Experimental Characterization of Strain Gauges for High-Temperature Applications

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Abstract: The article deals with a characterization of properties and behaviour of resistive strain gauges for high temperature measurement up to 1000 °C. Vishay ZC-series strain gauges are some of a few commercionally available products, with advantage of favourable date of delivery. On the other hand, their standard high temperature material of the grid causes a high apparent strain effect for single grid gauges. That is why strain gauges with a thermal compensation were in our interest. The object of other testing was the value of gauge factor depending on temperature.

Keywords: high-temperature; strain gauge; gauge factor; apparent strain.

1 Introduction

Experimenters should have good cognizance of their equipment and used sensors. In the case of a standard and well-known measurement, one can rely on datasheets of producers and common practice. However, there are non-standard, specialized or rarely used techniques of measurement which should be verified and a primary calibration should be done. As an example, resistive strain gauge measurements can be shown. There is the common practice with foil strain gauges for low-temperature measurement, which are installed by recommended procedure, and all characteristics (as the gauge factor, coefficient of transverse sensitivity and coefficient of thermal expansion) are given by the gauge producer. Special strain gauges for high-temperature measurement have their characteristics influenced by both harsh measurement condition itself and means of sensor installation. A brief introduction was given in [1]. The strain gauge can be mounted both using various types of ceramic cement and using thermal spray alumina coats (ROKIDE® technology). Each of the connective materials has its specific coefficient of thermal expansion and an establishment of influence on the apparent strain effect should be performed. Even if a dynamic measurement is estimated only, the knowledge of the apparent strain curve is needed for correct setting of the voltage range of the measuring chain to prevent from cutting off the signal.

Classic means of thermal influence compensation, as well-known for the common foil strain gauges, don´t exist for those designated for operation in very broad ranges of temperature (up to 1000 °C). However, there are special patterns of high-temperature strain gauges which consist of two grids – in the case of their half bridge wiring they should compensate the thermal influence and be able to measure strain in good sensitivity nevertheless.

The gage factor (GF) depends on temperature and also on the means of installation probably. Although some reference data are available, it would be optimal to attest the sensitivity of the sensor for given installation and wiring. A test device based on four-point bending is usually used for professional calibrations, but its development and debugging is not easy [2, 3]. That is why our testing laboratory has not thought about similar activities. Nevertheless, an experiment was designed for obtaining of reference results. The testing was performed with using of a special thermal chamber in the form of tensile loading of a superalloy specimen equipped with tested strain gauges. The strain was measured with using of an extensometer simultaneously and voltage readings coming from strain gauge signals were compared to this reference strain.

2 Experiments – realization and results

The tested strain gauges were mounted on “dog-bone” shape specimens of Haynes 285 superalloy, which chemical composition is given in Tab. 1. The thickness of the specimens was 1 mm only, therefore strain gauge installation with using of the Rokide flame spray technology had to be performed especially carefully and a special fixture had to be made to prevent from deformation.

Tab. 1: Nominal chemical composition (in per cent) of nickel based Haynes 282 superalloy

Cr	Co	Ti	Al	Fe	Mo	Mn	Ni
20	10	2.1	1.5	max 1.5	8.5	max 0.3	as balance (cca 57)

The specimens were always equipped with K-type thermocouples for purpose of the measurement of the actual temperature near strain gauge position. Signals both from the strain gauges processed by the ESAM Traveller 2 measuring device and from the thermocouple were led to the PC equipped with the PCI-6052E DAQ card (by National Instruments) and software applications built in-house on the LabVIEW platform. These analog signals were sampled at frequency of 1 kHz and stored on the hard-disk. The off-line evaluation has provided data with the period of 1 second (mean values and standard deviations).

2.1 Apparent strain of the strain gauge with thermal compensation

The Vishay ZC-NC-G1264-120 strain gauges with two grids (overall dimensions: 2.54 x 4.55 mm) were installed with using of the PBX cement only (Fig. 1). It is supposed their using for an accurate static measurement up to 500 °C, although the tests of the apparent strain behaviour were performed in the OMEGA LUX LMF – A550 type furnace for temperature up to 750 °C. Both grids have their separate ribbon leads and their wiring is in the form of the half-bridge circuit, but the compensation grid is inactive from the point of view of mechanical loading. That is why the resulting behaviour in the mode of quarter-brigde wiring is expected, including calibration for gauge factor of 2.80.

