

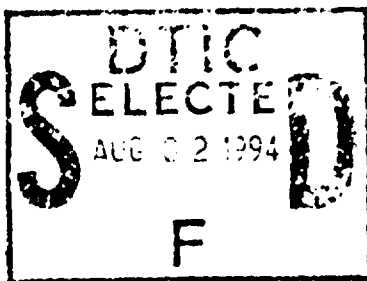
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EFFECTS OF JUNCTION MANUFACTURE ON
THERMOCOUPLE EMF GENERATION

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Effects of Junction Manufacture on Thermocouple EMF Generation

By E. A. Farber and M. R. Glickstein

Thermocouples (copper-constantan in this case) with junctions manufactured by different methods of soldering, brazing, and welding were bound in sets of eight and heated in a furnace with the junctions all maintained at the same temperature. Even though they were all at the same temperature a difference was noted in the emf generated by the various junctions, a fact which does not seem to have been covered in the literature. The greatest difference corresponded to a temperature difference of about 2 deg F. The thermocouples were first tested at constant temperature over a period of 600 hr, in order to determine any aging effects, and then with the temperature varying from 95 to 585 F. Con-

sidering the temperature indicated by one junction as an arbitrary reference, the indicated temperature differences between the reference junction and the other junctions were graphed against the junction age in the tests where the temperature was constant, and were graphed against temperature in the case where the temperature was varied. All the thermocouples, carefully manufactured by the same method, indicated the same temperature, which was, however, different from that indicated by thermocouples manufactured by a different method. The variations changed somewhat with age and temperature level, but the greatest deviation remained about 2 deg F over the range of 95 to 585 F.

Thermocouples are in wide use today as temperature - measuring devices and are used in a multitude of applications in which their temperature indications are relied upon for a high degree of accuracy with no discrimination as to the method of junction manufacture, which may be welding, brazing, soldering, or the like. Though the literature on the subject of thermocouples is extensive, there does not seem to have been any previous investigation into the effects of thermocouple junction manufacture on temperature indications. On the contrary, the literature either ignores the matter completely or gives the impression that the method of junction makes no difference. For instance, Mark's Handbook(1)¹ states that the only considerations in junction manufacture are good electrical contact and mechanical strength. In another work, Weber(2) lists the criteria for thermocouples but makes no mention of junction manufacture.

This investigation, contrary to statements found in the literature indicates that results obtained in calibrating a thermocouple with one type of junction cannot be used for a thermocouple

EXPERIMENTAL ARRANGEMENTS

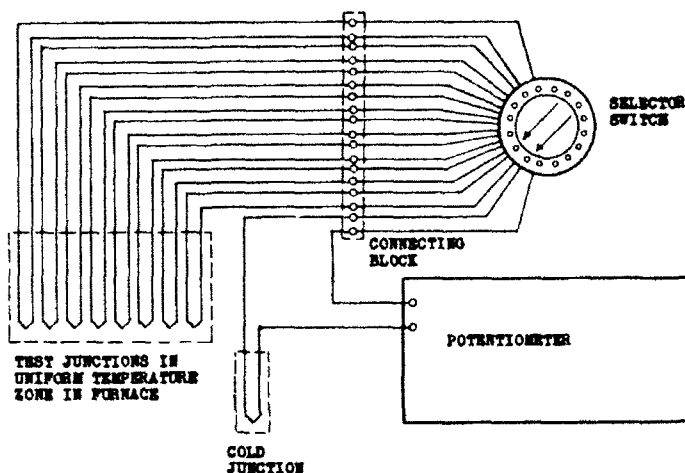
The equipment used in this investigation consisted of a thermocouple-calibration furnace with copper equalizing block and control circuits, a portable precision potentiometer, a thermocouple-selector switch with terminal blocks (all manufactured by Leeds and Northrup), a clock with a sweep-second hand, and the thermocouples to be tested.

