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Jih-Fen Lei
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

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THE APPARENT STRAIN STABILITY AND REPEATABILITY OF A BCL3 RESISTANCE STRAIN GAGE

Jih-Fen Lei
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio 44142

ABSTRACT

Experiments were conducted at NASA Lewis Research Center to investigate the effect of microstructural instability on the apparent strain stability and reproducibility of a BCL3 resistance strain gage. The resistance drift of the gage at various temperatures in the phase transition temperatures range (PTTR) was measured. The effects of the heating and the cooling rates with which the gage passed through the PTTR on the apparent strain characteristics of the gage were also investigated. BCL3 gage, like other Fe-Cr-Al based gages, exhibited apparent strain instability in the temperature range of 700-1100°F due to the reversible microstructural transition the gage materials experienced in this temperature range. The BCL3 gage had a maximum apparent strain drift in the neighborhood of 770°F with an average drift rate of approximately -440 microstrain per hour in two hours. The use of this BCL3 gage as well as other Fe-Cr-Al based gages for static strain measurements within the PTTR should be avoided unless the time durations in the PTTR are small enough (the order of minutes) to introduce a negligible drift. The microstructural transition that the BCL3 gage underwent occurred in the temperature range of 750-1050°F during heating and around 1000-800°F during cooling. The heating rate and, in particular, the cooling rate with which the gage passed through the PTTR affected the shape and the repeatability of the apparent strain curve of the gage. The higher the heating and the cooling rates were, the better the apparent strain repeatability between thermal cycles. In using the BCL3 gage and other Fe-Cr-Al gages for static strain measurements, care should be taken to insure that the heating and cooling rates during the actual testing and those used for apparent strain calibrations are as close as possible. Otherwise, apparent strain corrections will be in error.

INTRODUCTION

The rapid progress in aerospace and nuclear fields, in which extremely high operation temperatures are prevalent, resulted in a need for a high temperature static strain gage. The two basic qualities that a resistance static strain gage should have are as follows. First, it should have a stable and reproducible resistance at all temperatures up to the operating temperature. Second, its resistance change should mainly be due to the strain alone. Therefore, the apparent strain of the gage should be either small enough to be neglected or repeatable enough to be corrected. The existing resistance strain gages are not reliable for static strain measurements above 700°F.

The BCL3 gage, which is made of Fe-25Cr-7.5Al alloy, was first developed at Battelle Memorial Institute in the early 1970's under a contract with NASA Langley Research Center[1]. The results of this contract indicated that this BCL3 gage may be a viable strain sensor for use in the temperature range from 1200°F up to 1900°F. The apparent strain of the gage was repeatable at temperatures above 1200°F but zero-shifts were noticed at the lower temperatures. However, since the apparent strain of the gage during a heat-up cycle overlapped that of the previous cool-down cycle in the entire temperature range from room temperature to 1900°F, it was suggested that the cool-down cycle could be used as the apparent strain calibration curve for the consecutive heat-up test. Nevertheless, when pre-conditioning is not permissible, other gages that can provide accurate strain data in the temperature range of room temperature to about 1200°F are needed for use with the BCL3 gage[2].

The BCL3 gage and other gages of Fe-Cr-Al based alloy, including Kanthal A-1 gage, Chinese 700°C and 800°C gages and Dentronics gage, have been known to exhibit a microstructural transition in the temperature range of 700-1100°F. However, essentially no work has been taken to study the effect of this microstructural instability on the apparent strain characteristic of the gages. Efforts were therefore taken at NASA Lewis Research Center to study the BCL3 resistance strain gage. The drift behavior of the gage in the phase transition temperature range (PTTR) and the consequence of the high drifts on the apparent strain characteristics of the gage were evaluated. The effects of heating rate and cooling rate with which the gage passed through the PTTR on the apparent strain repeatability and zero-shift characteristics of the gage were also investigated.

EXPERIMENTAL SET-UP

Two BCL3 wire gages with a gage factor of 2.5 at room temperature were purchased from Battelle Columbus Laboratories. These gages were installed on a Hastelloy-X coupon at NASA Langley Research Center with flame sprayed powdered alumina. To improve the reliability, the gages were mounted back-to-back on each side of the coupon so that the measurements were conducted on two gages at the same time. Two chromel/alumel thermocouples were also spot welded back-to-back to each side of the Hastelloy-X coupon to measure the temperature of the gage and any temperature gradient across the thickness of the coupon. Throughout the entire test temperature range the temperature gradient was found to be less than 3°C across the coupon, which had a thickness of approximately 1 mm.