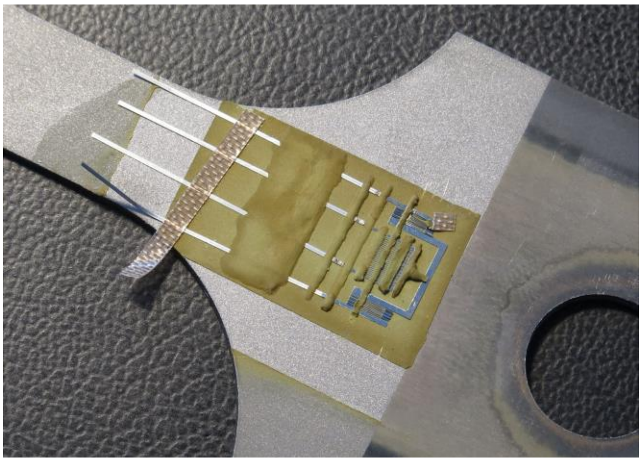

Fig. 1: Vishay ZC-NC-G1264-120 type strain gauge during instalation on the specimen.

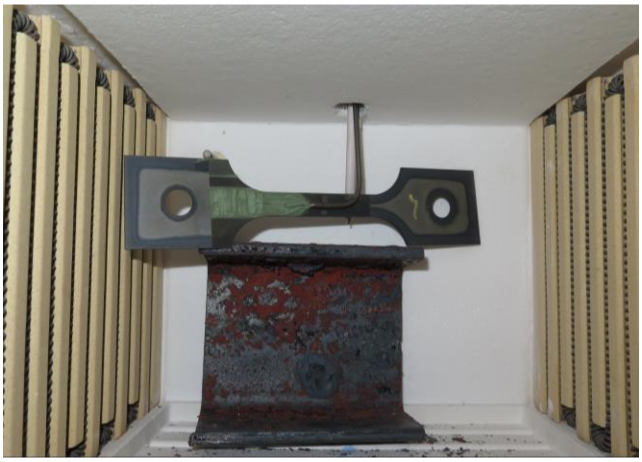

Fig. 2: Specimen with the installed strain gauge in the OMEGA furnace.

Two strain gauges have been tested. An example of established “apparent strain vs. temperature” curves is in Fig. 3. It is evident that curves for following temperature loading cycles slightly change their positions. For given instance of a real measurement (i.e. the expected temperature range and the number of measuring runs) it should be desirable to perform a goal-directed verification. However in comparison with a typical apparent strain curve for the “single” strain gauge given in Fig. 4, it is clearly shown the suppression of the apparent strain effect and the advantage of more accurate measurement.

