THE THERMAL EXPANSION OF FIVE TITANIUM CARBIDE CERMETS
FROM 68 TO 1800F

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By

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ABSTRACT

This paper presents measurements of the thermal expansion of five titanium carbide type cermets from 68 to 1800F. These cermets are designated by Kennametal, Inc., as K 138A, K 150A, K 151A, K 152B and K 162B. They contain from 64 to 80 weight percent titanium carbide, 10 to 30 weight percent metal binder and 6 to 10 weight percent other carbides. The metal binders are cobalt, nickel, or nickel and molybdenum.

An attempt was made to calculate the thermal expansion of each type cermet from the thermal expansions of the constituents. The expansion of the mixture was computed by weighting the expansions of the constituents according to (1) weight percent of the constituents, (2) volume percent of the constituents and (3) according to a value developed for mixtures by P. S. Turner.[1] It was found that expansions computed according to volume percent and by Turner's method agreed with measured values within ± 5 percent. The values calculated by weight percent were from 5 to 11 percent higher than the observed values.

The thermal expansions of these cermets are compared with the expansions of a group of metals and alloys.

[1]P. S. Turner, "Thermal-Expansion Stresses in Reinforced Plastics," J. Research NBS, Vol. 37, July-December 1946, R. P. 1745.

[*]Materials Laboratory-CANEL, Pratt & Whitney Aircraft, Division of United Aircraft Corporation, Middletown, Connecticut

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Introduction

The measurement of the thermal expansion of these titanium carbide cermets was undertaken to evaluate materials for valves and bearings at elevated temperatures. An attempt was made to find a method for calculating the thermal expansion of such mixtures.

Specimens

The materials studied were Kennametal, Inc. catalogue mixtures K 138A, K 150A, K 151A, K 152B and K 162B. No chemical analysis of these cermets was made at Pratt & Whitney Aircraft. The nominal compositions shown in Table I are from Kennametal, Inc. advertising literature.

The dilatometer specimens were purchased from Kennametal, Inc. They were approximately 0.158 in. (4 mm) in diameter and 1.97 in. (50 mm) long. The measured bulk density of each material is shown in Table I, together with nominal and calculated density values.

Method

A. Tests

The bulk densities of these specimens were obtained by dividing the weight by the volume. The specimens were weighed on an analytical balance to the nearest 0.0001 g. The length and diameter were measured with micrometer calipers to the nearest 0.0001 in.

The thermal expansion measurements were made with the aid of the Leitz dilatometer shown in Figures 1 and 2. In this dilatometer the specimen expansion is magnified about 200 times and recorded on a photographic film by a beam of light. A change in length of 0.1 mm may be estimated

on the photographic film. This represents a change in specimen length
of 0.0005 mm (0.00002 in.). For a specimen 50 mm (1.97 in.) long this
represents a change in length of 10^{-5} mm/mm or in./in. By repeating
measurements of a standard material such as copper the reproducibility
of the instrument, run at the heating rate we use, has been established
as less than $\pm$ 3 percent.

The magnification factor of the instrument is redetermined once a year.
It is determined by measuring the distance between dots made on the
photographic film for each 0.2 mm change in specimen length. The magni-
fication factor (196.2) has not changed more than 0.3 percent in the
last five years.

For recording the expansion results a film was selected which shrinks
less than 0.5 percent during processing. The films are stored, de-
veloped and measured at the same constant temperature and humidity at
which they are exposed. This treatment assured a negligible change in
dimensions of the film.

Heating of the specimen was accomplished by a program controlled elec-
tric resistance furnace. At the lower temperatures heating was supplied
at the rate of 3 degrees F per minute and was gradually increased to 5
degrees F per minute. Heating from room temperature to 1800F was accom-
plished in 6 1/2 hours. When a constant heating rate of 4 deg/min was
used the results showed a lag in specimen expansion at temperatures below
800F. When the heating rate from room temperature to 800F was reduced
this lag was avoided.

These specimens were heated in a vacuum at a pressure of from 0.1 to 0.4 microns. This vacuum was probably partially responsible for the poor heat transfer to the specimen at low temperatures.

The temperature of the specimen was assumed to be equal to the temperature measured with a chromel-alumel thermocouple, whose hot-junction was located in the groove in a standard chronin specimen. The test specimen and standard specimen were adjacent and symmetrically placed in the test zone. (See Figure 2). Temperatures were read on a Minneapolis Honeywell recorder, graduated in 10 deg F intervals. The test specimen and a standard specimen were placed horizontally in quartz troughs. The change in length of each is transmitted by a quartz rod to the head of the instrument. As these specimens expand, the quartz rods change the angle of the prism from which the beam of light is reflected to the photographic film. Thus, the change in specimen length causes a line to be drawn across the photographic film. The test specimen displaces the light vertically while the standard displaces it horizontally. If the test specimen and the standard specimen are of the same material the trace on the film would be a straight line at an angle of 45 degrees. During heating, the light is turned off at 100 degree F intervals. When analyzing the film, the vertical displacement of the light from the starting point is read at the breaks in the line. An expansion measurement is thus obtained for each 100 deg F. These readings are in millimeters on the film and must be divided by the magnification factor and the specimen length to bring the results to units of inches per inch of specimen length. A correction was made for the expansion of the 2 inch length of quartz trough under the specimen. No correction is necessary for the remaining length of trough and push rod since their expansions compensate for one another.