All of the tests were conducted in air. The test data were always taken after the temperature of the oven was stabilized. A standard IBM PC was used to provide computer control of the muffle furnace (Fisher 186) temperature and the data sampling. The testing system consisted of a 10-channel digital thermometer (Fluke 2190A), a 2-channel digital-to-analog converter to program the oven temperatures, and a digital multimeter (Fluke 8520A) for measuring the gage resistance. The computer communicated with the instrumentations by means of IEEE-488 bus and an RS-232 serial interface.

The standard four-probe resistance measuring method was used to minimize the lead wires effect. The four extension leads which extended to the digital multimeter were Nichrome wires. Two leads were spot welded to each of the two gage lead pads. The resistance at room temperature of the two gages were 118.7 and 119.7 ohm, respectively. The apparent strain of the gage was calculated with the assumption that the gage had a constant gage factor (G.F.) of 2.5 throughout the test temperature range, i.e. apparent strain=(R-Ro)/(Ro x 2.5), where Ro was the original gage resistance at the room temperature.

TESTS ON DRIFT CHARACTERISTIC

The resistance drift tests that were made followed the same test procedure as that mentioned in reference 3 in order to compare the drift behavior of this BCL3 gage to that of the other Fe-Cr-Al gages. The test coupon was first heated to 1200°F and then quickly cooled down to the test temperatures. The resistance drift of the gages during a sixteen hour soak was measured after the oven temperature reached the test temperature and stabilized. The gages were cooled down to room temperature after each soak.

The changes in resistance of two BCL3 gages after the sixteen hour soak at various temperatures are listed in Table 1. The behavior of these two gages was very similar. They both had a negative drift rate in the temperature range of 700°F to 900°F with a maximum drift rate in the neighborhood of 800°F. Fig. 1 presents the change in resistance vs time (R-Ro/Ro vs t) during the sixteen hour soak at various temperatures for one of the gages. Ro was the starting resistance of the gage at each drift temperature. The drift rate of this gage at 770°F was approximately -880 ppm per hour in the first two hours, and then slowed down to approximately -240 ppm per hour in the last two hours. If it is assumed the gage had a gage factor of 2 at this temperature, the apparent strain drift of the gage was then approximately -440 microstrain per hour in the first two hours. This value was too high to be neglected.

The resistance drift versus temperature characteristics of this BCL3 gage were compared to that of two Ni-Cr based gages (Nichrome and Evanohm S) and three other Fe-Cr-Al based gages (Chinese 700°C, 800°C gages and Kanthal A-1 gage) as shown in Fig. 2. Data on the other strain gages were adopted from reference 3. As shown, the BCL3 gage demonstrated similar behavior to that of the other Fe-Cr-Al based gages. However, the drift for the BCL3 gage was less than or equal to that for the other Fe-Cr-Al based gages. All of these gages had very high drift and therefore poor stability in the temperature range of 700-1100°F. The use of these gages for static strain measurements in this temperature range should be avoided unless the time durations in this temperature range are small enough (the order of minutes) to introduce a negligible drift.

The change in resistance of the BCL3 gage during these drift tests is presented in Fig. 3. Notice that the resistance of the gage always "recovered" to the original value at around 1100-1200°F; however, soaking the gage at various temperature produced variable resistance shift of the gage at the lower temperatures. This can be explained by the microstructural transition ("order-disorder" transition) that Fe-Cr-Al based materials have been known to undergo[4,5]. The equilibrium "disorder" phase of this BCL3 gage was probably reached at around 1200°F. Soaking the gage at the lower temperature, after fast cooled down from 1200°F, produced phases with various degree of "order". The degree of order that the microstructure of the gage material had at the low temperature strongly depended on its soaking temperature and time. The apparent strain of the gage at lower temperature is therefore both temperature and time dependent.

