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NASA Technical Memorandum 86973

Evaluation Results of the 700 °C Chinese Strain Gauges

(NASA-TM-86973) EVALUATION RESULTS OF THE 700 DEG C CHINESE STRAIN GAUGES (NASA) 11 p HC A02/MF A01 CSCL 14B

N85-21605

Unclas
G3/35 14533

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Prepared for the
High Temperature Measurements for Experimental Mechanics Conference
cosponsored by the Society for Experimental Mechanics
and Oak Ridge National Laboratory
Knoxville, Tennessee, March 27-28, 1985

APR 1985
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EVALUATION RESULTS OF THE 700 °C CHINESE STRAIN GAUGES

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E-2502

SUMMARY

There has been a continuing interest and need for resistance strain gauges capable of making static strain measurements on components located in the hot section of gas turbine engines. A number of gauges fabricated from specially developed Fe-Cr-Al-V-Ti-Y alloy wire were purchased for evaluation purposes from the Republic of China. Nine members of the aircraft turbine engine community were invited to participate in an evaluation of these gauges. This paper includes data on gauge factor variation with temperature, apparent strain and drift.

<u>Gauge factor</u>. - Results of gauge factor versus temperature tests show gauge factor decreasing with increasing temperature. The average slope is -3-1/2 percent/100 K, with an uncertainty band of ±8 percent. Values of room temperature gauge factor for the Chinese and Kanthal A-1 gauges averaged 2.73 and 2.12, respectively. The room temperature gauge factor of the Chinese gauges was specified to be 2.62.

<u>Apparent strain</u>. - The apparent strain data for both the Chinese alloy and Kanthal A-1 showed large cycle to cycle nonrepeatability. This variability is influenced by heating and cooling rates of the previous cycle, dwell times at various temperatures and type of substrate on which the gauge is bonded.

All apparent strain curves had a similar S-shape, first going negative and then rising to positive value with increasing temperatures. The mean curve for the Chinese gauges between room temperature and 100 K had a total apparent strain of 1500 microstrain. The equivalent value for Kanthal A-1 was about 9000 microstrain.

<u>Drift</u>. - Drift tests at 950 K for 50 hr show an average drift rate of about -9 microstrain/hr. Short-term (1 hr) rates are higher, averaging about -40 microstrain for the first hour. In the temperature range 700 to 870 K, however, short-term drift rates can be as high as 1700 microstrain for the first hour. Therefore, static strain measurements in this temperature range should be avoided and care must be taken in making drift corrections, especially when drift rate is expressed as a small hourly rate based on some long-term test.

INTRODUCTION

There has been a continuing interest and need for resistance strain gauges capable of making static strain measurements on components located in the hot section of gas turbine engines. A paper by Tsen-tai Wu et al. (ref. 1) describes the development and evaluation of high-temperature (700 °C) gauges fabricated from specially developed Fe-Cr-Al-V-Ti-Y (26 Cr, 5 Al, wt %) alloy wire. As part of the Lewis Research Center HOST program, a number of these gauges and a quantity of P12-2 ceramic adhesive were purchased for evaluation purposes from the China National Aero-Technology Import and Export Corporation of Beijing, China.

Nine members of the aircraft turbine engine community were invited to participate in an evaluation of these gauges. Each participant was sent one strain gauge, a small amount of ceramic adhesive, instructions for mounting the gauge on a test beam (not supplied) and a set of suggestions for the evaluation experiment.

The discussion which follows includes data on the variation of gauge factor, apparent strain and drift as a function of temperature. The reported results are from six participants.

DISCUSSION

Gauge Factor

Figure 1 is a plot of percent change in gauge factor from its room temperature value versus temperature for five different evaluators. The trend is for gauge factor to decrease with increasing temperature. The average slope is -3.5 percent/100 K, with a maximum data spread of ±8 percent. The curve labeled Wu is from reference 1 and is based on eight gauges bonded to both sides of a constant-moment beam strained to 938 microstrain. Curves from the other evaluators are averaged data in both tension and compression at several strain levels in the range 300 to 2000 microstrain.

