NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1419

EFFECTS OF INTERMITTENT VERSUS CONTINUOUS HEATING UPON THE TENSILE PROPERTIES OF 2024-T4, 6061-T6 AND 7075-T6 ALLOYS

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EFFECTS OF INTERMITTENT VERSUS CONTINUOUS HEATING UPON THE TENSILE PROPERTIES OF 2024-T4, 6061-T6 AND 7075-T6 ALLOYS*

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I. Introduction.

In some applications, aluminum alloys are subjected to intermittent heating at elevated temperature. It is generally considered that the effects of such intermittent heating are cumulative, and therefore, are the same as if the heating had been continuous for the same total length of time. To verify this, tests of 2024-T4, 6061-T6 and 7075-T6 alloys were made at 300 and 400°F as described in this report.

II. Object.

The object of these tests was to determine the effects of intermittent and continuous heating at 300 and 400°F, for total periods of 100 and 200 hr, upon the tensile properties of 2024-T4 and 6061-T6 alloy rolled-and-drawn rod and 7075-T6 alloy extrusions, at room temperature and at the temperature of heating.

III. Material.

The 2024 and 6061 alloy rod were produced commercially as 3/4-in. diameter rolled-and-drawn rod. The 2024 rod was supplied as cold drawn, and then was heat treated to the -T4 temper at Alcoa Aluminum Research Laboratories. The 6061 rod was supplied in the -T6 temper. The 7075-T6 extrusion was a 3/4-in. × 2-in. rectangle.

The nominal and actual chemical compositions of the three materials, shown in Table I, are in satisfactory agreement.

IV. Procedure.

Standard 1/2-in. diameter tensile specimens (Ref. 1) generally were used. In several tests of 2024-T4 alloy at elevated temperatures, however, 7/16-in. diameter specimens were used in order not to exceed the capacity of the testing machine. For comparison, similar tensile tests were made at room temperature using these two sizes of specimens.

*"Unedited by the NACA (the committee takes no responsibility for the correctness of the author's statements.)"

Tensile tests of each of the three alloys were made after heating for total periods of 100 and 200 hr, respectively, with some specimens heated intermittently and some heated continuously. The intermittent heating periods were 20 hr long. Two heating temperatures were used, 300 and 400°F, and for each of these conditions, one specimen was tested at room temperature after heating and one was tested at the heating temperature.

The specimens tested at 300°F were heated in an air furnace prior to testing and were in the furnace about 40 min longer than the required period of heating in order for the temperature of the specimen to reach 300°F. The specimens tested at 400°F were heated in a salt bath at 400°F and therefore reached 400°F quickly after being placed in the furnace. When the specimens were removed from the furnace, they were cooled in still air.

The tests at elevated temperature were made in one of two 10,000-lb capacity Olsen testing machines equipped with furnaces, and the yield strengths were determined from stress-strain curves obtained with a Riehle extensometer, as previously described (Ref. 2). All tests at room temperature were made in a 20,000-lb capacity Amsler Universal Testing machine, and yield strengths were determined with a Templin autographic extensometer (Ref. 3). In all tests, the elongation was recorded in a gage length of 4D.

V. Discussion of Results.

The results of the tensile tests at room temperature and at elevated temperatures are included in Table II, together with the published typical values for each material. At room temperature, the tensile strength of 2024-T4 is about 5 per cent above the typical, and those for 6061-T6 and 7075-T6 are in good agreement with the typical. The yield strengths of 2024-T4 and 6061-T6 are 7 and 5 per cent lower than the respective typical yield strengths, and that of 7075-T6 is in good agreement with the typical; all are within the ranges obtained commercially. The elongations for these three alloys agree satisfactorily with the typical values.

Comparison of the tensile properties obtained by continuous heating and by intermittent heating indicates that the differences in tensile strength, yield strength, elongation and reduction of area are insignificant. This applies to the results obtained at room temperature after heating at 300 and 400°F for periods of 100 and 200 hr, as well as to the results obtained at 300 and 400°F after similar periods of heating. The differences obtained are no larger than might be obtained in duplicate tensile tests made at room temperature. With one exception, the maximum difference in the tensile and yield strengths obtained by continuous and intermittent heating of these three alloys was less than

4 per cent. The exception is in the comparison of the yield strengths of the 2024-T4 specimens at 400°F after heating 100 hr, which show a difference of about 8 per cent.