TESTS ON APPARENT STRAIN CHARACTERISTIC

After the drift tests, the two BCL3 gages were subjected to thermal cycling tests in order to study the effect of heating rates and cooling rates on the apparent strain characteristics of the gage. The history of the thermal cycling tests together with the heating and cooling rates of each cycle are listed in Table 2. Note that the rates listed were the average rates with which the gages passed through the phase transition temperature range (PTTR) of 700-1100°F.

The apparent strain versus temperature of one of the gages during the first three consecutive thermal cycles to 1200°F and a four hour soak at 1200°F is presented in Fig. 4. The heating and cooling rates of these three cycles were the same at 60°F/min and 40°F/min, respectively. Since the two gages had very similar behaviors, only results from one gage were presented. The change in apparent strain of the gage in the temperature range from room temperature to 1200°F was approximately 10000 microstrain. The apparent strain of the gage decreased with increasing temperature except in the temperature range of 750-1050°F, where the apparent strain versus temperature characteristic was different between the heat-up and cool-down cycles. The reproducibility of the data between cycles was examined more closely by plotting the deviation of the data between cycles as shown in Fig. 5. The data were derived by subtracting the data for each cycle from a third degree curve fit to the first heat-up cycle. As shown, the apparent strain of the gage was repeatable in the temperatures range of 1050-1200°F. However, the repeatability at lower temperature was poor with approximately 250 microstrain zero-shift at room temperature between cycles. The soak at 1200°F for four hours changed the transition temperatures and the amount of apparent stain change during the transition in the subsequent cool-down cycle (cooling cycle 2). The soak also produced an approximately 750 microstrain zero-shift at room temperature. However, the gage returned to its cycle one apparent strain characteristic after an additional thermal cycle (cycle 3). Note the reproducibility between the data for cooling cycle one and three. This indicated that the apparent strain characteristics of this BCL3 gage depends on the thermal history of the gage. The repeatability of the apparent strain could be improved if the heating/cooling rates could be kept the same between thermal cycles.

Fig. 6 presents the results from thermal cycles three to five where cycle four had a different cooling rate. As shown, the shape of the apparent strain versus temperature curve changed as a result of changing the cooling rate. There was approximately 1800 microstrain zero shift at room temperature when the cooling rate changed from 40°F/min to 210°F/min. The irregularity shown in the temperature range of 750-1050°F during the first three cycles was not observed during the fourth fast cool-down cycle and the subsequent heat-up cycle. The apparent strain vs temperature characteristic of the gage therefore strongly depended on the cooling rate that gage passed though the PTTR. The faster the cooling rate was, the smaller the change in apparent strain due to the phase transition that gage underwent. The apparent strain retraceability between a heat-up cycle and the previous cool-down cycle could therefore be improved by fast cool-down the gage. Note the repeatability between heating cycle five and cooling cycle four in the deviation curves in Fig. 7.

The apparent strain versus temperature curves of thermal cycles five to seven are shown in Fig. 8 and the deviations of the data between cycles are shown in Fig. 9. The heating rates of these three cycles were 60, 50, and 40°F/min, respectively. Although the effect of changing the heating rate on the apparent strain characteristics of the gage was not as great as that of changing the cooling rate, the amount of apparent strain change in the transition temperature range during the subsequent cooling cycles were different even when the cooling rates were the same. The lower the heating rate was, the larger the change in the apparent strain characteristic. The reproducibility of the apparent strain between the heating and cooling cycle was also changed with heating rate. The higher the heating rate, the better the repeatability. Note that the achievable differences in heating rates were not as great as the differences in cooling rates. This may explain why the effect of changing the heating rate was not as great as that of changing the cooling rate.

The results of these tests suggested that the reversible order-disorder transition this BCL3 gage underwent occurred in the temperature range of 750-1050°F during heating and in the temperature range of 1000-800°F during cooling. The amount of apparent strain change of the gage due to this transition depended on the heating and the cooling rates with which the gage passed through the PTTR. The higher the heating/cooling rates were, the smaller the change in apparent strain due to this phase transition and therefore the better the apparent strain repeatability. In order to use this gage for measuring static strain to a reasonable accuracy level, the heating/cooling rates during the actual measurements and those during apparent strain calibration should be as close as possible.