By way of comparison, some interesting results have recently been reported on by Stetson (ref. 2) with Kanthal A-1 (Fe, 22 Cr, 5.7 Al, 0.5 Co, wt %) gauges. These gauges exhibit gauge factor characteristics similar to the Chinese gauges as shown in figure 2. The solid line curves are the envelope of curves from figure 1 and the dashed line curves show the data spread on the eight Kanthal A-1 gauges tested in reference 2.

The average values of gauge factor at room temperature and the indicated high temperatures are listed in table I. All the Chinese gauges used in the evaluation had a specified room temperature gauge factor of 2.62, which is within 4 percent of the average of the five gauges listed in table I.

Apparent Strain

The comparison of apparent strain data between evaluators is difficult because several factors influence the shape of the resistance-temperature curve. Aside from the sensor temperature coefficient of resistance, the magnitude and curve shape appear to be most strongly affected by the cooling rate of the previous temperature excursion and to a lesser degree by the difference in temperature coefficient of expansion between the gage alloy and the substrate material. A further consideration is the construction of the Chinese gauges. These gauges have a relatively large amount of ceramic cement which encapsulates the wire and, together with the large size of the gauge, could influence apparent strain by causing a bending moment to occur, especially if bonded to a thin substrate.

Table II lists the evaluator, the substrate material used in the test and the number of thermal cycles reported.

Figure 3, a plot of apparent strain versus temperature, is based on an average of the number of cycles from table II. All curves are normalized to pass through zero at room temperature. A gauge factor of 2.0 was used to calculate microstrain.

In order to compare the Kanthal A-1 data to the Chinese gauges, figure 4 was drawn to show the envelope of the curves from figure 3, shown as solid lines, and the Kanthal A-1 data plotted as dashed lines. It is obvious from figure 4 that both alloys have similar S-shaped curves, but the Kanthal A-1 has a much higher value of apparent strain at elevated temperatures. It can also be noted that the maximum data spread at any temperature for both alloys is similar in spite of the fact that the Kanthal data were obtained from a single facility and the same substrate material for all eight gauges as opposed to how the Chinese gauge data were obtained. The implication here is that under carefully controlled tests, the Chinese alloy should exhibit much better repeatability in cycle-to-cycle apparent strain testing.

Figure 5 has been reproduced directly from the report of evaluator 5. This figure is a typical slow heating cycle and is presented to illustrate the inflection point which is present in each cycle at about 700 K (425 °C). Two other evaluators also show a "bump" occurring near that same temperature. A possible explanation for this anomaly is the extremely high negative drift rate in the range of 700 to 870 K, as reported by evaluator 3. This behavior, related to some specific metallurgical process, reinforces the statements in the Conclusions pertaining to the care required in using these gauges in that unstable temperature region.

Drift

Drift test results are shown in figure 6. All evaluators reporting drift data agree on the slope of the curves, with the long-term (50 hr) Lewis Research Center data having an overall drift rate of about -9 microstrain/hr. Short-term drift rates, however, are higher, in the range -30 to -50 microstrain for the first hour.

Recent supplementary data by evaluator 3 (fig. 7) indicates drift rate is a strong function of temperature level. There appears to be short-term instability in the 700 to 870 K range, with drift rates as high as 1700 microstrain for the first hour at 870 K. (Data in fig. 6 was taken at 950 K).

CONCLUSIONS

Test results have been presented from five participants in the comparative evaluation of the Chinese strain gauges. Data are also included from work done by Professor Wu from his original paper describing the Chinese alloy. K. Stetson of UTRC and H. Grant, PWA, as part of a recent contract effort for NASA, have published data in a contractor report on Kanthal A-1 gauges. Kanthal A-1 is a ternary alloy similar to the Chinese alloy, each with different trace elements. These data are also included.

Gauge factor. - Results of gauge factor versus temperature tests show gauge factor decreasing with increasing temperature. The average slope is -3.5 percent/100 K, with an uncertainty band of ±8 percent. Values of room temperature gauge factor for the Chinese and Kanthal A-1 gauges averaged 2.73 and 2.12, respectively. The room temperature gauge factor of the Chinese gauges was specified to be 2.62.