A parabola, $y = A + BT + CT^2$ was fitted to the temperature-expansion data by the least squares method. For each material the curve fitted the experimental data within ± 3 percent for all temperatures above 800F for 2 or more runs. The mean coefficient, α, from 68F to T is $\frac{y}{T-68}$. The instantaneous coefficient of expansion is the slope of the expansion-temperature curve, i.e., $\frac{dy}{dT} = B + 2CT$.

B. Calculations

An attempt was made to find a method for calculating the thermal expansion of these cermets from the known expansions of the constituents. The method presented by Turner (Ref 1) seemed the best approach for our material. He considers the coefficient of expansion of a mechanical mixture as the result of the stresses set up by the difference in coefficient of expansion of the constituents. The resulting coefficient of expansion would be:

$$\alpha_r = \frac{\dfrac{\alpha_1 P_1 K_1}{d_1} + \dfrac{\alpha_2 P_2 K_2}{d_2} + \cdots\cdots\cdots + \dfrac{\alpha_n P_n K_n}{d_n}}{\dfrac{P_1 K_1}{d_1} + \dfrac{P_2 K_2}{d_2} + \cdots\cdots\cdots + \dfrac{P_n K_n}{d_n}}$$

in which α = mean coefficient of thermal expansion

  P = weight fraction of constituent

  K = bulk modulus

  d = density

Subscripts i (1 to n) and r refer respectively to the ith component and to the resultant mixture. It can be seen that if the K's in the above formulas

are nearly equal, the calculated α will be proportional to the volume
fraction of the constituents. If the K/d ratios are nearly equal the re-
sulting α will be nearly proportional to the weight fractions of the
constituents. For these constituents the K's are about equal, with the
exception of molybdenum. The K/d ratio for TiC is about twice that of
nickel or cobalt.

In calculating the thermal expansions of these cermets, the mean coef-
ficients of thermal expansion of the constituents used are shown in the
curves of Figure 4. The values for the bulk modulus and density of nickel,
cobalt, molybdenum, columbium-tantalum-titanium mixed carbides and titanium
carbide used in our calculations are given in Table II. The thermal ex-
pansion of molybdenum was measured at Pratt & Whitney Aircraft-CANEL
(Ref 2). The expansion data for nickel were from NBS Circular 592 (Ref 3)
from room temperature to 1652F, and from WADC-TR-55-495 (Ref 4) from
1000F to 1800F. The thermal expansion data for cobalt were from measure-
ments by Fine and Ellis (Ref 5). The expansion data for the carbides were
from the data of Mauer and Bolz (Ref 6). These measurements were made by
the X-ray diffraction method on a single crystal. Expansion measurements
made on a specimen rather than a single crystal, would be more representative
of the material with which we are dealing. Values for the thermal expansion
of hot pressed titanium carbide reported in Ref 7 are higher than Mauer and
Bolz, while those reported in Ref 8 are lower.

Results

The thermal expansion curves to 1800F of these five titanium carbide cermets are shown in Figure 3. Measurements after test showed no permanent change in length. Their mean coefficients of expansion, together with that of their constituents are shown in Figure 4. The mean coefficients of thermal expansion of these cermets are compared with those for a group of metals and alloys in Figure 5. The instantaneous coefficient of expansion for these cermets is given in Figure 6. The measured coefficients of expansion of these cermets are compared with the coefficients calculated from the expansions of the constituents by three different methods, in Figure 7. The calculated values were obtained by weighting the expansions of the constituents according to (1) the weight percent, (2) the volume percent and (3) Turner's stress method. The constants for the least squares parabola obtained for the thermal expansion curve of each cermet are given in Table III.

Our thermal expansion data for these cermets is compared with data reported by others in Table IV. The compositions of the cermets reported in Refs 9 and 10 differ slightly from our cermets. The difference between their measured expansions and ours is in the direction to be expected from the difference in composition.