The thermocouples were connected to the selector switch in such a way that they could be coupled into the measuring circuit in sequence. The same cold junction was used for all eight thermocouples. All connections of the thermocouples and switch leads were made on a connection block which was then mounted in a closed box and insulated with glass wool. The circuit diagram and arrangement of the apparatus used in this investigation are shown in Figs. 1(a and b).

TEST THERMOCOUPLES

All the thermocouples referred to here were with a different type of junction, even though it has come off the same spool of wire.

¹ Numbers in parentheses refer to the Bibliography at the end of the paper.



(a) Wiring diagram of thermocouple test circuit



(b) Writer with equipment in operation

Fig.1 Arrangement of apparatus

made of copper-constantan wire off the same spool, Type GG-20-DT, Gage 20 B&S, with single and duplex fiberglass insulation, which was manufactured by the Thermo Electric Company of New Jersey. The methods used in manufacturing the junctions were as follows:

- 1 Welding in a neutral oxyacetylene flame with a borax flux.
 - 2 Silver soldering with an 1160 F solder and flux using an oxyacetylene flame for heat.
 - 3 Spot-welding on an Electronic Welder No. 401-LE, made by Eisler Engineering Company of New Jersey, with the transformer on the second tap and the timer on six cycles.
 - 4 Welding by inserting the junction into an arc approximately 1/2-in. long between two 1/4-in. carbon electrodes in series with a 7-ohm resistor. A 110-volt a-c supply was used for power. No flux was used, and the junction was withdrawn from the arc and cooled in air as soon as fusion had occurred.
 - 5 Welding by drawing an arc between the junction and a carbon electrode with the same supply current as in item 4. No flux was used and the junction was cooled in air.
 - 6 Welding by drawing an arc between the junction and a mercury pool under a 2-in. layer of mineral oil. The same supply circuit was used as in item 4, and the junction was cooled under oil after fusion.
 - 7 Brazing with 1600 F yellow bronze, using an oxyacetylene flame for heat and a borax flux.
 - 8 Twisting a junction about 1/8 in. long.
- A set of prepared junctions is shown in Fig. 2(a). Each of the eight types of junctions was made on a 5-ft length of wire, and the eight

thermocouples were then bound together in a bundle, as shown in Fig. 2(b), for insertion into the equalizing block in the furnace. The thermocouple bundle was inserted to a depth of 17 in. into the equalizing block, with all the junctions lying in the same horizontal plane. A spot-welded cold junction was used with all the thermocouples in this investigation.

EXPERIMENTAL ACCURACY

After the apparatus was assembled it seemed that errors might be caused by temperature gradients in the connecting blocks, temperature changes in the cold junction, and effects from the selector switch.

In order to overcome the problem of temperature gradients in the furnace, the junctions were bound together and inserted into the center hole of the equalizing block to a depth of 17 in. All junctions were then in a horizontal plane. All the tests were conducted between the hours of 8:00 and 11:00 in the evening in order to eliminate variations in furnace temperature due to fluctuating line voltage. By late evening the temperature distribution of the furnace had become constant and the small heat flow up the equalizing block had become steady. The horizontal plane of the thermocouple junctions coincided with an isotherm and all of the junctions were then at the same temperature.

Temperature gradients in the connecting blocks could only be caused by air moving over the copper strips on the block. Gradients of such origin were eliminated when the blocks were packed in glass wool.

The cold junction was inserted into a thermos



1 2 3 4 5 6 7 8
Fig.2(a) Thermocouples prepared junctions

bottle which was kept filled with a mixture of cracked ice and water. The water-ice mixture was stirred periodically to prevent changes in the temperature of the cold junction.

In order to check the effect of switch on effects on the measurements, experiments were conducted with the switch in, and then with the switch out of the circuit. The results were the same for all cases, and the measurements were relative rather than absolute. Therefore, the small differences, having to do with the switch, could be ignored. As another check, one thermocouple was connected in common to all the lead wires from the switch, to give a common input. No difference was found in the results as the switch was rotated through its different positions, and therefore the switch was considered to have no effect on the relative temperature measurements.