The gages were then subjected to a higher temperature of 1800°F for another four cycles (cycles 8-11) and a four hour soak at 1800°F. The change in apparent strain of the gage during the four heat-up cycles are shown in Fig. 10. Not shown is the apparent strain of the gage during the four cool-down cycles. The apparent strain of the gage during a heat-up cycle almost overlapped that of the previous cool-down cycle except in the PTTR. Notice that the zero-shifts at the lower temperatures were increased as the gage was subjected to this higher temperature. However, this zero-shift was decreased and the reproducibility of the gage was improved with thermal cycling and a four hour soak at 1800°F. This is consistent with that recommended for BCL3 gage; the gage should be preconditioned by subjecting it to a four hour soak at the maximum test temperature and to at least two thermal cycles to the maximum test temperature in order to stabilize the gage[6].

Delamination of the gages from the substrate was observed after cycle eleven, therefore the tests on these gages were terminated. This delamination problem was expected because the simplified attachment technique used here was only good to approximately 1300°F. At the higher temperature, the thermal expansion mismatch between the substrate and the alumina bondcoat results in the poor adherence. The proper and more complicated graded bonding process for installing the BCL3 gage for high temperature use was described in reference 1.

CONCLUSION

This work suggests that due to the microstructural transition that the gage materials experienced, there are certain precautions required when using the BCL3 gage as well as other Fe-Cr-Al based gages for static strain application. The use of these gages within the phase transition temperature range (PTTR, 750-1050°F) should be avoided unless the time durations in this temperature range are small enough (the order of minutes) to introduce a negligible drift. The apparent strain of the gage was repeatable at temperatures above 1200°F, however, the apparent strain characteristic of the gage at lower temperatures was temperature and time dependent. The higher the heating and cooling rates were as the gage passed through the PTTR, the better the apparent strain repeatability of the gage between a heat-up cycle and the previous cool-down cycles. The heating and cooling rates used in the actual measurements and those used in the apparent strain calibration should be as close as possible to assure accurate apparent strain corrections.

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REFERENCES

1. M. M. Lemcoe, "Development of Strain Gages for Use to 1311K (1900°F)", NASA Report CR-132485, 1974.

2. M. M. Lemcoe, "High-Temperature Strain Gage Measurements to 2000°F: Can it be Done?". Sensors Expo International Conference Proceedings, p203C-1-7, 1989.

3. H. P. Grant, W. L. Anderson and J. S. Przbyszewski, "Rotating Tests of Advanced High Temperature Wire and Thin-Film Strain Gages"; AIAA-88-3146, 24th Joint AIAA Prop. Conf. Proceeding, 1988.

4. H. F. Hobart; "Evaluation Results of the 700°C Chinese Strain Gages", NASA Technical Memorandum 86973, 1985.

5. T. T. Wu and L. C. Ma; "Comparison of Characteristics of Two Temperature-Compensated Resistance Strain Gages for Use to 700°C and 800°C" Fourth Annual Hostile Environments and High Temperature Measurements Conference Proceedings, SEM, p.30-37, 1987.

4. M. M. Lemcoe, "Procedures for Determination of Apparent Strain Calibration Curves", Battelle Memorial Institute Publication.

Table 1. THE SIXTEEN HOUR RESISTANCE DRIFT (R-Ro/Ro, in ppm) OF BCL3 GAGES AT VARIOUS TEST TEMPERATURES.

Temp (°F)	545	660	715	770	840	945
Gage #1	111	1312	-1912	-6366	-5081	17
Gage #2	163	1349	-2006	-6504	-5153	-26

Table 2. THERMAL HISTORY OF THE APPARENT STRAIN TESTS ON THE BCL3 GAGES.

Cycle No.		Temp Range °F	Heating Rate °F/min	Cooling Rate °F/min	Comments
1	Heat	70-1200	60		
	Cool	1200-135		40	
2	Heat	120-1200	60		
	Soak	Hold at 1190°F for four hours			Soaking Effect
	Cool	1190-120		40	
3	Heat	95-1200	60		
	Cool	1200-150		40	
4	Heat	70-1200	60		Changing Cooling Rate
	Cool	1200-200		205	
5	Heat	160-1200	60		
	Cool	1200-120		40	
6	Heat	70-1200	50		Changing Heating Rate
	Cool	1200-70		40	
7	Heat	70-1200	40		
	Cool	1200-120		40	
8	Heat	70-1800	60		
	Cool	1800-70		40	
9	Heat	70-1800	60		
	Soak	Hold at 1800°F for four hours			Soaking Effect
	Cool	1800-70		40	
10	Heat	70-1800	60		
	Cool	1800-70		40	
11	Heat	70-1800	60		
	Cool	1800-70		40	