Discussion

The thermal expansions of five titanium carbide cermets were measured and an attempt made to find a method for computing their thermal expansions from the expansions of the constituents. The values calculated by weight percent were from 5 to 11 percent higher than the observed values. The method presented by Turner (Ref 1) and the method based upon volume percent were found to yield values which agreed with measured values within ± 5 percent. This is considered a very good approximation since values reported for various specimens of TiC by one observer (Ref 8) differ by ± 4 percent and values reported by other observers

differ more widely. The thermal expansion of hot pressed TiC bodies (Ref 7) showed a thermal expansion from room temperature to 1100F which was 2 percent higher than that measured by Mauer and Bolz (Ref 6). The thermal expansion of two hot pressed TiC bodies measured by Engberg and Zehms (Ref 8) showed expansions from RT to 1000C which were 9 to 11 percent below that of Mauer and Bolz. Using an expansion value for TiC 10 percent lower than that used in our calculations would lower the calculated Turner value approximately 6 to 8 percent. Using a value for α of TiC 4 percent lower than Mauer and Bolz would give calculated values for all these materials within ± 3 percent of the observed.

Knudsen, Moreland and Geller (Ref 9 and Ref 11) reported thermal expansion data for K 151A and K 138A. Their specimens apparently contained two percent less binder and 5 percent more mixed carbides than did ours. It is therefore to be expected that their expansions were less than ours. However, the difference in measured expansions was larger than was to be expected from this cause alone. The thermal expansions of K 162B and K 152B reported by Kennametal, Inc., (Ref 14, 15 and 16) are somewhat higher than our measurements. Expansions for 80 TiC, 20 Co measured by G. D. Deutsch, et al (Ref 12) are somewhat higher than our measured expansions for K 138A 20 Co, 10 Cb(TaTi)C, 70 TiC. A higher expansion is to be expected since the expansion of TiC is greater than Cb(TaTi)C.

Summary

The thermal expansions of four TiC cermets reported here have been compared with those reported in the literature and found to agree within a reasonable accuracy.

Turner's method for calculating thermal expansions of mixtures was found to yield results within the accuracy range of various observers of a single constituent such as TiC.

The expansions of these five cermets have been compared (Fig 5) with the expansions of various metals and alloys. This group of cermets could probably be used with the metals such as chromium and columbium without difficulties due to differences in expansion.

Acknowledgement

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15. Kennametal Inc., "Designing with Kennametal" (B-222).

16. Kennametal Inc., "Physical Property Data of K 160 Series Kentanium
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TABLE I

Chemical Composition and Density

| | Nominal Chemical Composition, weight % | | | | | Density, g/cc | | |
	Ni	Co	Mo	Cb(TaTi)C*	TiC	Measured	Calculated	Nominal (Kennametal)
K 150A	10			10	80	5.82	5.34	5.8
K 151A	20			10	70	5.64	5.61	5.8
K 138A		20		10	70	5.75	5.61	5.8
K 162B	25		5	6	64	6.07	5.84	6.0
K 152B	30			6	64	5.93	5.81	6.0

*Added as a solid solution of CbC, TaC and TiC, containing about 90 per cent CbC.

TABLE II

Values for the Bulk Modulus and Density Used in These Calculations

	Ni	Co	Mo	Cb(TaTi)C	TiC
K, 10^6 psi	26.3	25	43.6	24	25
d, g/cc	8.90	8.90	10.2	7.72	4.90
lb/cu in.	.322	.322	.369	.279	.177
K/d, 10^6 in.	81.7	77.6	118.2	86.0	141.2

TABLE III

Constants for the Thermal Expansion versus Temperature

Equation $Y = A + BT + CT^2$ *

	A	B	C
K 150A	$-.247 \times 10^{-3}$	3.62×10^{-6}	$.500 \times 10^{-9}$
K 151A	$-.282$	3.80	$.527$
K 138A	$-.275$	3.88	$.520$
K 162B	$-.294$	4.16	$.547$
K 152B	$-.302$	4.14	$.608$

*Y in inches/inch
T in degrees F

TABLE IV

THERMAL EXPANSION DATA FROM OTHER OBSERVERS

Thermal Expansion, inches/inch

Temperature deg F	K 151A					K 153A						Temperature deg F	K 162B	
	Ref 9				P&WA	Ref 9				P&WA			Ref 15	P&WA
	Specimen #1		Specimen #2			Specimen #1		Specimen #2						
	Heating	Cooling	Heating	Cooling	Heating	Heating	Cooling	Heating	Cooling	Heating				
79 to 572	.0019	.0013	.0018	–	.00206	.0019	.0018	.0018	.0017	.00211		RT to 1200	.00594	.00519
79 to 752	.0027	.0020	.0027	.0020	.00286	.0027	.0026	.0026	.0025	.00298		RT to 1600	.00807	.00776
79 to 932	.0035	.0027	.0035	.0029	.00371	.0036	.0035	.0035	.0034	.00379				
79 to 1112	.0043	.0035	.0044	.0037	.00459	.0044	.0044	.0043	.0042	.00468				
79 to 1292	.0051	.0044	.0053	.0046	.00550	.0053	.0053	.0052	.0051	.00560				
79 to 1472	.0059	.0053	.0062	.0055	.00645	.0061	.0062	.0061	.0060	.00656				
79 to 1652	.0068	.0061	.0071	.0063	.00743	.0071	.0073	.0070	.0070	.00755				
79 to 1832	.0077	.0070	.0080	.0073	.00844*	.0081	.0080	.0080	.0080	.00858*				
79 to 2201	.0093	.0091	.0096	.0093		.0101	.0100	.0102	.0100					