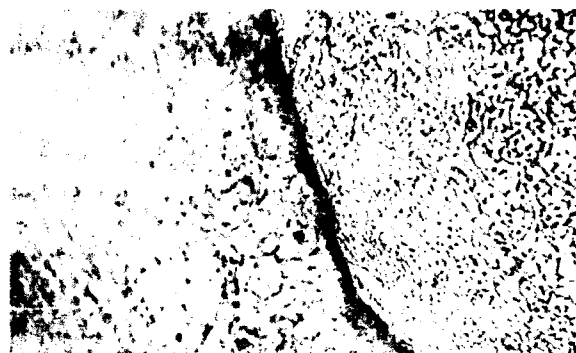
TEST PROCEDURE

The furnace was adjusted by means of the control rheostat to the desired temperature and allowed to come to equilibrium, which usually took about 2 or 3 days. For the entire test the furnace remained at 900° F during the whole time, but for the remainder of the investigations conducted for about 4 days at each of four different temperatures.

The cold junction was inserted into the ice bath and packed with ice, the potentiometer



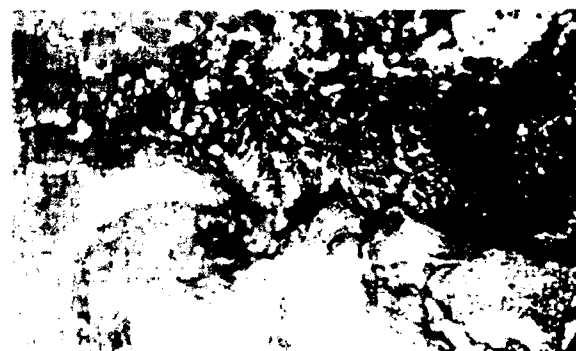
Fig.2(b) Thermocouples being inserted in furnace



(a) Acetylene welded



(b) Silver soldered



(c) Double carbon arc welded

Fig.2 Photomicrographs of thermocouple junctions, X 50

standardized, and the sweep second hand on the clock was started.

Starting with the first junction and proceeding in sequence at 30-sec intervals, the emf's of the thermocouples were measured and recorded. The sequential measurements were continued for

was made, as long as the entire junction was maintained at the temperature to be measured. However, several findings of previous thermocouples studies have shown facts contrary to the aforementioned suggestion. For instance, it has been found that base-metal thermocouples,

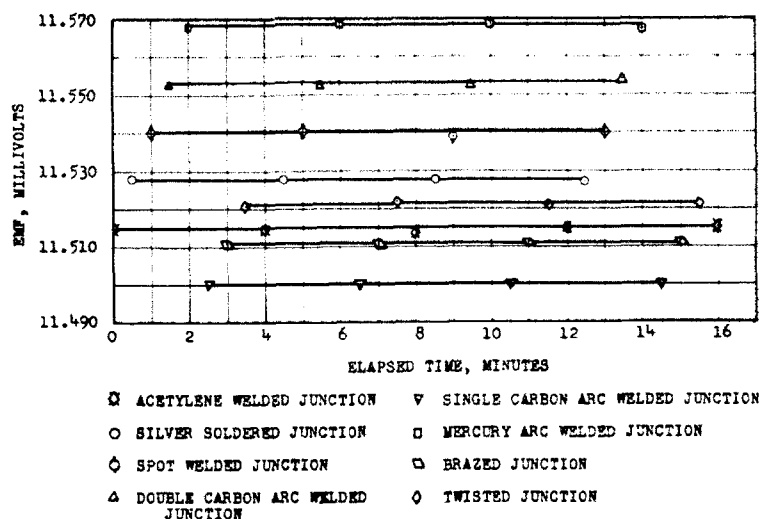


Fig.4 Curves of elapsed time versus emf generated

16 min, which gave four measurements for each junction and five for the first.

