

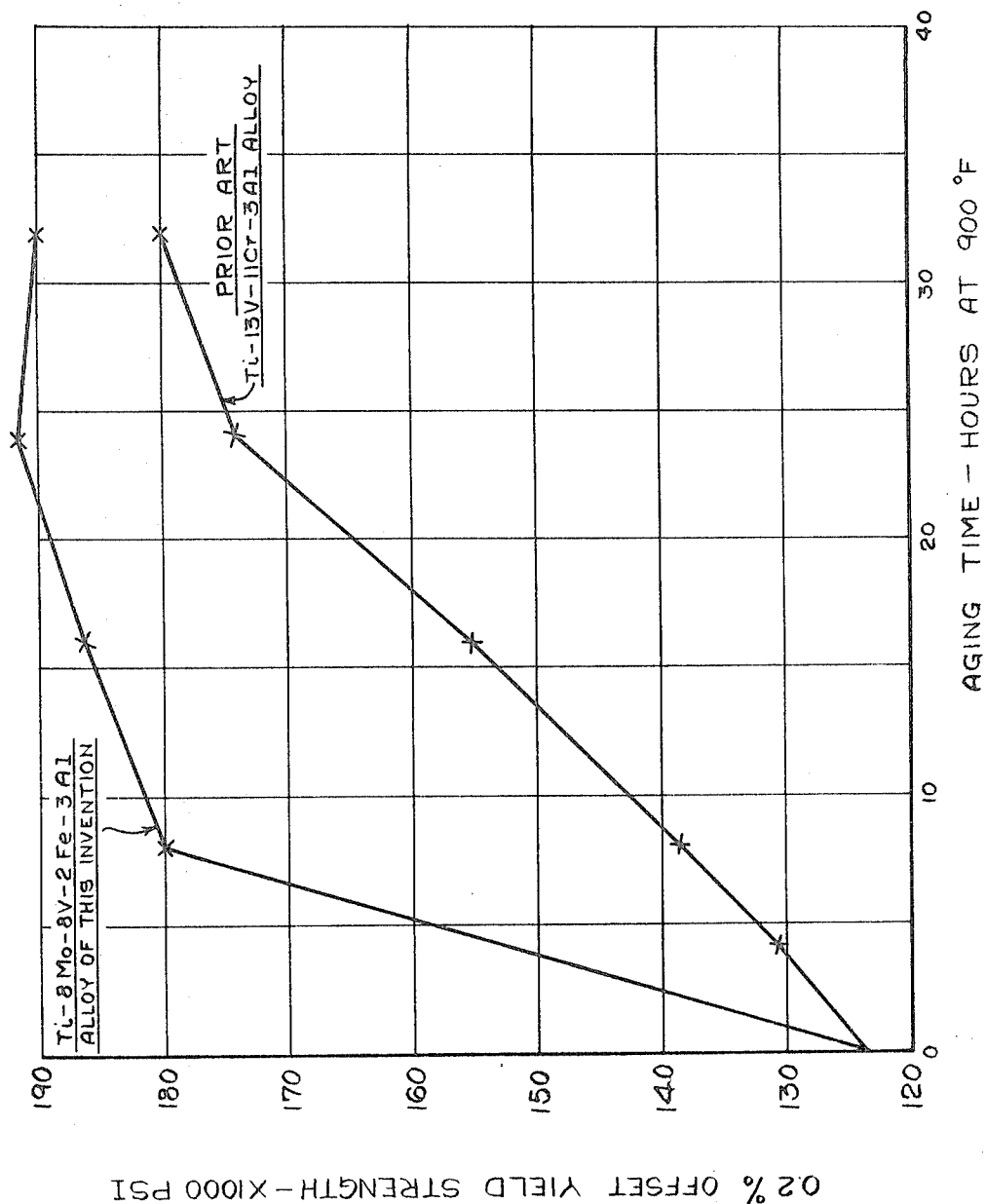
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HEAT TREATABLE BETA TITANIUM BASE ALLOY AND PROCESSING THEREOF

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3,595,645

**HEAT TREATABLE BETA TITANIUM BASE ALLOY
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ABSTRACT OF THE DISCLOSURE

A titanium base alloy consisting essentially of about 7 to 9% each of molybdenum and vanadium, 1.5–2.75% iron, 2.5 to 3.5% aluminum and the balance titanium.

