATION
SUPERSOLVUS
SUBSOLVUS
37.1-22.7*LOG(CR)+4.07*(LOG(CR))^2
ELONGATION (%)
0
10
20
30
40
50
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1400F ELONGATION
OIL (2.98E-4*LMP-10.3)
AIR (7.32E-4*LMP-28.1)
BLANKET (5.62E-5*LMP-1.01)
NORMALIZED ELONGATION
0
1
2
3
4
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))

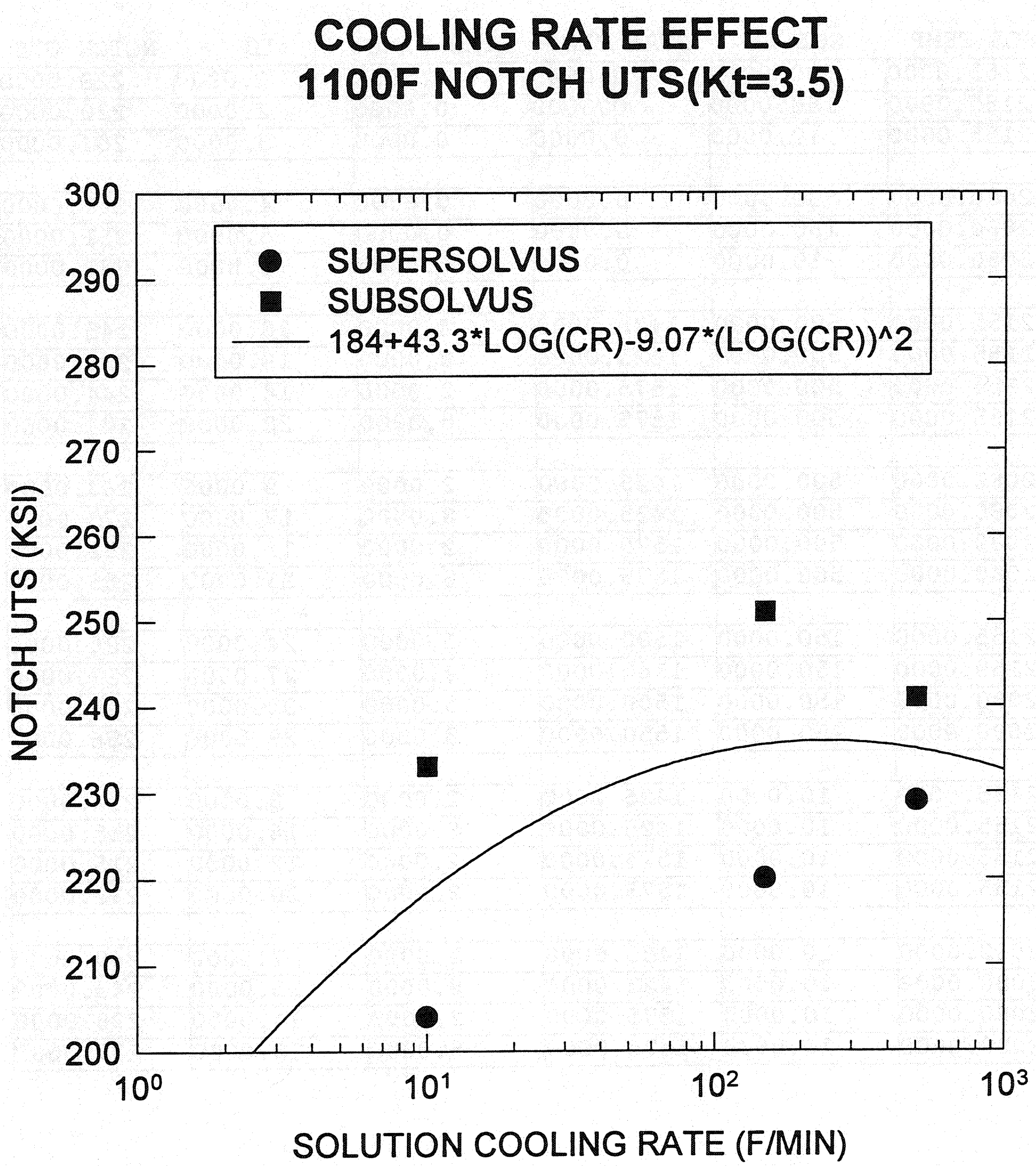

SOLUTION FACTOR
1400F ELONGATION
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
5.19E-3*TEMP-9.99
NORMALIZED ELONGATION
0
1
2
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160
SOLUTION TEMP(F)