Apparent strain. - The apparent strain data for both the Chinese alloy and Kanthal A-1 showed large cycle to cycle nonrepeatability. This variability is influenced by heating and cooling rates of the previous cycle, dwell times at various temperatures and type of substrate on which the gauge is bonded. H. Grant of PWA CT, as a result of extensive testing, has identified cooling rate as the predominant factor.

All apparent strain curves had a similar S-shape, first going negative and then rising to positive value with increasing temperatures. The mean curve for the Chinese gauges between room temperature and 1000 K had a total apparent strain of 1500 microstrain. The equivalent value for Kanthal A-1 was about 9000 microstrain.

Drift. - Drift tests at 950 K for 50 hr show an average drift rate of about -9 microstrain/hr. Short-term (1 hr) rates are higher, averaging about -40 microstrain for the first hour. In the temperature range 700 to 870 K, however, short-term drift rates can be as high as 1700 microstrain for the first hour. Therefore, static strain measurements in this temperature range should be avoided and care must be taken in making drift corrections, especially when drift rate is expressed as a small hourly rate based on some long-term test.

The results of these tests indicate that to use these gauges at high temperatures for measuring static strain to a reasonable accuracy level, certain precautions are required. Gauge temperature must be known to allow compensation for gauge factor and apparent strain; also, gauges must be calibrated at known cooling rates to establish repeatable apparent strain. A high-temperature soak for at least 1 hr appears necessary to assure the apparent strain reaches the same value "starting point" for each cycle. The actual strain measurement should then be made at the same cooling rate if possible.

REFERENCES

1. Wu, Tsen-tai et al., "Development of Temperature-compensated Resistance Strain Gauges for Use to 700 °C," Fourth International Congress on Experimental Mechanics, Boston, MA, May 25-30, 1980.

2. Stetson, K. A., "Demonstration Test of Burner Liner Strain Measuring System," UTRC Report No. R84-926376-15, June 1984.

TABLE I. - AVERAGE GAUGE FACTOR AT ROOM AND HIGH TEMPERATURE

Evaluator	Room temperature	High temperature, K
Evaluator 1	2.60	2.21 (946)
Evaluator 2	2.79	2.14 (955)
Evaluator 3	3.06	2.19 (950)
LeRC	2.66	1.96 (973)
Wu	2.56	1.90 (973)
	Avg. 2.73	
UTRC[a]	2.12	1.81 (800)

[a]Kanthal A-1 gauges from reference 2.

TABLE II.

Evaluator	Substrate, thickness	Number of cycles
Evaluator 1	Hastelloy X (0.25 in)	7
Evaluator 2	Incoloy 901	8
Evaluator 3[a]	Rene 41 (0.187 in)	3
Evaluator 4	IN-100	5
Evaluator 5	IN-600 (0.5 in)	10
LeRC 2[a]	IN-718 (0.129 in)	7
Wu	GH 30	3

[a]Beams used by these evaluators had gauges bonded to both sides of the test beam in a symmetrical arrangement.