Nominal Composition

Co						18%					20%		
Ni				18%		20%								
Cb(Ta,Ti)C				15		10				15		10		
TiC				67		70				67		70		

Mean Coefficient of Thermal Expansion, microinch/inch-deg F

Temperature deg F	K 162B		K 152B			Temperature deg F			K 135A	
	Ref 15	P&WA	Ref 15	P&WA			Ref 10		P&WA	
200 to 1200	5.3	4.94	5.3	4.99		68 to 1100	4.6	4.9	4.46	
70 to 1200	4.95	4.85	5.0	4.90		Composition				
						Co	20%	30%	20%	
						TiC	80	70	70	
						Cb(Ta,Ti)C			10	

Figure 1

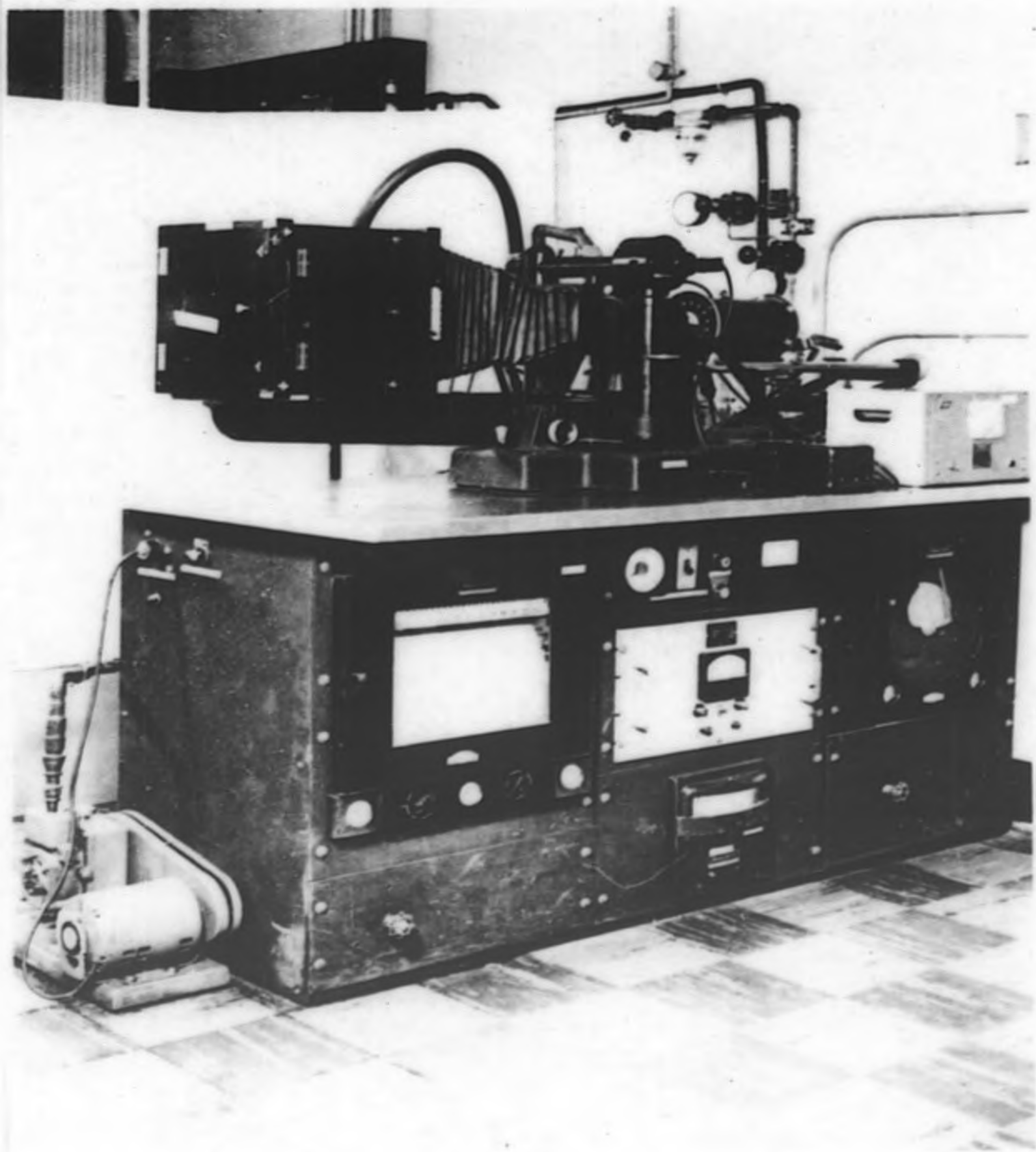Thermal expansion apparatus.