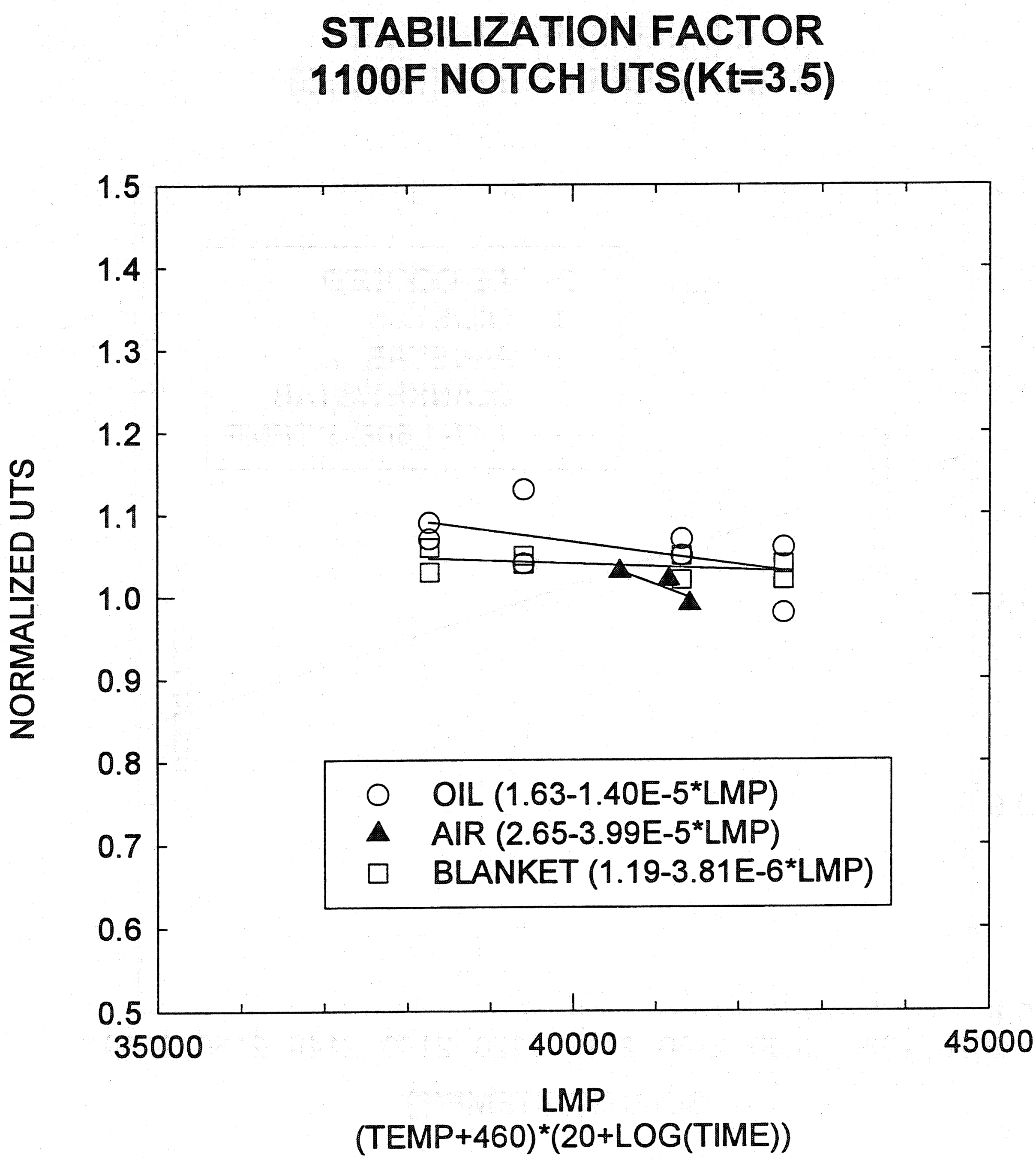

1400F ELONGATION FOR ALLOY 2
R^2=.94
40
30
20
10
0
PREDICTED
0
10
20
30
40
OBSERVED

APPENDIX 10

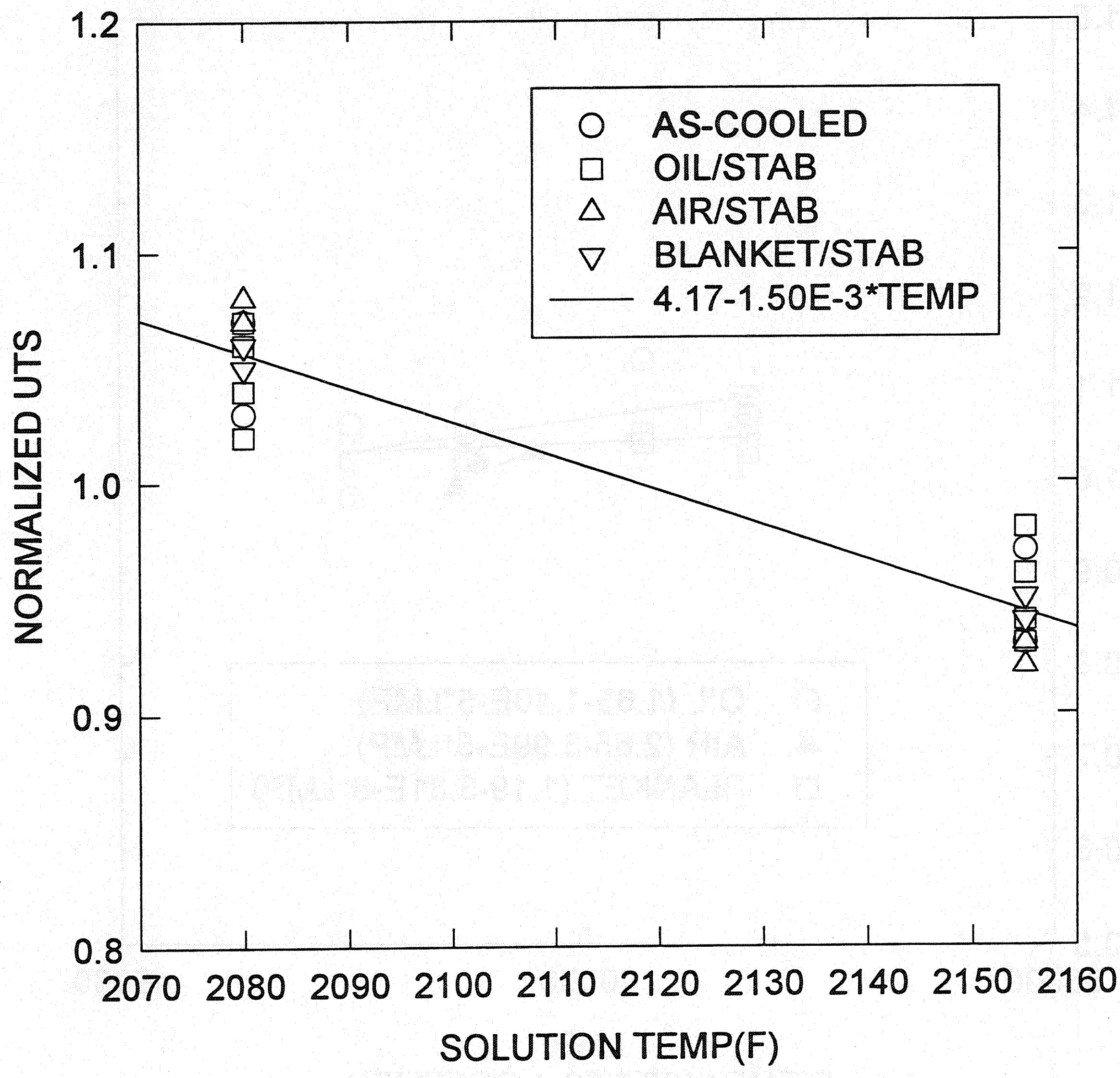
1100F NOTCH TENSILE STRENGTH ANALYSIS

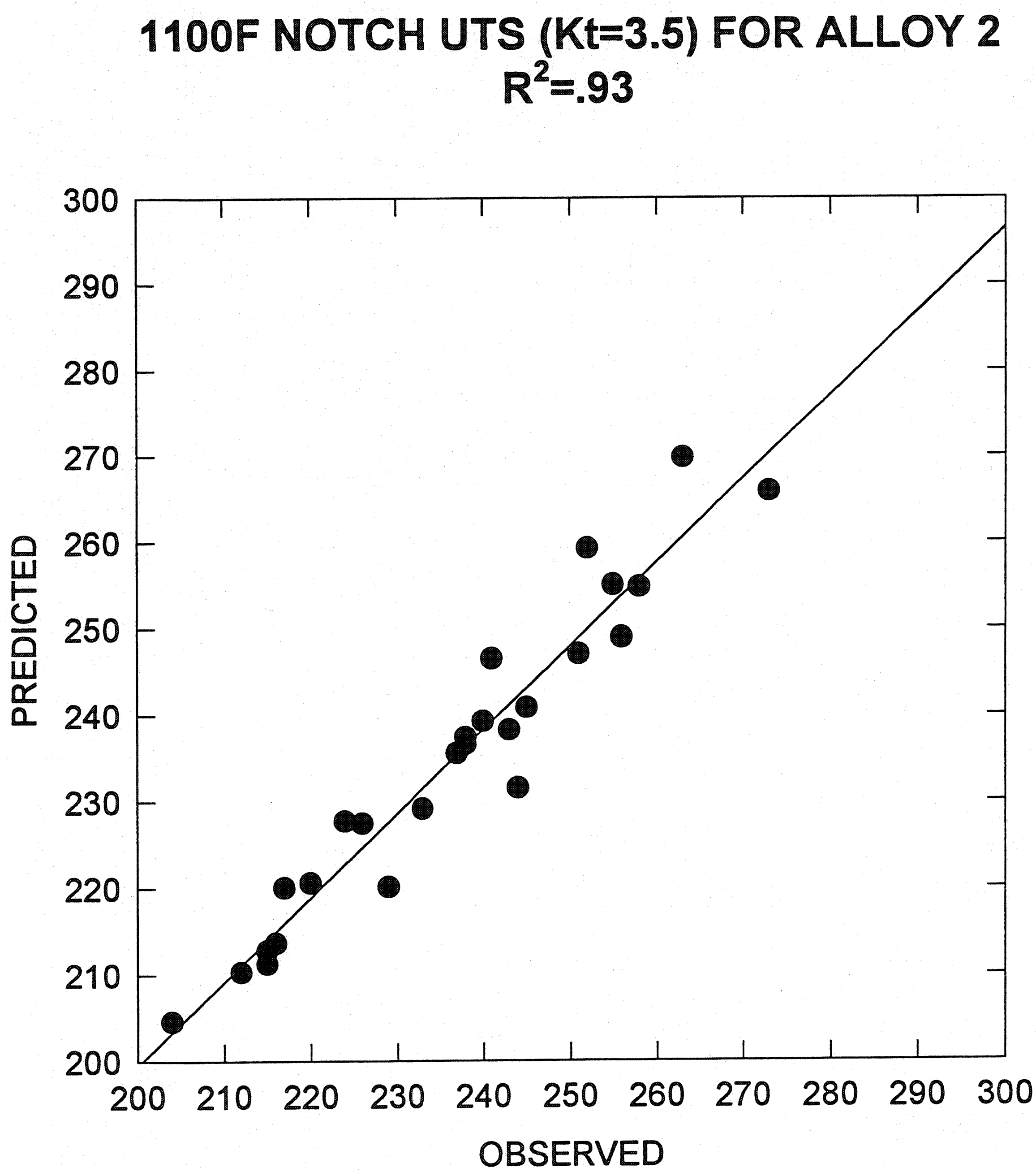
SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	NOTCH UTS
2155.0000	500.0000	0.0000	0.0000	1.0000	229.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	220.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	204.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	241.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	251.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	233.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	245.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	238.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	244.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	224.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	263.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	273.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	252.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	255.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	226.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	217.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	258.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	256.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	216.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	215.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	215.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	212.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	240.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	243.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	238.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	237.0000


COOLING RATE EFFECT
1100F NOTCH UTS(Kt=3.5)
SUPERSOLVUS
SUBSOLVUS
184+43.3*LOG(CR)-9.07*(LOG(CR))^2
NOTCH UTS (KSI)
300
290
280
270
260
250
240
230
220
210
200
10^0
10^1
10^2
10^3
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1100F NOTCH UTS(Kt=3.5)
NORMALIZED UTS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))
OIL (1.63-1.40E-5*LMP)
AIR (2.65-3.99E-5*LMP)
BLANKET (1.19-3.81E-6*LMP)

SOLUTION FACTOR
1100F NOTCH UTS(Kt=3.5)