At the completion of the tests, the thermocouples were removed from the furnace and the junctions were cut off for inspection. The junctions were mounted in lucite, ground, and then polished on the cross section, and etched with an etchant consisting of a mixture of potassium dichromate, sulphuric acid, and sodium chloride. After etching, photo-micrographs were made of each junction. Samples are shown in Figs. 3(a), 3(b), and 3(c).

Two more sets of thermocouples were prepared exactly as the first set, and the test results of each compared with those obtained from the first set.

THEORETICAL EVALUATION OF THERMOCOUPLE CONSTRUCTION

One of the thermoelectric laws, the law of intermediate metals, states that if a metal C is inserted between metals A and B in a thermocouple junction, and if the junctions AC and CB, as well as the whole length of C, are at the same temperature, the emf of the circuit will be unaffected and will act the same as the original junction AB(3). This law would seem to suggest that the thermocouple would indicate the same temperature no matter what materials were inserted in the hot junction or how the junction

when heated in air, oxidize and form inhomogeneities which affect the emf-temperature characteristics of the junction (4). Also, it has been noticed that when copper-constantan junctions are heat-treated above about 400 F they have a tendency to indicate temperatures higher than actually exist (5). It has furthermore been found that the sensitivity of copper-constantan thermocouples changes when the junctions are annealed in air and when they are sandpapered (6). These findings show that the physical treatment and condition of the junction has a definite effect on the emf-temperature characteristics of a junction.

Since it should now be recognized from the foregoing that the emf-temperature characteristics of a junction will be changed if the condition of the junction is changed, it is to be expected that two junctions made from the same materials and maintained at the same temperature should indicate differently if their physical conditions are different. Metallurgically, a difference in condition of the junctions could be caused by any of the following:

- Differences in grain size or structure.
- Presence of other metals in solution.
- Inclusions of gases or solids in the matrix.
- Heterogeneous mixing of the two metals.
- Nonintimacy of the thermocouple compo-

nents allowing oxidation to occur within the junction.

(f) Substitution or lattice-vacancy diffusion in the lattice structure of the junction.

These various effects could occur during junction manufacture for several reasons, such as:

time of the test. From the emf-temperature conversion tables (National Bureau of Standards Circular 561), the emf differences were converted to temperature differences, and the temperature differences obtained from the aging experiments were plotted against the age in hours at the time of the experiment (Fig. 5). The

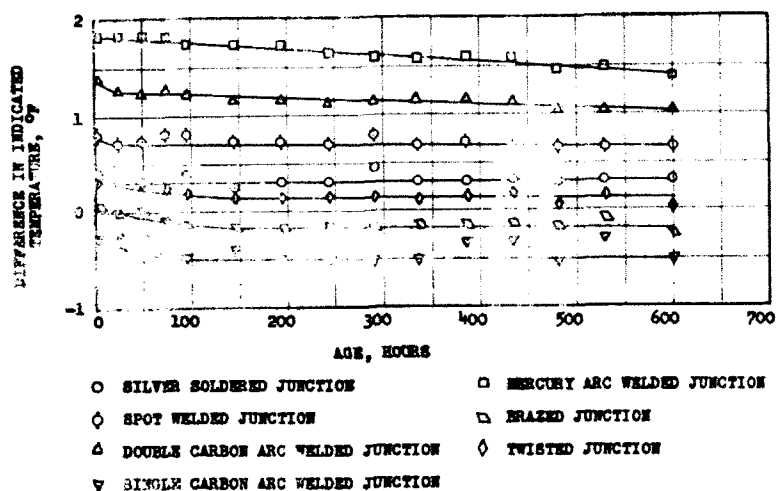


Fig. 5 Curves of indicated temperature difference versus age, temperature 460°F

- 1 Nature and stability of welding flame.
- 2 Metallic or nonmetallic vapors carried in the flame.
- 3 Lack or presence of a protective atmosphere around the junction.
- 4 Temperature attained by the junction during manufacture and subsequent heat-treatment.