Figure 2

Thermal expansion apparatus showing specimen in place.

Figure 3

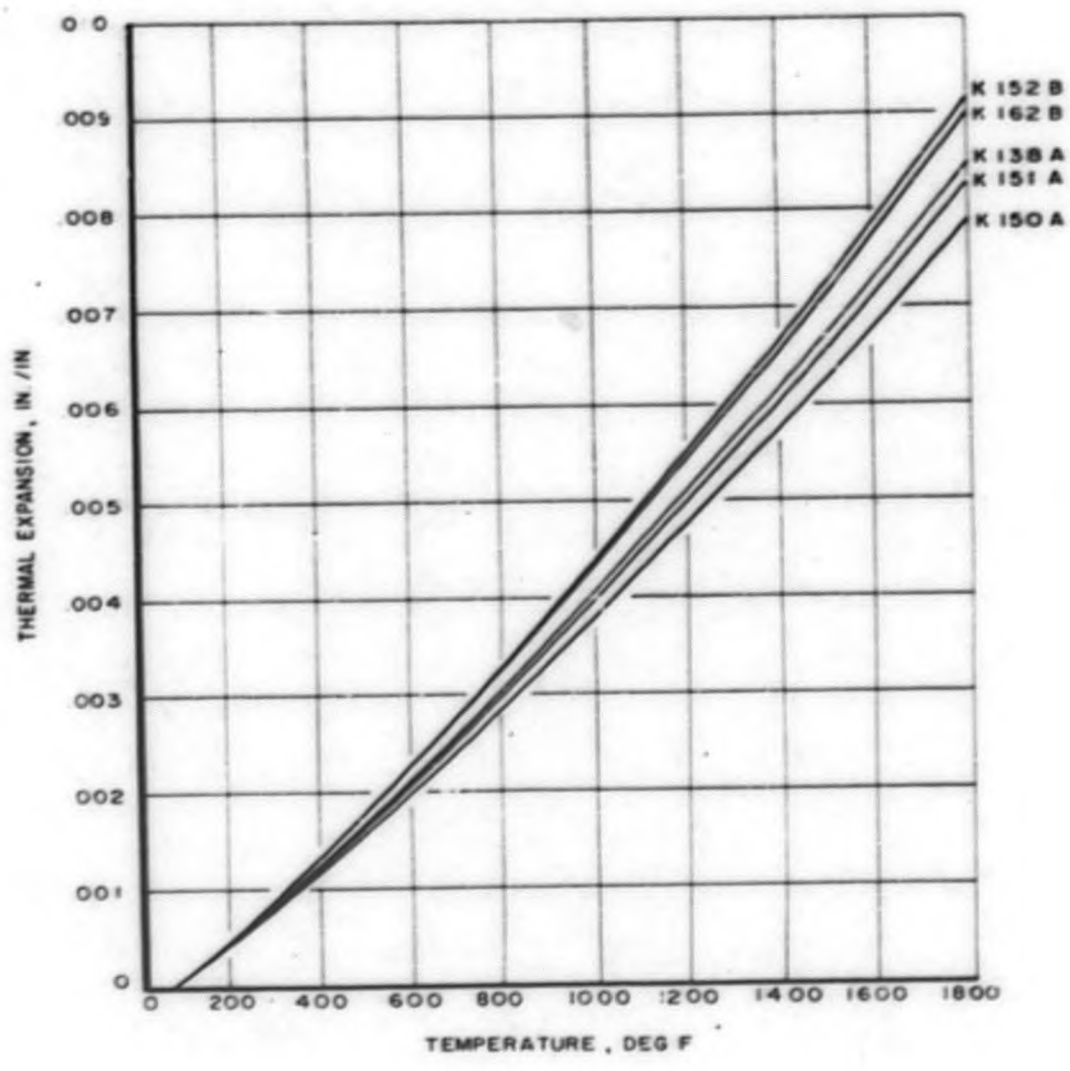Thermal expansion of five titanium carbide cermets.