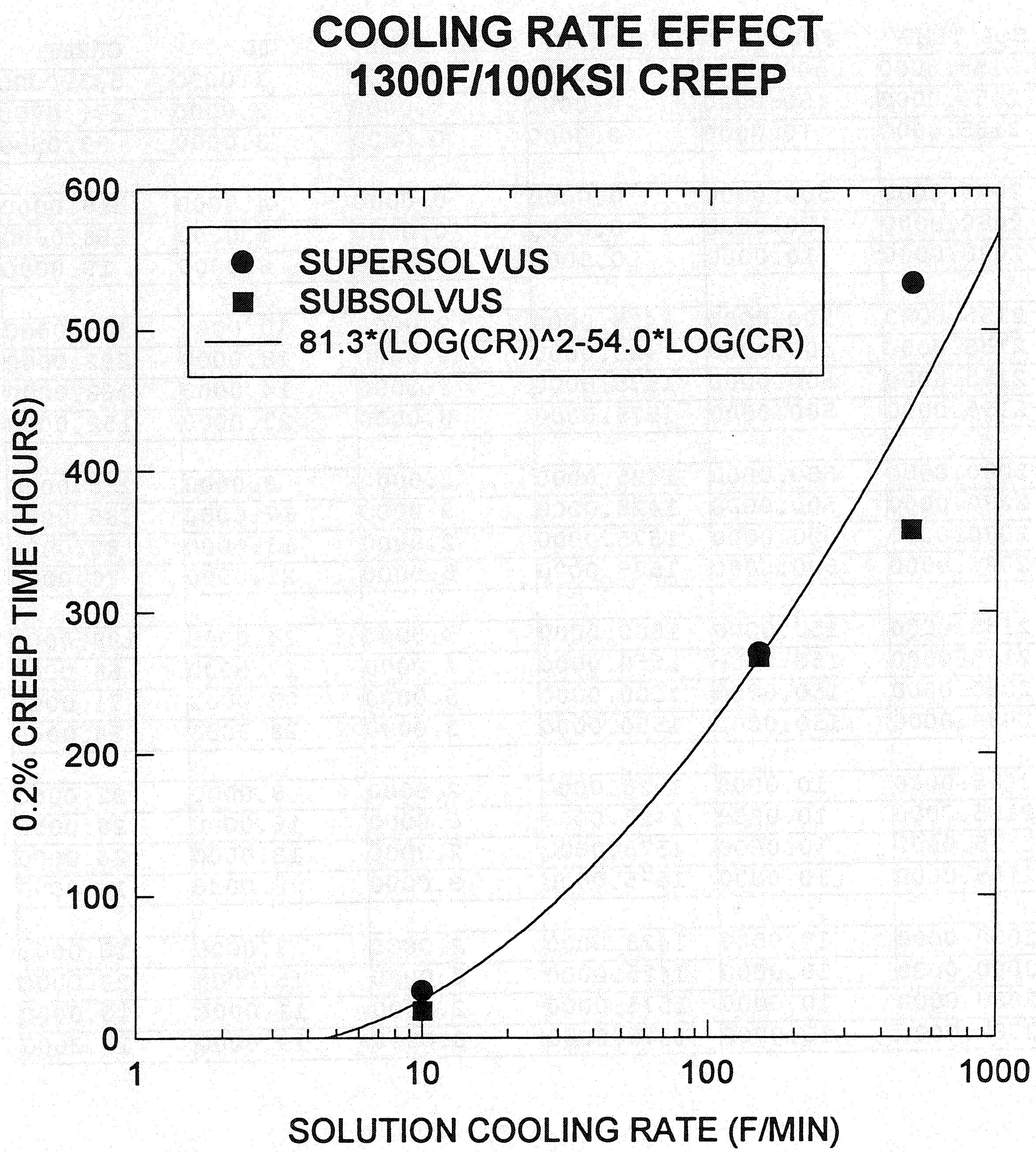



1100F NOTCH UTS (Kt=3.5) FOR ALLOY 2
R^2=.93
PREDICTED
OBSERVED
300
290
280
270
260
250
240
230
220
210
200
200 210 220 230 240 250 260 270 280 290 300