At room temperature after heating at 300°F for either the 100 or 200 hr period, there is no loss in tensile or yield strength for either 2024-T4 or 6061-T6. The yield strength of 2024-T4 actually is increased because of artificial aging. For 7075-T6 there is a reduction of about 10 per cent for the 100 hr period and about 20 per cent for the 200 hr period. At room temperature after heating at 400°F, the tensile and yield strengths of 2024-T4 and 6061-T6 are decreased from 20 to 25 per cent for both the 100 and 200 hr periods but for 7075-T6 these properties are reduced from about 50 to 65 per cent.

In Table III, the tensile and yield strengths at 300 and 400°F after 100 hr heating are expressed in percentage of their respective tensile and yield strengths at room temperature, along with similar data for the same alloys and tempers included in the ANC-5 Bulletin, "Strength of Metal Aircraft Elements," June 1951. Data from these two sources agree reasonably well, considering that losses in these properties are so greatly affected by small changes in temperature in the range of 300 to 400°F.

VI. Conclusions.

From a comparison of the results obtained in this investigation of intermittent vs continuous heating of 2024-T4 and 6061-T6 alloy rolled-and-drawn rod and the 7075-T6 alloy extrusion, the following conclusions seem warranted:

1. The tensile properties of the materials tested exceed the requirements of applicable specifications, and agree satisfactorily with the published typical values.

2. The effects of intermittent heating upon the tensile properties, both at elevated temperature and at room temperature after heating, are cumulative and are the same as for continuous heating.

3. Heating 2024-T4 and 6061-T6 alloys for as long as 200 hr at 300°F causes no significant loss in tensile strength or yield strength at room temperature. Similar heating of 7075-T6 alloy, however, reduces these properties about 20 per cent.

4. Heating 2024-T4 and 6061-T6 alloys for 200 hr at 400°F decreases their tensile strengths and yield strengths at room temperature about 25 per cent. For 7075-T6 alloy, the reductions in tensile strength and yield strength are about 55 and 70 per cent, respectively.

5. The tensile strengths and yield strengths of 2024-T4 and 6061-T6 alloys at 300°F after heating 200 hr are from 0 to 15 per cent lower than originally. The losses in tensile strength and yield strength for 7075-T6 alloy are about 40 per cent.

6. The tensile strengths and yield strengths of 2024-T4 and 6061-T6 alloys at 400°F after heating 200 hr are from 40 to 55 per cent lower than originally. The losses in tensile strength and yield strength for 7075-T6 alloy are about 80 per cent.

7. The losses in tensile strength and yield strength obtained in this investigation as a result of either continuous or intermittent heating are in reasonable agreement with those indicated in ANC-5 considering that the properties are greatly affected by rather small changes in temperatures in the range of 300 to 400°F.

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VII. REFERENCES

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2. Templin, R. L., Braglio, C. and Marsh, K.: Mechanical Properties of Aluminum Casting Alloys at Elevated Temperature, Trans. ASME, 50, 1S-50-8, 1928.

3. Templin, R. L.: An Automatic Autographic Extensometer for Use in Tension Tests of Materials, Proc. A.S.T.M., vol. 32, pt. II, 1932, p. 783.

4. Anon.: Alcoa Aluminum and Its Alloys. Aluminum Co. of Am., 1950.

5. Anon.: Alcoa Aluminum Extruded Shapes. Aluminum Co. of Am., 1950.

6. Anon.: Strength of Metal Aircraft Elements. ANC-5, Munitions Board Aircraft Committee, Dep't. of Defense. Revised ed., June 1951.

TABLE I

CHEMICAL COMPOSITIONS

Alloy and temper	Sample no.	Analysis no.	Element, percent								
			Cu	Fe	Si	Mn	Mg	Zn	Cr	Ti	Ni
2024-T4	117314	(Nominal[a])	4.50	---	---	0.60	1.50	---	---	---	---
		3995	4.37	0.25	0.11	0.62	1.41	<0.01	0.01	0.02	<0.01
6061-T6	116515	(Nominal[a])	0.25	---	0.60	---	1.00	---	0.25	---	---
		3994	0.23	0.38	0.59	0.04	0.88	0.05	0.22	0.07	---
7075-T6	105740	(Nominal[a])	1.60	---	---	---	2.50	5.60	0.30	---	---
		91546	1.58	0.25	0.16	0.10	2.53	5.69	0.24	0.03	---