Figure 4

Mean coefficients of thermal expansion of five titanium carbide cermets
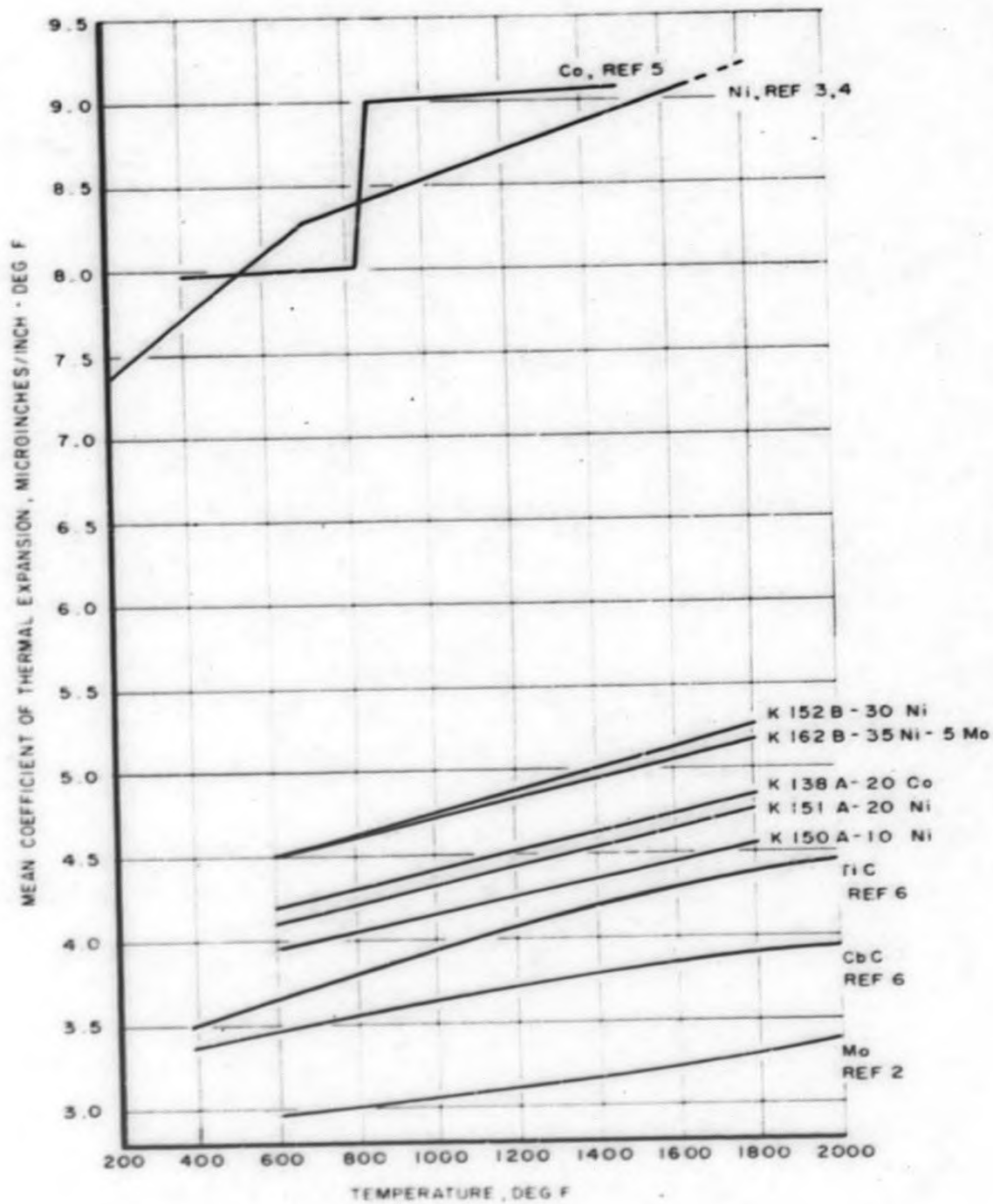and of their constituents.
(room temperature to T deg F)

Figure showing MEAN COEFFICIENT OF THERMAL EXPANSION, MICROINCHES/INCH · DEG F versus TEMPERATURE, DEG F.

Curves labeled:
- Co, REF 5
- Ni, REF 3,4
- K 152 B - 30 Ni
- K 162 B - 35 Ni - 5 Mo
- K 138 A - 20 Co
- K 151 A - 20 Ni
- K 150 A - 10 Ni
- TiC REF 6
- CbC REF 6
- Mo REF 2