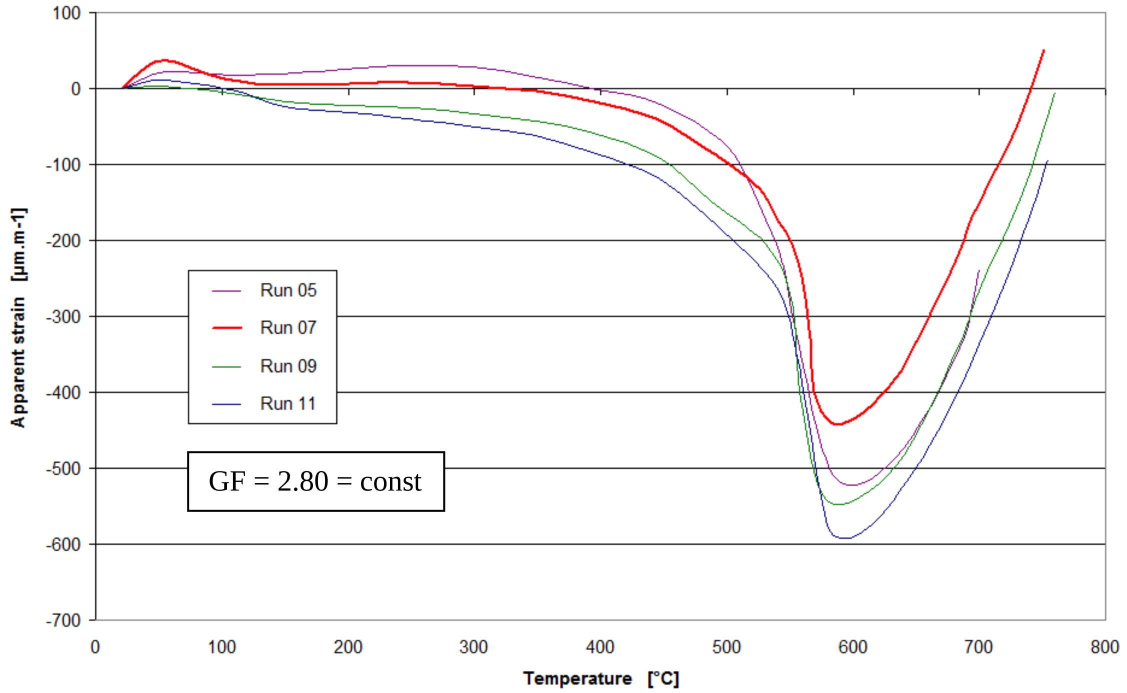

Fig. 3: Apparent strain curves for the Vishay ZC-NC-G1264-120 strain gauge, installed using of PBX cement.

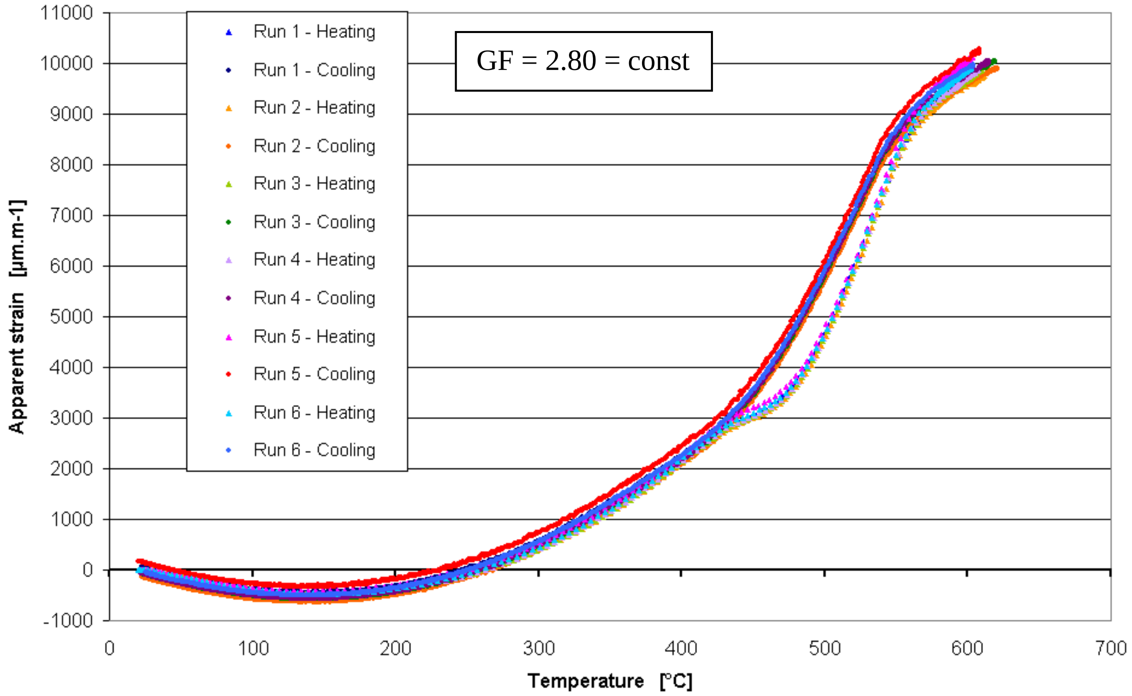

Fig. 4: Apparent strain curves for the Vishay ZC-NC-G1262-120 strain gauge, installed using of PBX cement.