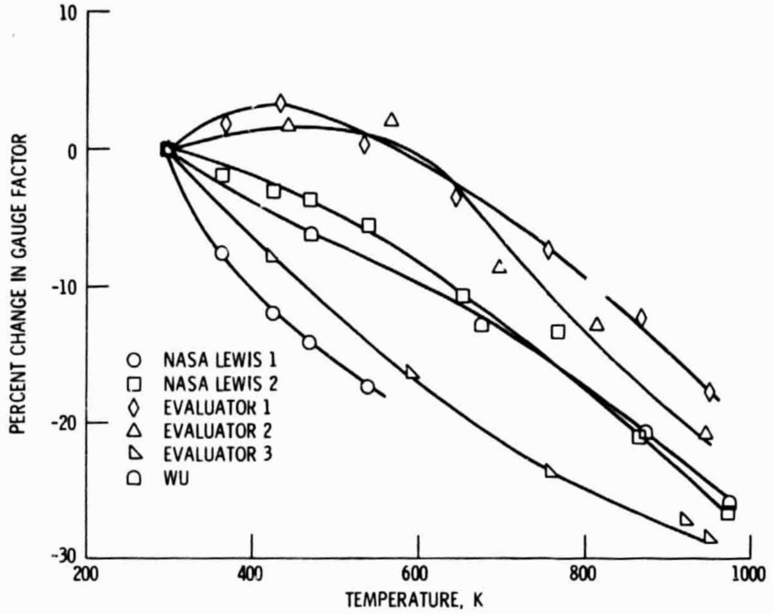

Figure 1. - Gauge factor variation versus temperature. Room temperature value as reference.

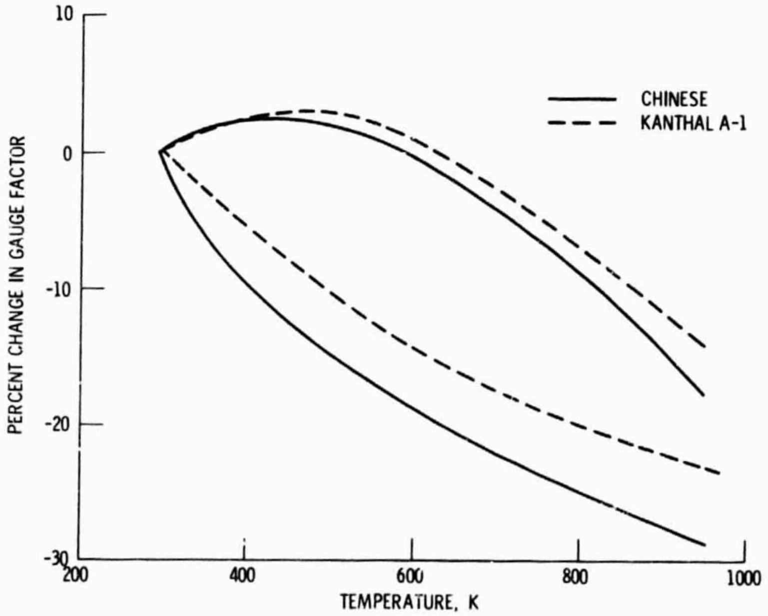

Figure 2. - Gauge factor variation versus temperature. Room temperature value as reference.

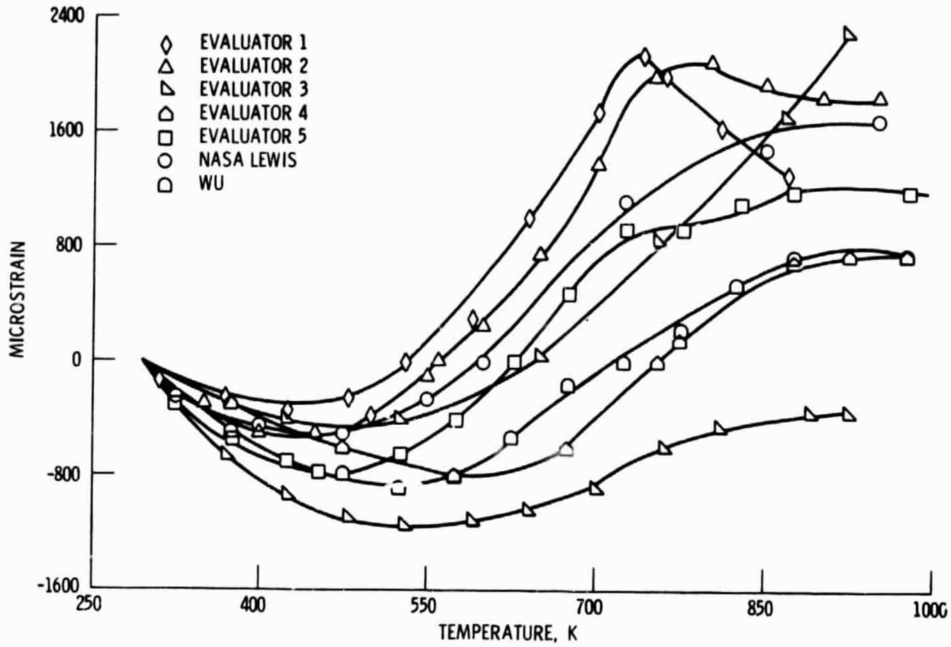

Figure 3. - Apparent strain versus temperature.