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment of any royalty thereon.

This invention pertains to heat-treatable, beta titanium-base alloys, and more particularly to a novel alloy of this type of critically-limited alloy content such as to impart a combination of useful properties rendering the same superior in various respects to previously known titanium-base alloys of the substantially all-beta type.

The alloy of the invention consists essentially as to composition of about 7 to 9% each of molybdenum and vanadium, 1.5 to 2.75% of iron, 2.5 to 3.5% aluminum, and the balance titanium except for interstitials and impurities within commercial tolerances. The preferred composition of the alloy for most commercial applications is about 8% each of molybdenum and vanadium, 2% iron and 3% aluminum, balance substantially all titanium.

As missions become more sophisticated, and as aerospace vehicles become larger, the more important structural efficiency becomes. Structural efficiency entails not only high ratios of strength to weight but also resistance to all forms of cracking. Moreover, in order that a designer can take maximum advantage of an alloy's tensile properties, these properties must be attainable throughout sections of varying thickness under a wide variety of service conditions. Notched fatigue strength, crack initiation and propagation resistance and metallurgical stability are particularly important. The alloy of this invention represents an improvement in the present state of the art in these respects.

Also from the producer's and fabricator's points of view, formability and aging response are important aspects in component manufacture. The alloy of this invention as solution treated above the beta transus has a relatively low yield strength on the order of 120,000 p.s.i., 0.2% offset and excellent ductility on the order of 16% elongation in 2" for ease of forming. As thereafter aged at about 900° F. for a relatively short time of about 24 hours, the ultimate and yield strengths are increased to about 200,000 and 190,000 p.s.i., respectively, with retention of good ductility of 5% or better in tensile elongation. A unique property of the aged strength of the alloy is that it remains substantially constant at the above level on further prolonged aging treatment, and in this respect differs remarkably from the commercial Ti-13V-11Cr-3Al alloy, the aged strength of which progressively increases with time of aging treatment and never attains the relatively constant plateau strength of the instant alloy. Also the aged yield strength of the instant alloy increases much more rapidly with aging time than that of the commercial alloy. Thus the aged ultimate strength of the instant alloy attains a value of 180,000 p.s.i. in 8 hours as against only about 138,000 p.s.i. of the commercial alloy within that aging period. Also as developed below

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the alloy of this invention is superior in various other respects to the Ti-13V-11Cr-3Al beta alloy, which heretofore has been the best commercial alloy of this type.

The alloy of the present invention may be produced as flat rolled mill product or in such other forms as forgings, extrusions or wire by conventional fabrication techniques. The room temperature and 600° F. tensile properties of the preferred Ti-8Mo-8V-2Fe-3Al modification are shown in the following Tables I and II:

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15 TABLE I.—ROOM TEMPERATURE TENSILE PROPERTIES
OF Ti-8 Mo-8 V-2 Fe-3 Al. AGED AT 900° F.

[0.080" thick sheet, solution treated 1,500° F.—10 minutes—water quenched]

Aging heat treatment	UTS K s.i.	YS K s.i.	Elongation percent in 2"	Modulus, p.s.i. X 10 ⁶
Non-aged.....	124	119	16	10.3
900° F.:				
1 Hour—AC.....	122	119	20	11.3
8 hours—AC.....	197	180	7	15.1
16 hours—AC.....	195	186	7	14.8
24 hours—AC.....	204	191	5	15.0
32 hours—AC.....	198	190	6	15.4
64 hours—AC.....	197	190	5	14.8
24 hours—AC ¹	204	188	5.5	16.1

¹ Sample aged after machining and tested with oxidized surface.

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TABLE II.—600° F. TENSILE PROPERTIES

[0.080" thick sheet solution treated as above]

Aging heat treatment	UTS K s.i.	YS K s.i.	Elongation percent in 2"			Modulus
			Local	Uni-form	Total	
900° F.:						
8 hours—AC.....	167	142	10	1	4	14.6
24 hours—AC.....	170	154	22.5	1.25	3.5	14.0

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From the data of Table I it will be seen that the alloy of this invention when recrystallized by aging from the solution-treated conditions attains a yield strength of 180,000 p.s.i., i.e. 180K s.i. after aging for 8 hours at 900° F., and thereafter prolonging the aging time to 64 hours results in only a small further strength increase up to about 190K s.i. attained in 24 hours.