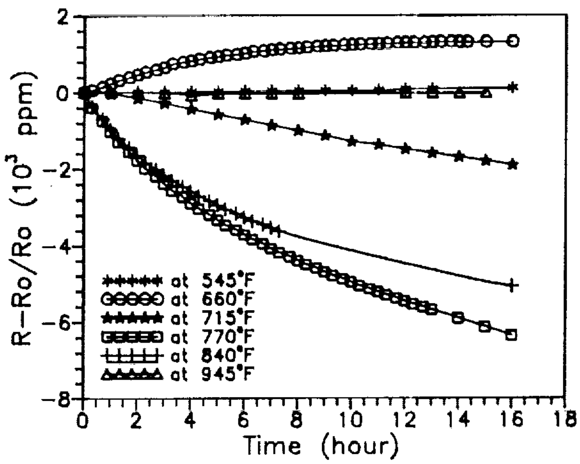


Figure 1.—The change in resistance of a BCL3 gage during the sixteen hour soak at various temperatures.

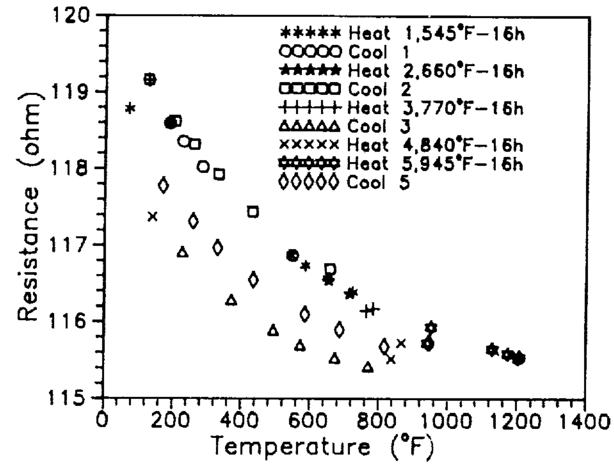
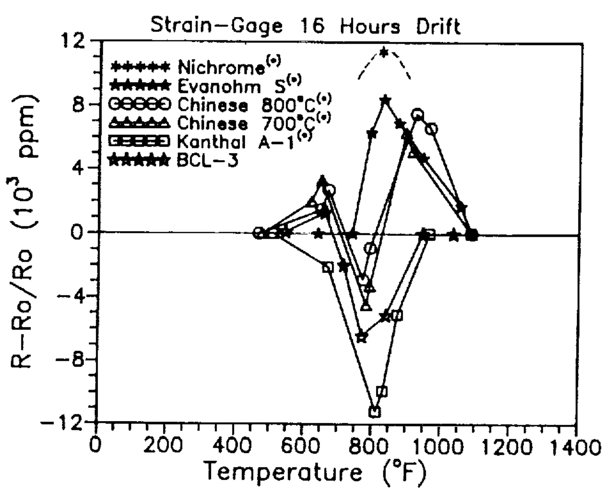


Figure 3.—The change in resistance of a BCL3 gage during the series of drift tests.



* Ref: H. P. Grant etc, AIAA Prof. Conf., 1988

Figure 2.—Comparison of the sixteen hour resistance drift versus temperature behaviors between BCL3 gage and other resistance strain gages.

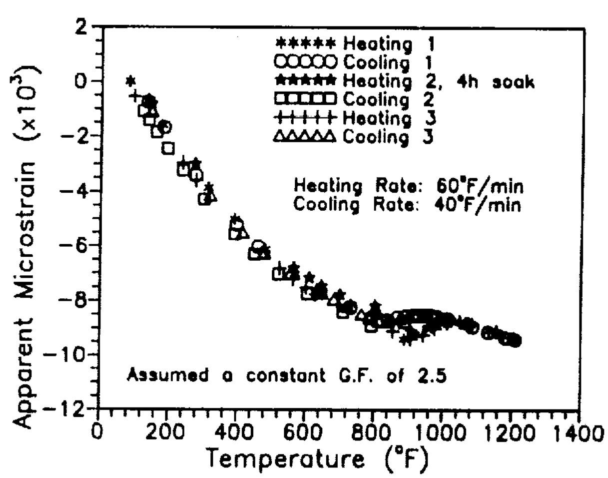


Figure 4.—The change in apparent strain versus temperature of a BCL3 gage during the first three thermal cycles to 1200 °F and a four hour soak.