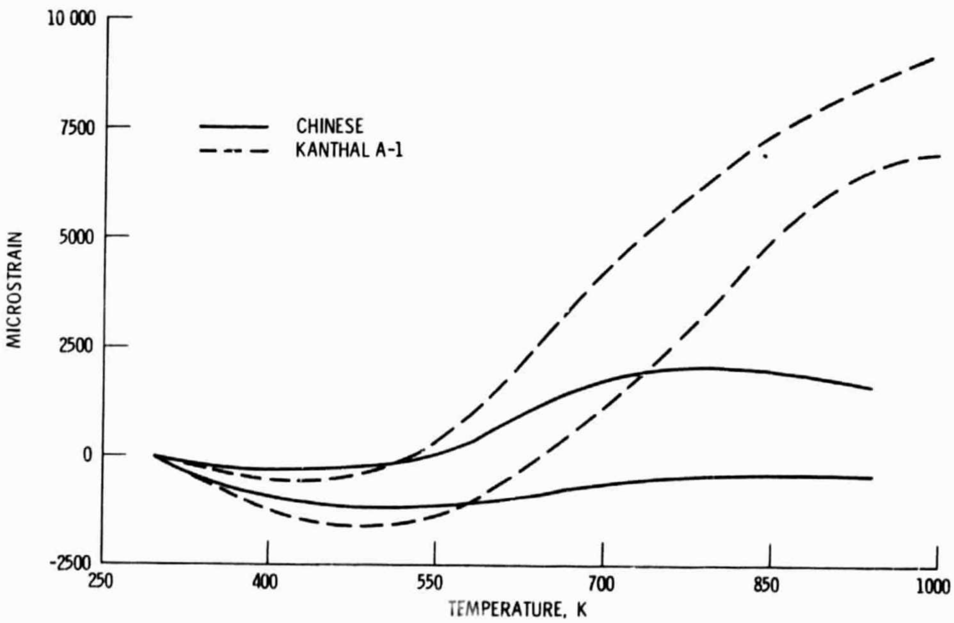

Figure 4. - Apparent strain versus temperature.

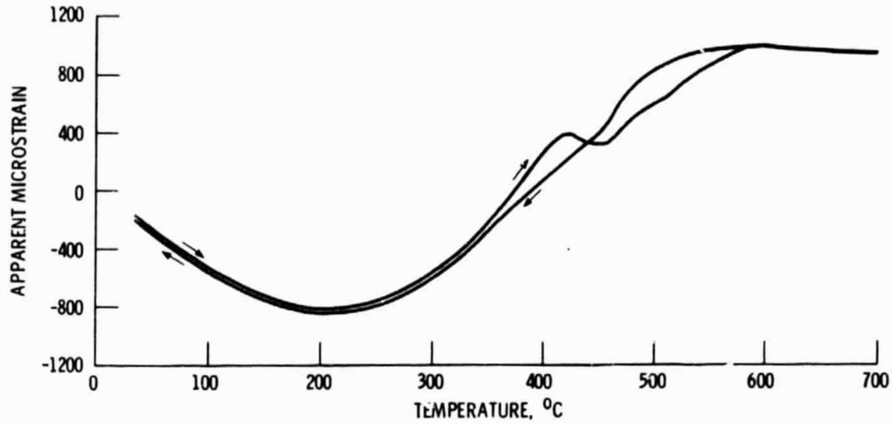

Figure 5. - Apparent strain versus temperature.