This is also shown graphically in the accompanying drawing which also shows the aging response for the commercial Ti-13V-11Cr-3Al alloy. Note that after aging for 8 hours at 900° F., Ti-8Mo-8V-2Fe-3Al reaches a plateau of high strength in the range of 180–190K s.i., whereas the commercial alloy Ti-13V-11Cr-3Al possesses a yield strength of only 140K s.i. and continues to gain strength with increasing aging time, so that no plateau of constant strength is attained within 32 hours. This therefore is an important advantage of Ti-8Mo-8V-2Fe-3Al over Ti-13V-11Cr-3Al, that it ages rapidly to a 180K s.i. yield strength, and thereafter undergoes little change in strength. This lack of a critical time for aging the Ti-8Mo-8V-2Fe-3Al alloy thus constitutes an important aspect of this invention. Furthermore, whereas the Ti-13V-11Cr-3Al alloy is very difficult to age to a preselected strength level, the aged strength of Ti-8Mo-8V-2Fe-3Al alloy can be readily controlled by selection of proper aging temperature. Higher aging temperatures result in lower strength and vice versa.

Moreover, as shown by the test data of Table II above, the alloy of this invention retains a useful degree of strength up to 600° F. That is to say, in the aged condition the alloy typically retains up to 600° F., 80% of its room temperature strength.

The notched fatigue properties of the alloy of this invention are shown below in Table III, from which it will be evident that the notched fatigue run out strength of the Ti-8Mo-8V-2Fe-3Al alloy lies in the range of 30–35K s.i. By contrast the notched fatigue limit of the commercial Ti-13V-11Cr-3Al alloy is only 20–25K s.i. at run out time of 10⁷ cycles. This superiority in notch fatigue is another important feature of this invention.

TABLE III

Room temperature notched fatigue properties ¹
(Specimen heat treated 1450° F.—10 min.—AC
+900° F.—8 hrs.—AC)

Stress K s.i.:	Cycles to failure
60	19,000.
50	43,100.
40	49,600.
35	9,315,000.
35	Run out at 10,158,600.
33	1,004,200.
30	11,469,900.
30	Run out at 12,416,700.

¹ Sheet specimens tested at a minimum to maximum load ratio (R) of 0.25 at a notch concentration factor of K_t=3.5.

TABLE IV.—SUMMARY OF PROPERTIES OF Ti-8 Mo-8 V-2 Fe 3 Al ALLOY (0.060" SHEET)

Property	Value
Density, lb./cu. inch	0.175
Annealed yield strength, K s.i.	118–120
Annealed strength/weight ratio, in. ⁻¹	680,000
Aged yield strength:	
900° F.—8 hours age (strength/weight ratio) K s.i.	1180
900° F.—16 hours age (strength/weight ratio) K s.i.	2186
900° F.—24 hours age (strength/weight ratio) K s.i.	3191
Room temperature notch tensile:	
900° F.—8 hours age, K s.i.	172
NTS/UTS ratio ¹	0.87
900° F.—24 hours age, K s.i.	164
NTS/UTS ratio	0.83
—65° F. Notch tensile (900° F.—8 hours AC) K s.i.	145
600° F. notch tensile:	
900° F.—8 hours age, K s.i.	184
NTS/UTS ratio	1.10
900° F.—24 hours age, K s.i.	188
NTS/UTS ratio	1.10
K _{1c} value; 900° F.—8 hours age, p.s.i./in.	45,000
Notched fatigue strength, 900° F.—8 hours age, K s.i.	30–35
Minimum bend radius; 1,500° F.—10 minutes—AC	<2T
¹ 7% elongation (1,030,000 in. ⁻¹).	
² 7% elongation (1,060,000 in. ⁻¹).	
³ 5% elongation (1,090,000 in. ⁻¹).	
⁴ Notched tensile strength/ultimate strength ratio.	
⁵ Stress for 10 million cycles.	

A further feature of this invention is that Ti-8Mo-8V-2Fe-3Al alloy displays a superior resistance to stress corrosion cracking at 800° F. induced by the presence of salt, Table V below, than the commercial beta alloy Ti-13V-11Cr-3Al. In view of the growing importance of the relative susceptibility of titanium alloys to stress corrosion, this also constitutes an important advantage of this invention over the present state of the art.