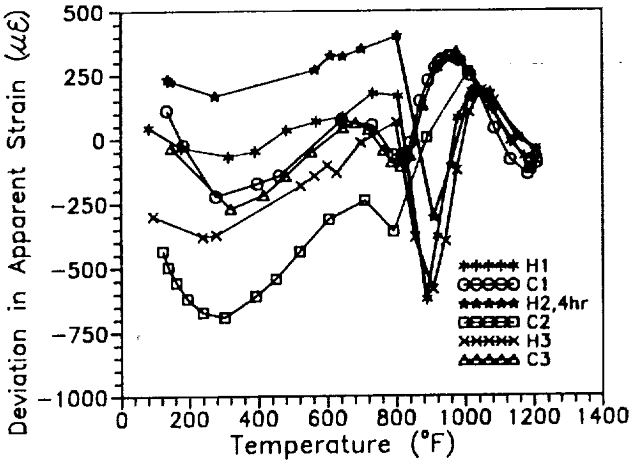


Figure 5.—The deviation of the apparent strain of a BCL3 gage between the first three thermal cycles.

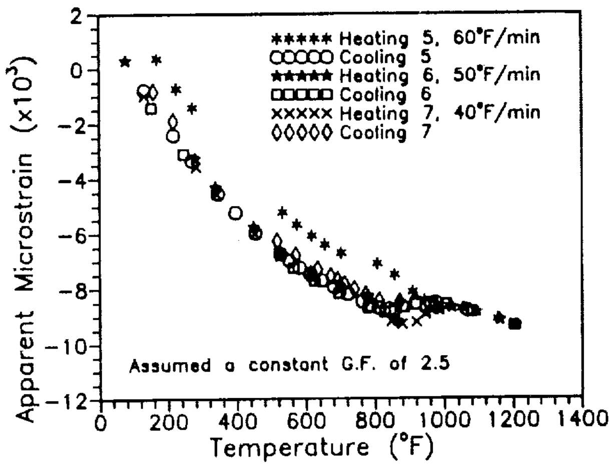


Figure 8.—The effect of changing in heating rates on the apparent strain characteristic of a BCL3 gage.

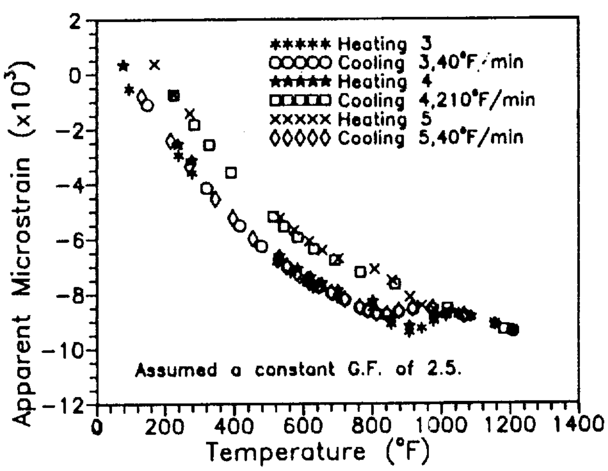


Figure 6.—The effect of changing in cooling rates on the apparent strain characteristic of a BCL3 gage.

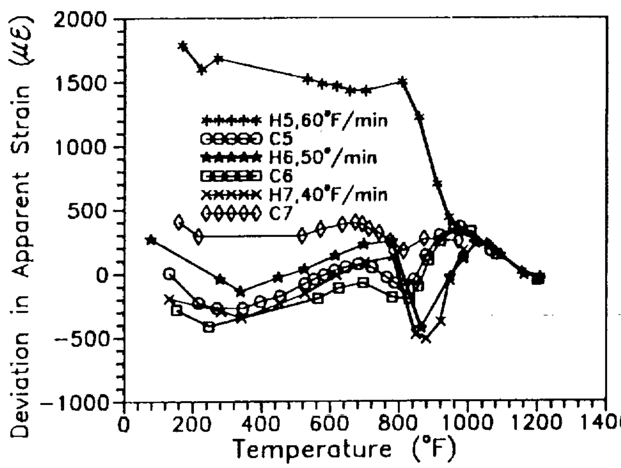


Figure 9.—The deviation of the apparent strain of a BCL3 gage between thermal cycles five to seven.