2.2 Gauge factor dependence on temperature

The single grid Vishay ZC-NC-G1262-120 type strain gauges were always mounted in the total number of two pieces on opposite sides of the specimen – the installation was accomplished both with the PBX ceramic cement and with the ROKIDE flame spray coats. Three-wire configuration of the quarter bridge strain gauge circuit was always used; for wiring in the interior and near exterior of the thermal chamber a special thermal insulated wire system of AerOpak 120-3M-C(AQ)/J type by Okazaki company was used. The specimens were loaded in tensile using the INSTRON 1185 machine equipped with water cooled suspensions and the ATS 3210 thermal chamber (for heating up to 1100 °C). The Epsilon model 3548-025M extensometer is also a special device intended for high-temperature measurement. The measuring chain is the same as is described above, moreover the signals from the loading machine (i.e. tensile force, displacement of the crossbeam and strain measured by the extensometer) was adopted to our DAQ system.

In all, nine specimens in two seasons were loaded in the tensile manner within the temperature range of RT – 900 °C. The temperature in the chamber was increased by steps of 200 °C (later in the range of high temperature by steps of 100 °C for better data collection) and after temperature stabilization the tensile loading was always performed three-times up to 2100 $\mu m.m^{-1}$ indicated by the extensometer. Attempts for the temperature of 1000 °C were discarded by the reason of intensive yielding of the specimen material (nonlinear behaviour).

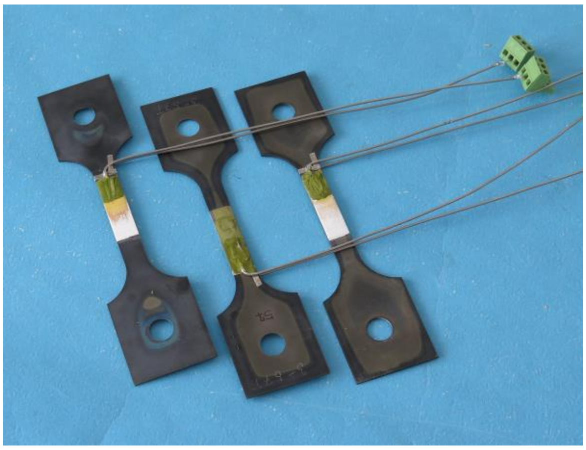

Fig. 5: Specimens with installed strain gauges and the AerOpak thermal insulated cable.

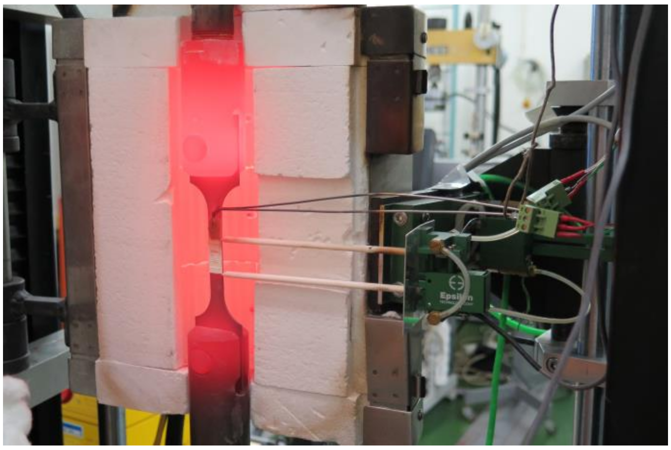

Fig. 6: Tensile loading test of the specimen – shortly after ending and opening the thermal chamber.

The basic presumption for this principle of experiment was that the extensometer as an etalon measured accurately, without slippage. That is why each tensile testing run was checked during evaluation (an example in Fig. 8) and some runs with evident irregularities were discarded.

Values of the strain gauge voltage signals were then plotted in graphs in dependence on the strain given by the extensometer and gradients of these lines were extablished. Their comparisons with gradients for the room temperature condition (i.e. for the basic gauge factor) have given corresponding changes of the gauge factor. It should be noted that the select mean of the experiment is rather difficult for correct evaluation, especially concerning to criterions for selection of linear parts of the loading curves and establishment of their gradients. Only a few specimens, strain gauges respectively, have given excellent results for each temperature conditions (Fig. 9).