Figure 5

Comparison of the thermal expansions of some metals and alloys with
the expansions of these five titanium carbide cermets.
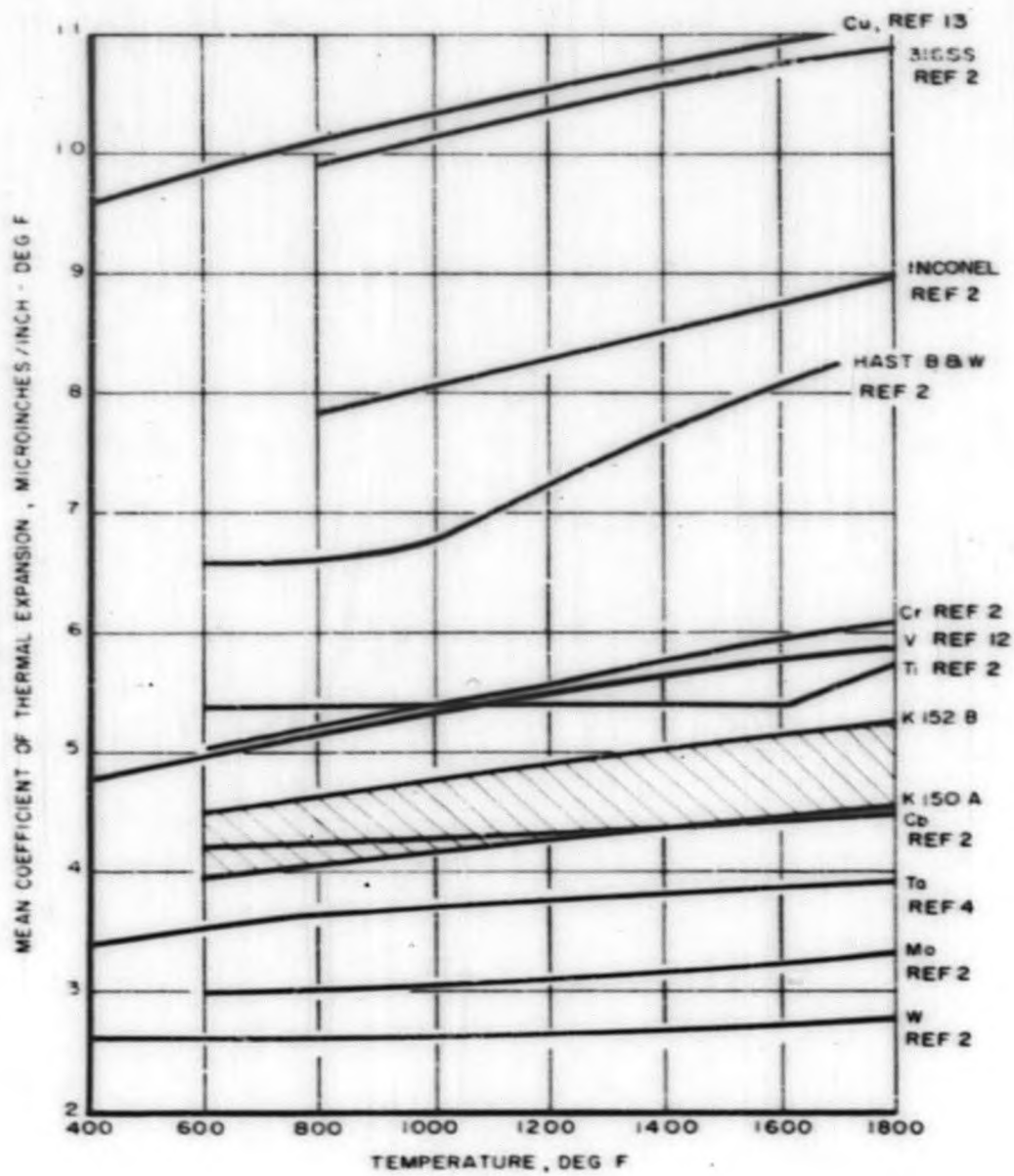(mean coefficients room temperature to T deg F)

Cu, REF 13
316 SS REF 2
INCONEL REF 2
HAST B & W REF 2
Cr REF 2
V REF 12
Ti REF 2
K 152 B
K 150 A
Cb REF 2
Ta REF 4
Mo REF 2
W REF 2