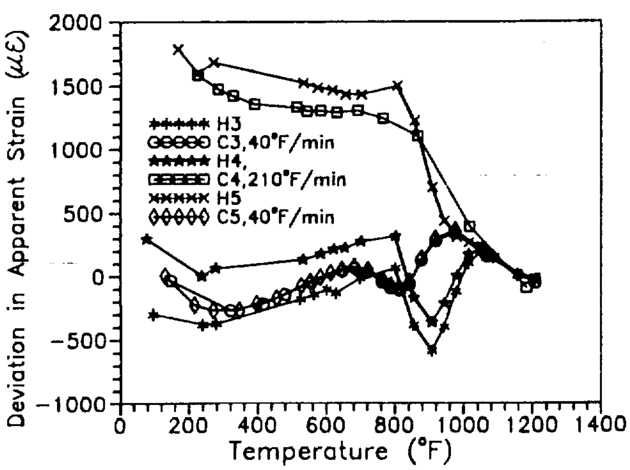


Figure 7.—The deviation of the apparent strain of a BCL3 gage between thermal cycles three to five.

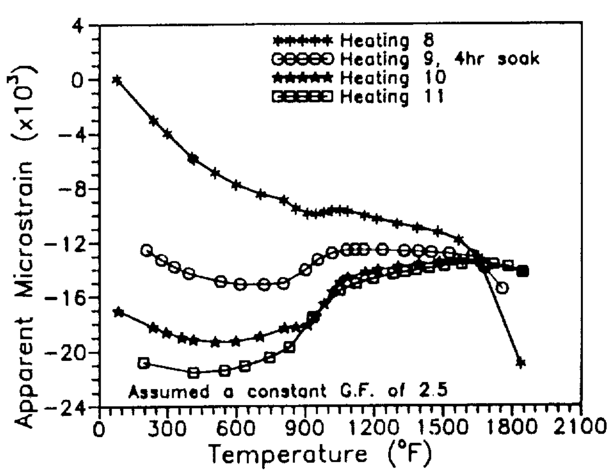


Figure 10.—The change in apparent strain versus temperature of a BCL3 gage during four heat-up cycle to 1800 °F, and a four hour soak.

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15. Supplementary Notes

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16. Abstract

Experiments were conducted at NASA Lewis Research Center to investigate the effect of microstructural instability on the apparent strain stability and reproducibility of a BCL3 resistance strain gage. The resistance drift of the gage at various temperatures in the phase transition temperatures range (PTTR) was measured. The effects of the heating and the cooling rates with which the gage passed through the PTTR on the apparent strain characteristics of the gage were also investigated. BCL3 gage, like other Fe-Cr-Al based gages, exhibited apparent strain instability in the temperature range of 700–1100 °F due to the reversible microstructural transition the gage materials experienced in this temperature range. The BCL3 gage had a maximum apparent strain drift in the neighborhood of 770 °F with an average drift rate of approximately −440 microstrain per hour in two hours. The use of the BCL3 gage as well as other Fe-Cr-Al based gages for static strain measurements within the PTTR should be avoided unless the time durations in the PTTR are small enough (the order of minutes) to introduce a negligible drift. The microstructural transition that the BCL3 gage underwent occurred in the temperature range of 750–1050 °F during heating and around 1000–800 °F during cooling. The heating rate and, in particular, the cooling rate with which the gage passed through the PTTR affected the shape and the repeatability of the apparent strain curve of the gage. The higher the heating and the cooling rates were, the better the apparent strain repeatability between thermal cycles. In using the BCL3 gage and the other Fe-Cr-Al gages for static strain measurements, care should be taken to insure that the heating and cooling rates during the actual testing and those used for apparent strain calibrations are as close as possible. Otherwise, apparent strain corrections will be in error.

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