[a]Reference 4

TABLE II

SUMMARY OF TENSILE TESTS AT ROOM TEMPERATURE AND AT 300 AND 400°F AFTER CONTINUOUS AND INTERMITTENT HEATING

Testing Temp., °F	Heating Temp., °F	Heating Period, hr	Continuous Heating: Tensile Strength, psi	Continuous Heating: Yield Strength (Offset=0.2%), psi	Continuous Heating: Elong. in 4D, %	Continuous Heating: Red. of Area, %	Intermittent Heating: Tensile Strength, psi	Intermittent Heating: Yield Strength (Offset=0.2%), psi	Intermittent Heating: Elong. in 4D, %	Intermittent Heating: Red. of Area, %
			2024-T4 Rolled-and-Drawn Rod, 3/4-in. Diameter							
Room	(Typical Properties[A])		68 000	48 000	19.0	---	---	---	---	---
Room	None	None	71 500	44 400	21.5	35	---	---	---	---
			71 300[c]	44 500[c]	17.7[c]	33[c]	---	---	---	---
Room	300	100	70 000	45 300	21.5	32	70 400	44 700	21.0	31
		200	70 900	48 900	19.0	29	70 800	47 800	19.0	30
Room	400	100	53 000	35 700	11.0	30	52 500	35 400	11.0	31
		200	51 700	34 100	11.5	31	52 600	34 600	11.0	30
300	300	100	60 400[c]	42 300[c]	21.7[c]	38[c]	61 600[c]	42 900[c]	22.3[c]	38[c]
		200	61 300[c]	45 500[c]	20.0[c]	36[c]	60 300[c]	44 200[c]	20.6[c]	39[c]
400	400	100	33 100	24 200	20.0	54	32 700	26 400	17.0	52
		200	32 900	26 400	18.5	53	32 200	26 200	19.5	56
			6061-T6 Rolled-and-Drawn Rod, 3/4-in. Diameter							
Room	(Typical Properties[A])		45 000	40 000	17.0	---	---	---	---	---
Room	None	None	44 000	38 100	18.5	48	---	---	---	---
Room	300	100	44 600	40 100	17.0	47	44 400	39 700	17.0	46
		200	44 300	40 200	16.5	49	44 900	40 600	16.5	46
Room	400	100	36 400	30 600	17.0	55	36 300	30 400	16.5	54
		200	34 700	28 000	16.5	56	35 300	28 700	16.5	55
300	300	100	36 300	34 300	19.5	58	37 000	34 900	19.0	56
		200	36 800	34 900	19.0	56	36 600	34 800	18.5	56
400	400	100	25 200	23 300	22.0	66	25 300	23 400	22.5	68
		200	23 700	21 900	22.0	68	24 300	22 700	22.5	68
			7075-T6 Extruded Bar 3/4 x 2-in.							
Room	(Typical Properties[B])		91 000	83 000	9.0	---	---	---	---	---
Room	None	None	89 400	81 100	11.9	16	---	---	---	---
Room	300	100	79 800	71 300	10.0	25	80 800	72 300	9.5	23
		200	74 100	64 400	11.5	29	76 300	67 200	11.0	28
Room	400	100	42 300	26 800	15.0	43	42 300	26 800	15.0	43
		200	39 600	23 900	16.0	46	39 700	23 900	16.0	42
300	300	100	57 800	52 600	17.5	45	57 200	51 400	18.5	46
		200	52 100	47 800	19.0	50	54 600	49 000	18.0	48
400	400	100	21 000	18 200	34.5	78	20 600	18 400	31.0	78
		200	19 900	17 200	38.5	80	19 700	17 300	37.0	80

[c] 7/16-in. instead of 1/2-in. diam. specimen.
[A] Reference 4
[B] Reference 5

TABLE III

TENSILE AND YIELD STRENGTHS OF 2024-T4 AND 6061-T6 ROD
AND 7075-T6 EXTRUSION AT ELEVATED TEMPERATURES
AFTER HEATING 100 HOURS AT THE
TESTING TEMPERATURES

Alloy and temper	Temp, °F	Tensile strength, % of original value		Yield strength, % of original value	
		a	b	a	b
2024-T4	300	85	83	96	87
	400	46	55	57	66
6061-T6	300	83	80	91	82
	400	57	56	61	59
7075-T6	300	64	47	64	46
	400	23	20	23	19

[a]From data in table II.
[b]From reference 6.

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