MEAN COEFFICIENT OF THERMAL EXPANSION, MICROINCHES/INCH - DEG F

TEMPERATURE, DEG F

25

Figure 6

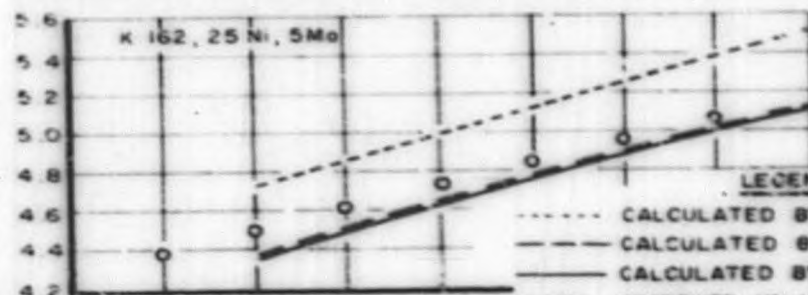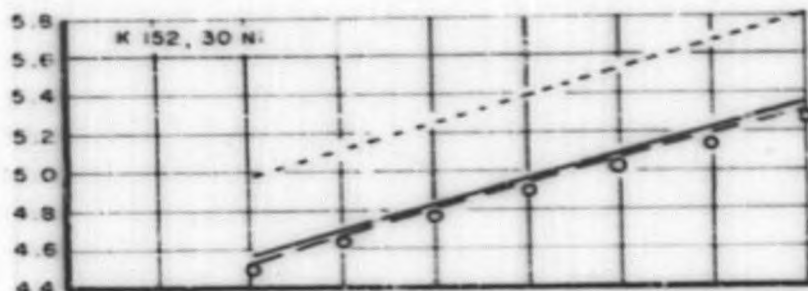Instantaneous coefficients of thermal expansion of five titanium carbide cermets.
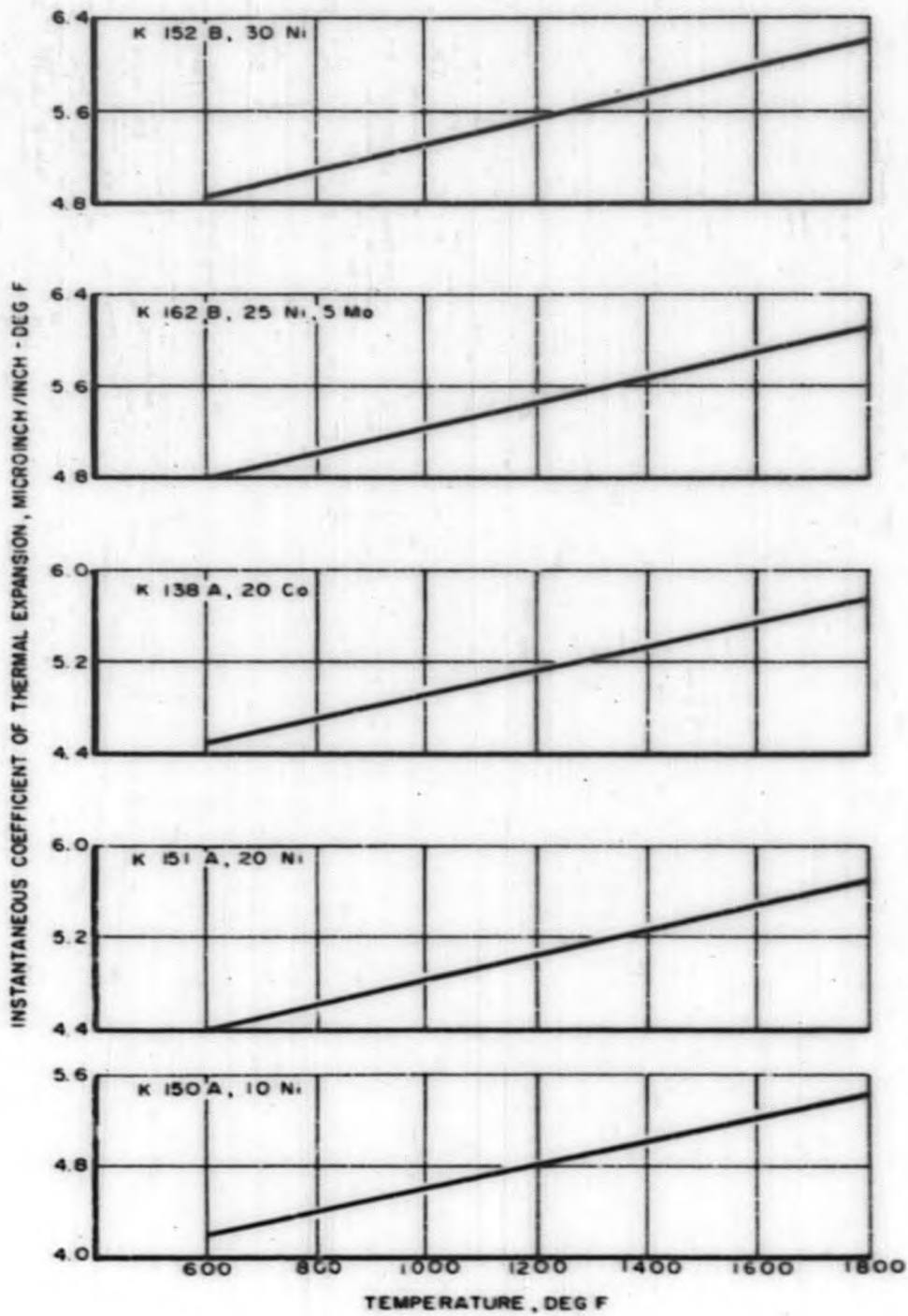
Figure 7

Comparison of the measured thermal expansion of five titanium carbide cermets
with that calculated from their compositions by three different methods.
(mean coefficients of thermal expansion 68 to T deg F)

END

LEGEND

······· CALCULATED BY WEIGHT PER CENT
— — — CALCULATED BY VOLUME PER CENT
———— CALCULATED BY TURNER'S METHOD
ooo OBSERVED VALUES