TABLE V.—COMPARISON OF HOT SALT STRESS CORROSION BEHAVIOR OF Ti-8 Mo-8 V-2 Fe-3 Al AND Ti-13 V-11 Cr-3 Al ALLOYS (BOTH IN SOLUTION TREATED AND AGED CONDITIONS)

Alloy	Bend radius	Treatment	Result of flattening
Ti-8 Mo-8 V-2 Fe-3 Al	6T	None (control)	No cracks.
Same as above	6T	800 F.—2 hours, no salt	Do.
Do	5.6T	800 F.—2 hours, salt coated	Do.
Do	5.7T	do	Do.
Do	6T	do	Do.
Ti-13 V-11 Cr-3 Al	5.8T	None (control)	Do.
Same as above	5.8T	800 F.—2 hours, no salt	Do.
Do	5.8T	800 F.—2 hours, salt coated	Numerous small cracks.
Do	5.8T	do	Do.
Do	5.8T	do	Do.

The following Table IV gives a summary of the mechanical properties of Ti-8Mo-8V-2Fe-3Al. From this it is seen that this alloy possesses good notch toughness, even in the fully aged condition, (900 F.—24 hours), and also retains good notch toughness over a range of temperatures from —65 F. to 600 F. This notch toughness is an important feature of this invention.

From the above data it will be seen that whereas the alloy of the instant invention is immune to salt corrosion cracking under the conditions of testing, the Ti-13V-11Cr-3Al alloy of the prior art was not.

A further useful property of Ti-8Mo-8V-2Fe-3Al alloy of this invention is that even after exposure to temperatures of 600 F. for 500 hours under load it still retains a useful amount of ductility as shown in the following Table VI. Ductility is also found when samples of this alloy are tested after exposure to aging temperature without subsequent pickling to remove the oxidized surface, Table I.

TABLE VI.—CREEP STABILITY DATA ON Ti-8 Mo-8 V-2 Fe-3 Al ALLOY

Exposure	Stress, K s.i.	Time, hours	Percent deformation	UTS, K s.i.	YS, K s.i.	Elongation percent in 1"	Modulus p.s.i. ×100
160 ¹	123	150	0.320	203	196	6	15.2
			0.264	204	197	6	15.6
			0.276	201	194	5	16.1
			0.429	206	200	4	15.5
		500	0.367	205	200	4	15.6
			0.382	204	198	4	15.4
			0.292	208	202	6	17.0
		150	0.288	208	201	6	15.9
			0.248	206	200	6	15.9
			0.364	204	201	4	15.7
		500	0.407	206	203	5	15.7
			0.396	204	197	6	16.4

¹ Heat treatment prior to exposure —1,500° F. for 10 minutes and water quenched followed by aging at 900° F. for 8 hours and air cooled.

² Same as above except for aging 24 hours.

From the standpoint of practical useage it is important that titanium alloys be weldable. Data in Table VII below, shows that Ti-8Mo-8V-2Fe-3Al alloy has good ductility in the as-welded condition, and that by aging for a short period at 900° F. (2 hours) a simultaneous increase in both strength and ductility can be brought about. The application of a short post-weld aging cycle to improve the properties of the alloy of this invention is a further important point. Table VII shows that by prolonging the aging time at 900° F. to 4 hours, weldments may attain a strength of over 180 K s.i., with good ductility. By aging at 1100° F. a condition of intermediate strength with ductility is produced. By contrast, aging Ti-13V-11Cr-3Al alloy at 1100° F. following welding results in embrittlement. Hence, variation of aging temperature in the range 900-1100° F. is less important for Ti-8Mo-8V-2Fe-3Al weldments than Ti-13V-11Cr-3Al weldments and the lack of a critical post-welding aging temperature constitutes another aspect of this invention.

TABLE VII.—WELDED PROPERTIES OF Ti-8Mo-8V-2Fe-3Al¹ ALLOY (BUTT WELDS, NO FILLER, 0.060" SHEET HEAT TREATED 1,500° F.—10 MINUTES—AC)

Treatment	Test temperature	UTS, K.s.i.	YS, K.s.i.	Elongation percent in 2"	Modulus, p.s.i. X10 ⁶
Unwelded.....	RT.....	124	119	16	10.3
Welded.....	RT.....	124	121	4.25	12.6
Do. ¹	RT.....	139	134	7	13.3
Do. ²	RT.....	195	183	3.25	15.0
Do. ³	RT.....	190	182	3.25	15.0
Do. ⁴	RT.....	153	146	2	15.0
Do. ⁴	600° F.....	120	107	4	13.9

¹ Welded plus 900° F.—2 hours—AC.