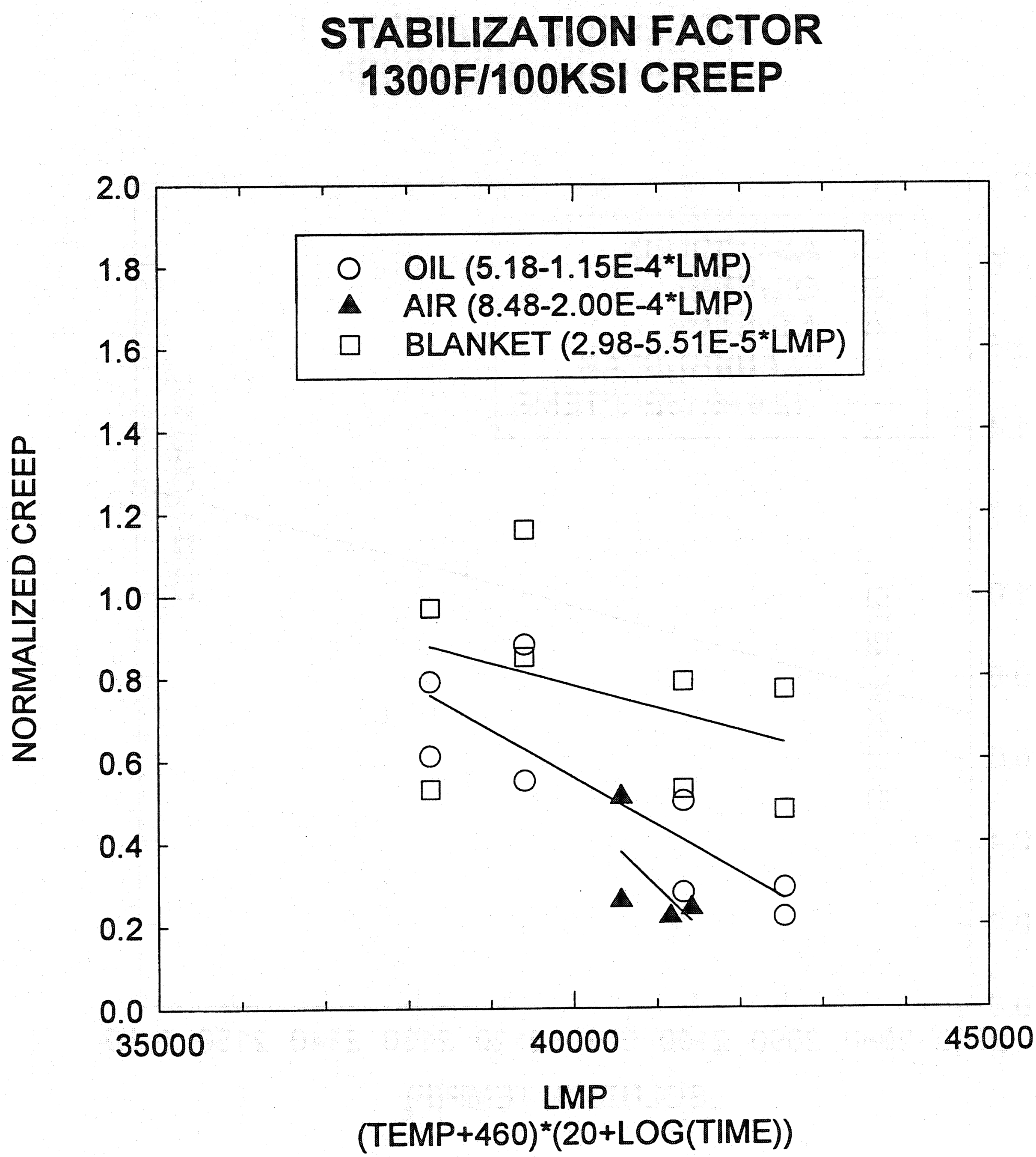
APPENDIX 11

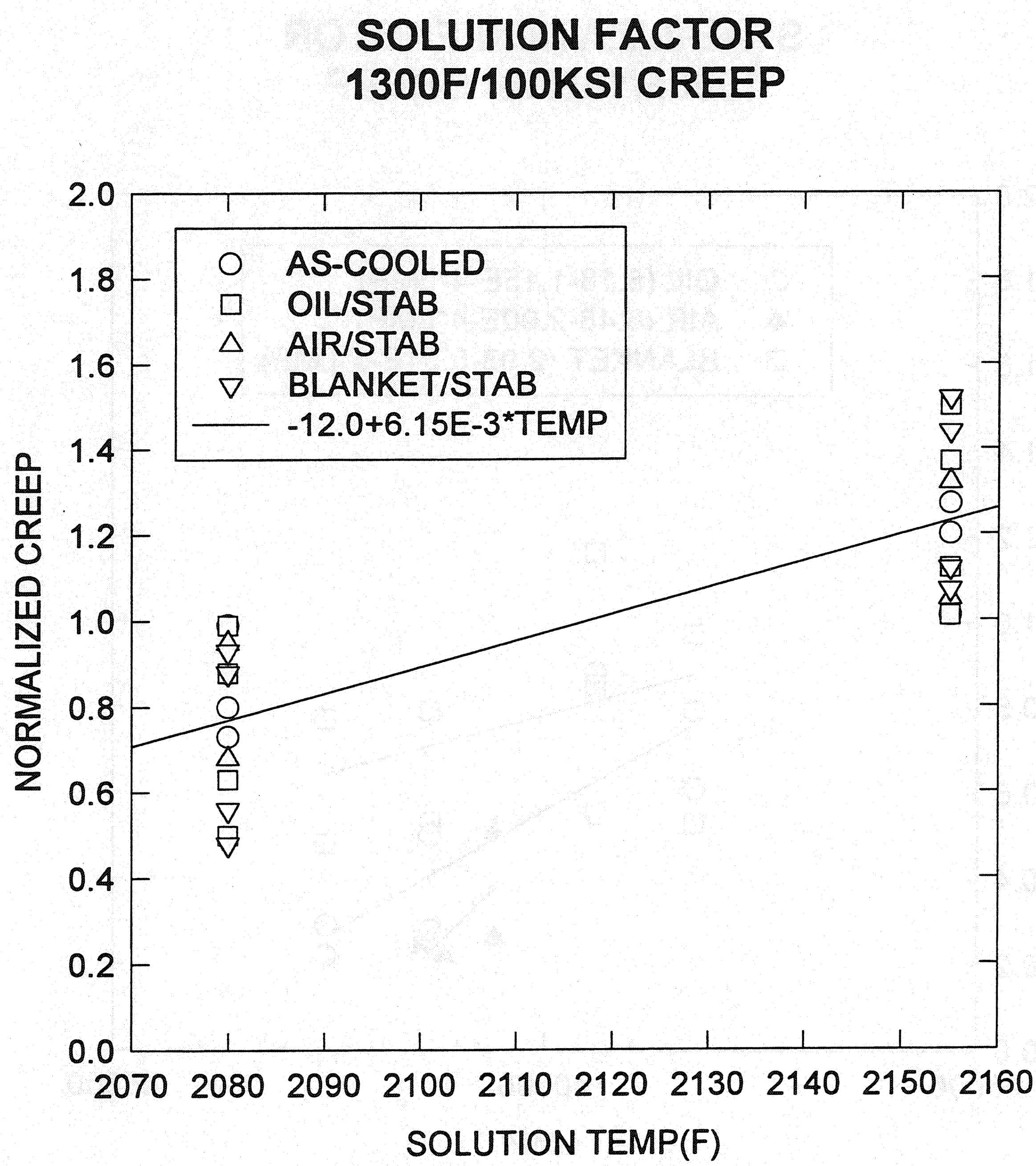
1300F/100KSI CREEP ANALYSIS

SOL TEMP	SOL CR	STAB TEMP	STAB TIME	ID	CREEP
2155.0000	500.0000	0.0000	0.0000	1.0000	533.0000
2155.0000	150.0000	0.0000	0.0000	2.0000	271.0000
2155.0000	10.0000	0.0000	0.0000	3.0000	33.0000
2080.0000	500.0000	0.0000	0.0000	4.0000	358.0000
2080.0000	150.0000	0.0000	0.0000	5.0000	268.0000
2080.0000	10.0000	0.0000	0.0000	6.0000	19.0000
2155.0000	500.0000	1425.0000	2.0000	10.0000	323.0000
2155.0000	500.0000	1425.0000	8.0000	18.0000	292.0000
2155.0000	500.0000	1575.0000	2.0000	14.0000	268.0000
2155.0000	500.0000	1575.0000	8.0000	22.0000	152.0000
2080.0000	500.0000	1425.0000	2.0000	9.0000	255.0000
2080.0000	500.0000	1425.0000	8.0000	17.0000	285.0000
2080.0000	500.0000	1575.0000	2.0000	13.0000	89.0000
2080.0000	500.0000	1575.0000	8.0000	21.0000	70.0000
2155.0000	150.0000	1500.0000	5.0000	24.0000	138.0000
2155.0000	150.0000	1550.0000	4.0000	27.0000	64.0000
2080.0000	150.0000	1500.0000	5.0000	23.0000	71.0000
2080.0000	150.0000	1550.0000	3.0000	28.0000	58.0000
2155.0000	10.0000	1425.0000	2.0000	8.0000	32.0000
2155.0000	10.0000	1425.0000	8.0000	16.0000	28.0000
2155.0000	10.0000	1575.0000	2.0000	12.0000	26.0000
2155.0000	10.0000	1575.0000	8.0000	20.0000	16.0000
2080.0000	10.0000	1425.0000	2.0000	7.0000	10.0000
2080.0000	10.0000	1425.0000	8.0000	15.0000	22.0000
2080.0000	10.0000	1575.0000	2.0000	11.0000	10.0000
2080.0000	10.0000	1575.0000	8.0000	19.0000	14.0000