From an analysis of the nature of the methods of manufacture used in this investigation and the physical properties of the thermocouple materials, it would seem that the physical condition of each junction should be different from the condition of the others. From this difference in condition, therefore, a difference in indicated temperature should be expected.

EXPERIMENTAL RESULTS

The emf's measured during the experiments were plotted against elapsed time in minutes, from the start of the experiment, giving time-emf curves for each junction (Fig. 4). These curves are horizontal, indicating that the furnace had reached equilibrium at the time the test was performed.

Using the time-emf curves and arbitrarily considering one junction as reference, the difference in emf between it and each of the other junctions was determined for the same

temperature differences obtained from the variable temperature experiments were plotted against the temperature at which the experiments were conducted.

Looking at the results of the foregoing experiments, the following statements can be made:

Junction manufacture has a definite effect on the temperature indication of a thermocouple. Thermocouples with junctions made by different methods do not indicate the same temperature, even though subjected to the same temperature. The maximum difference in indicated temperatures for the methods of juncture investigated was about 2 deg F over the range 95 to 585 F (Fig. 6).

All junctions tested were affected to some degree by aging. The greatest aging effect was noted for the mercury arc-welded junction, amounting to -6×10^{-4} degF/hr with respect to the reference junction.

The differences in indicated temperature of the junctions changed with the temperature level. However, the maximum indicated temperature difference remained about the same over the temperature range studied.

Photomicrographs of cross sections of the junctions reveal that the physical conditions of junctions made by different methods are quite different.

All three sets of junctions, manufactured

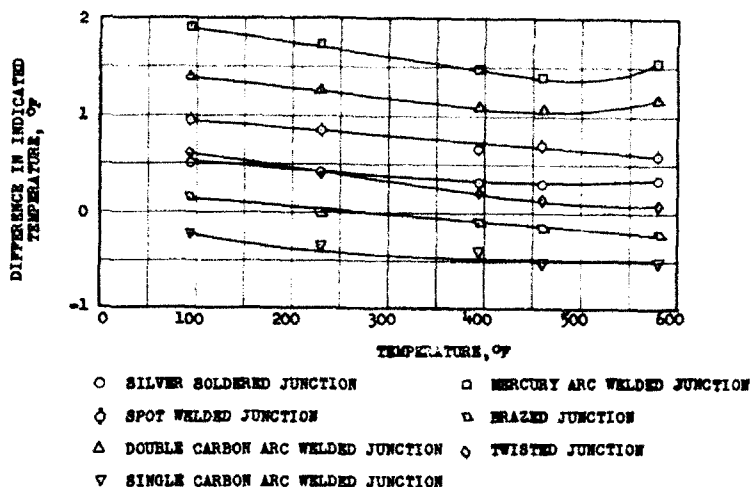


Fig.6 Curves of indicated temperature difference versus temperature

by the same methods, produced the same temperature-time curves.

CONCLUSIONS

From consideration of the theoretical analysis and a close study of the experimental results covered by this investigation, the following conclusions seem to be in order:

(a) The investigation described, as well as other data collected by the authors over a period of years, shows the definite effect of thermocouple-junction manufacture upon emf generation (a fact which seems to have been neglected in the literature).

(b) The temperatures indicated by thermocouples carefully made by the same method are the same.

(c) The difference in indicated temperature with the thermocouples tested here can be as much as 2 deg F as a result of the junction manufacturing method alone.

(d) A photomicrographic study of the junctions indicates a considerable structural difference produced by the various methods of junction.

(e) Junctions manufactured by different methods exhibit different aging characteristics.

(f) Junctions manufactured by different methods exhibit different temperature coefficients.

(g) From this as well as other studies it seems that a thermocouple should be calibrated

immediately before use over the whole range of temperature measurement.

(h) From the microstructure-emf correlation it is evident that anything which will change the microstructure will also change the emf characteristics of the thermocouple. Examples are annealing, cold-working, diffusion, oxidation, and so on.

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