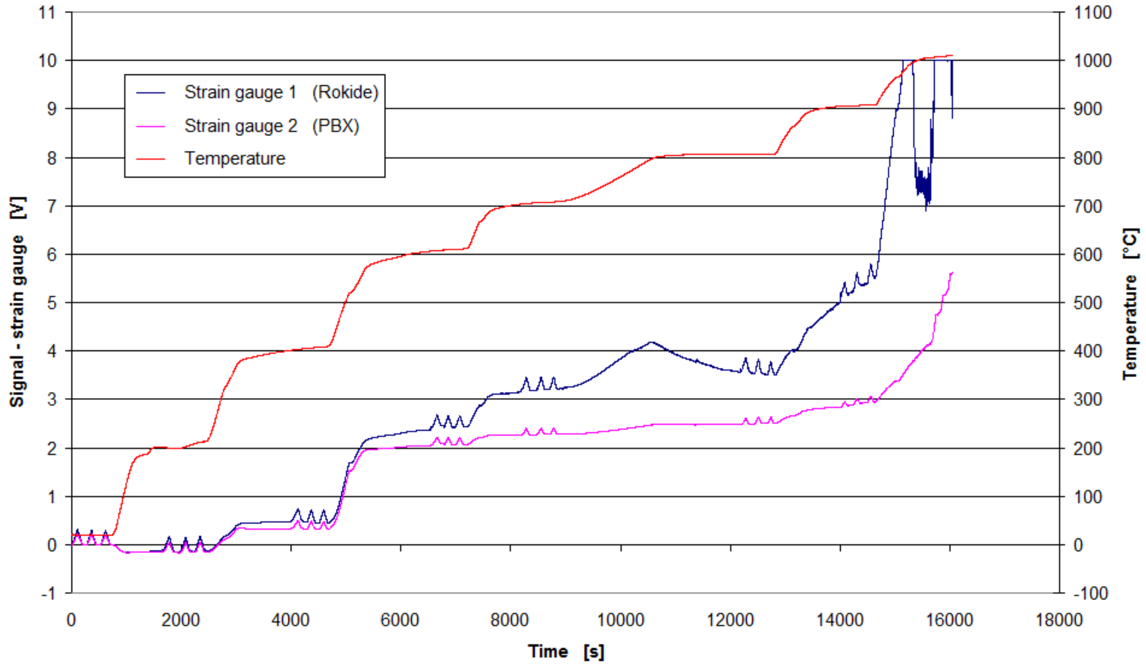

Fig. 7: Test of the specimen no. 3 – time record of the strain gauge voltage signals together with temperature. The huge effect of apparent strain in comparison with tensile loading up to 2100 µm.m^{-1} is evident.