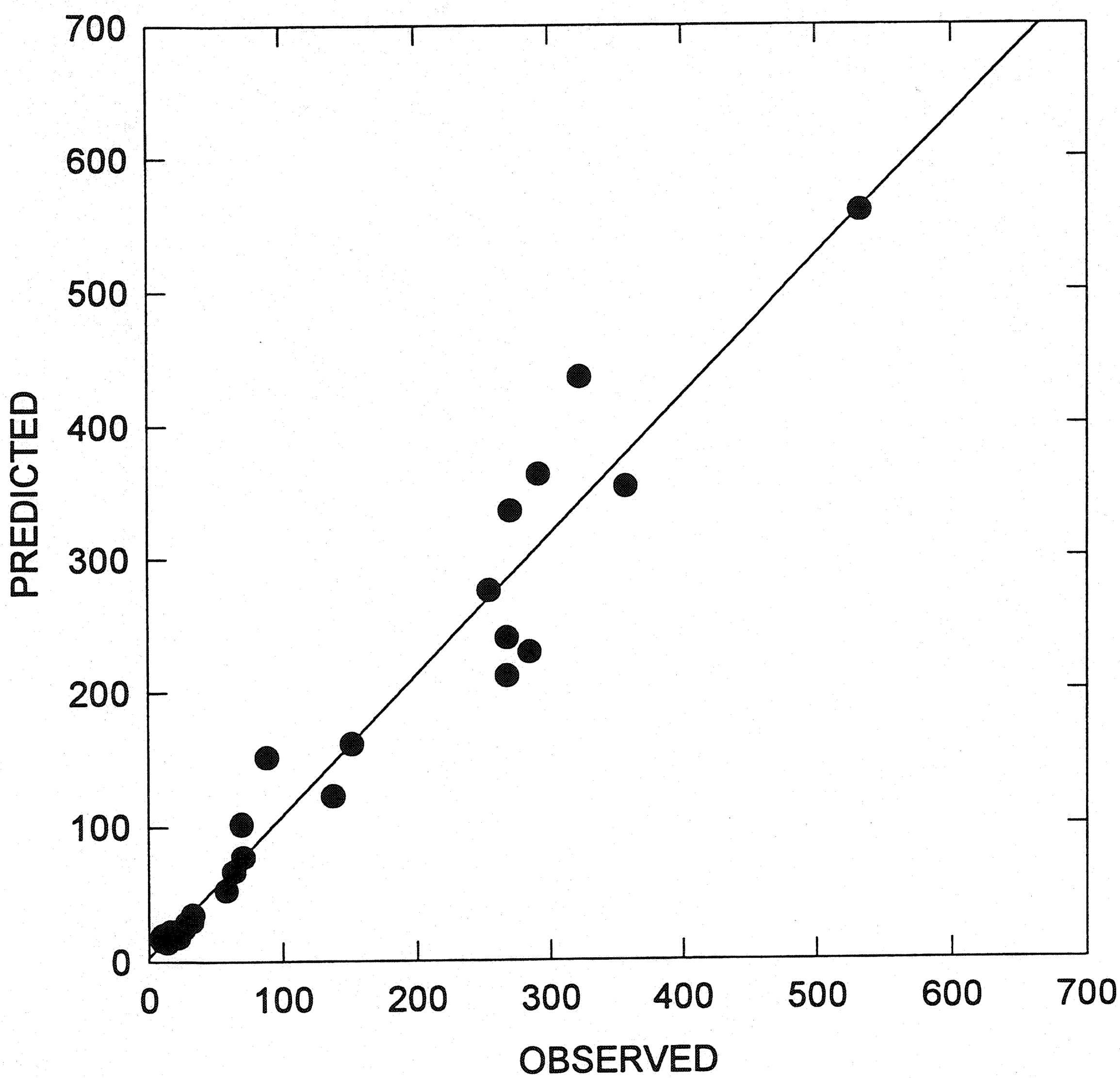


COOLING RATE EFFECT
1300F/100KSI CREEP
SUPERSOLVUS
SUBSOLVUS
81.3*(LOG(CR))^2-54.0*LOG(CR)
0.2% CREEP TIME (HOURS)
600
500
400
300
200
100
0
1
10
100
1000
SOLUTION COOLING RATE (F/MIN)


STABILIZATION FACTOR
1300F/100KSI CREEP
OIL (5.18-1.15E-4*LMP)
AIR (8.48-2.00E-4*LMP)
BLANKET (2.98-5.51E-5*LMP)
NORMALIZED CREEP
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
35000
40000
45000
LMP
(TEMP+460)*(20+LOG(TIME))


SOLUTION FACTOR
1300F/100KSI CREEP
AS-COOLED
OIL/STAB
AIR/STAB
BLANKET/STAB
-12.0+6.15E-3*TEMP
NORMALIZED CREEP
SOLUTION TEMP(F)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2070
2080
2090
2100
2110
2120
2130
2140
2150
2160

1300F/100KSI 0.2% CREEP TIME FOR ALLOY 2
R^2=.95



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12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***
As part of NASA's Advanced Subsonic Technology Program, a study of stabilization heat treatment options for an advanced nickel-base disk alloy, ME–209, was performed. Using a simple, physically based approach, the effect of stabilization heat treatments on tensile and creep properties was analyzed in this paper. Solutions temperature, solution cooling rate, and stabilization temperature/time were found to have a significant impact on tensile and creep properties. These effects were readily quantified using the following methodology. First, the effect of solution cooling rate was assessed to determine its impact on a given property. The as-cooled property was then modified by using two multiplicative factors which assess the impact of solution temperature and stabilization parameters. Comparison of experimental data with predicted values showed this physically based analysis produced good results that rivaled the statistical analysis employed in Reference 1 (P.L. Reynolds, Effects of Residual Stress Heat Treatments (Sub-AoI 4.2.6), NASA AST Resport FR–25331, December 1999.), which required numerous changes in the form of the regression equation depending on the property and temperature in question. As this physically based analysis uses the data for input, it should be noted that predictions which attempt to extrapolate beyond the bounds of the data must be viewed with skepticism. Future work aimed at expanding the range of the stabilization/aging parameters explored in this study would be highly desirable, especially at the higher solution cooling rates.

14. SUBJECT TERMS
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