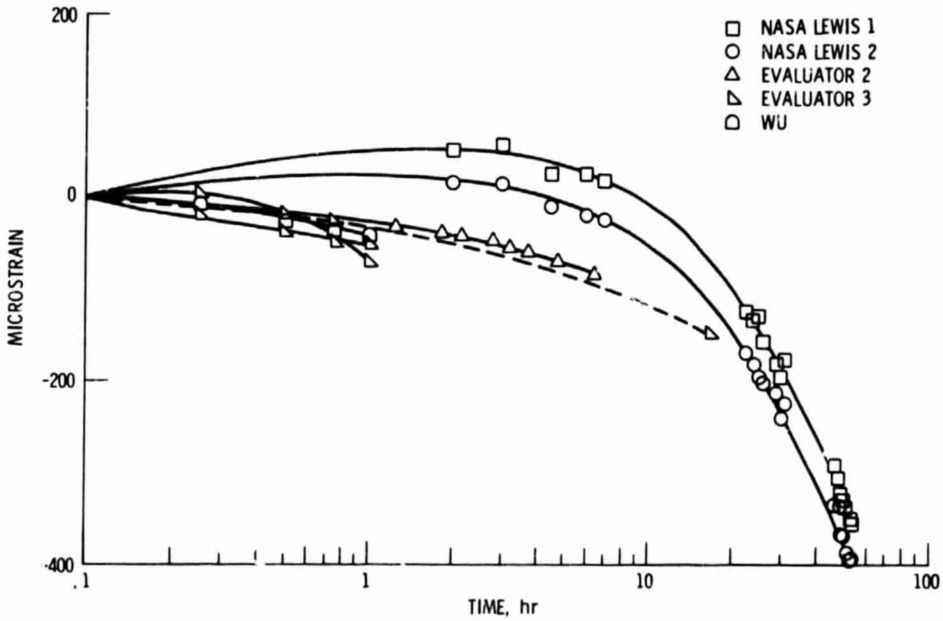

Figure 6. - Microstrain versus time. Drift test at 950 K; gauge factor, 2.(.

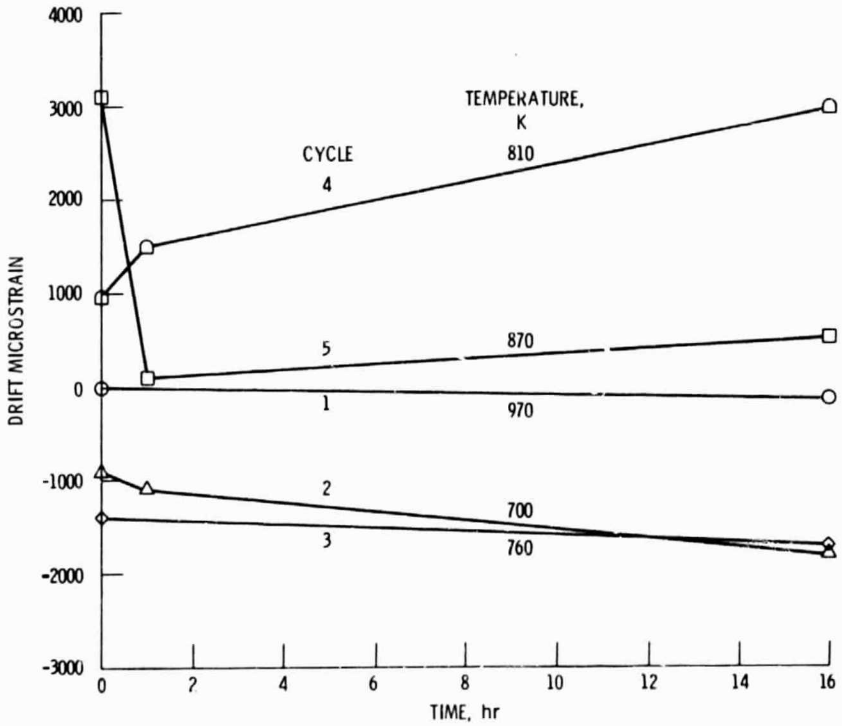

Figure 7. - Drift versus time at five temperature levels.