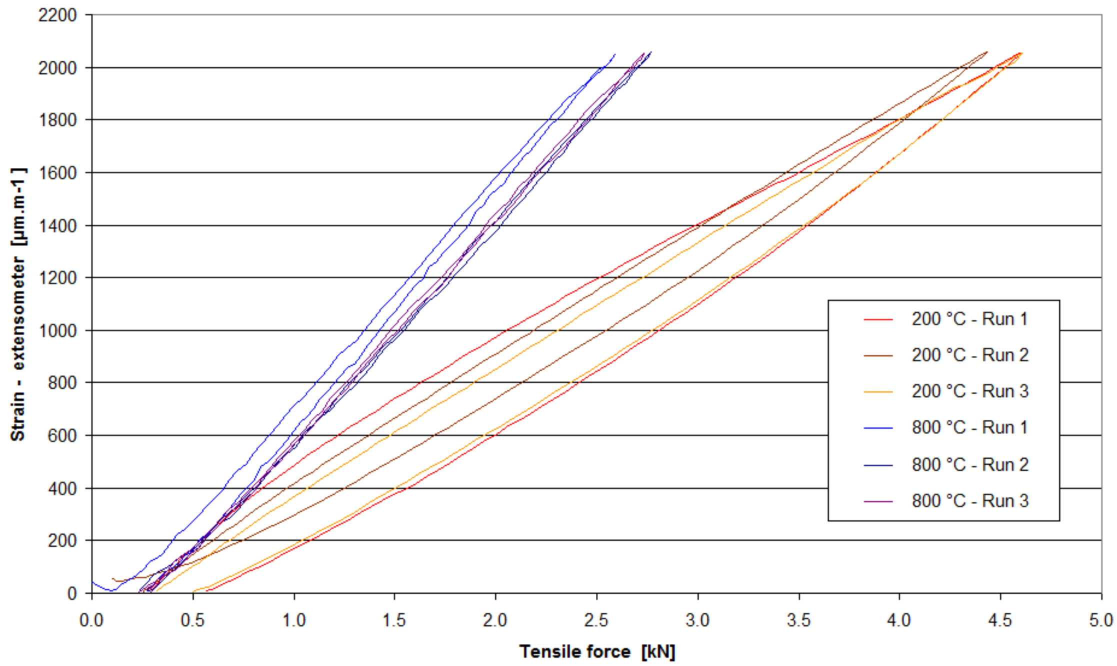

Fig. 8: Examples of tensile loading curves measured during the test of the specimen no. 3 – comparison for condition of 200 °C and 800 °C also documents the change of Haynes 282 superalloy stiffness under high-temperature condition.

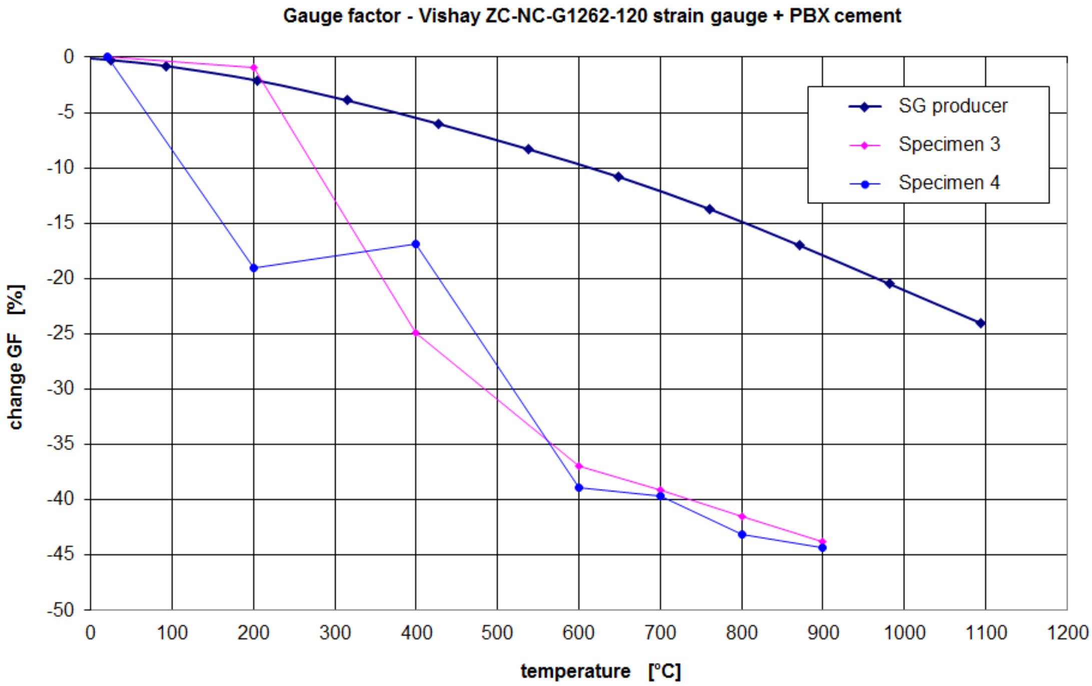

Fig. 9: Comparison of some measured results with producer´s data.

3 Conclusion

The apparent strain of the G1264 strain gauge type with the compensating grid does not exceed the value of 300 $\mu m.m^{-1}$ in all range of temperature up to 550 °C and the curves for correction of a real measurement were obtained. The temperature range above 550 °C is characterized by sharp change of apparent strain and that is why the error of correction can be higher. The results of tensile loading for the establishment of the gauge factor for G1262 tstrain gauge type were rather complicated with appreciable variability, but the most plausible results show a significant swing from gauge producer´s data. Therefore this preliminary experiment points out that more effort should be expended in this field.

Acknowledgement

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