² Welded plus 900° F.—4 hours—AC.

³ Welded plus 900° F.—8 hours—AC.

⁴ Welded plus 900° F.—16 hours—AC.

Another useful feature of the alloy of this invention is that aging at 1100° F. for 8 hours or more results in the

abortion of the aging response, so that the alloy treatments insensitive (metallurgically) to further aging treatments or service exposure below this temperature. Although this process may be applied to any metastable beta titanium alloy, Table VIII shows that the alloy of this invention has good creep properties in the stabilized condition, and retains its ductility.

TABLE VIII.—PROPERTIES OF Ti-8Mo-8V-2Fe-3Al ALLOY IN STABILIZED CONDITION¹

¹ Heat treatment: 1,500° F.—10 minutes—AC plus 1,100° F.—8 hours—AC

(a) Tensile properties as above stabilized

Test temperature	UTS, K.s.i.	YS, K.s.i.	Elongation percent in 2"			Modulus, K.s.i.	NTS, K.s.i.	NTS/UTS
			L	U	T			
RT.....	149	139	45	8.0	14	14.7	174	1.16
600° F.....	122	104	35	5.3	9	14.1	136	1.11

(b) Following creep exposure

Creep exposure				Subsequent tensile properties			
Temperature, ° F.	Stress, K.s.i. ¹	Time, hours	Percent deformation	UTS, K.s.i.	YS, K.s.i.	Elongation percent in 1"	Modulus, p.s.i. X10 ⁶
600.....	93.5	150	0.098	152	143	18	14.6
			0.141	150	140	18	14.6
			0.116	151	142	16	14.9
		500	0.160	157	142	16	15.0
			0.193	156	147	17	15.1
			0.244	156	143	14	15.0

¹ See footnotes Table VI.

The mechanical properties of Ti-8Mo-8V-2Fe-3Al in the form of 1/2-inch plate are shown in the following Table IX. The alloy is readily air-hardenable at this gage. Similar results were obtained in 2" plate. The excellent notch properties and plane strain crack propagation resistance are inherent features of this alloy.

TABLE IX.—MECHANICAL PROPERTIES OF 1/2" THICK PLATE OF Ti-8Mo-8V-2Fe-3Al

Heat-treatment	UTS, K s.i.	YS, K s.i.	RA per- cent	Elon- gation percent in 1"	Modulus, p.s.i. ×10 ⁶	
(a) Room temperature tensile test:						
1,500° F.—10 minutes—AC.....	119	118	48	24	14.1	
Do.....	116	114	53	27	12.5	
Do.....	117	116	53	29	12.2	
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	210	197	4	4	16.2	
Do.....	210	195	7	4	16.0	
Do.....	209	195	9.5	8	16.3	
(b) 600° F. smooth tensile:						
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	161	143	54	4	12.6	
Do.....	181	159	16	7	13.2	
Do.....	179	157	16	4	13.9	
(c) RT notch tensile:						
	K _t value		NTS		Average	
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	2.8		262		263	
Do.....	2.8		263			
Do.....	2.8		263			
1,500° F.—10 minutes—AC plus 900° F.— 8 hours—AC.....	8		233		226	
Do.....	8		223			
Do.....	8		223			
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	8		230		229	
Do.....	8		227			
Do.....	8		231			
(d) 600° F. notch tensile:						
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	2.8		234		241	
Do.....	2.8		244			
Do.....	2.8		246			
1,500° F.—10 minutes—AC plus 900° F.— 8 hours—AC.....	8		231		230	
Do.....	8		226			
Do.....	8		233			
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	8		230		235	
Do.....	8		234			
Do.....	8		231			
(e) K _{1c} values:						
	K _{1c} (K p.s.i./√in)					
1,500° F.—10 minutes—AC plus 900° F.— 16 hours—AC.....	48.5					45.4
Do.....	46.7					
Do.....	41.1					

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Ti-8Mo-8V-2Fe-3Al also possesses good forming characteristics with a minimum bend radius in the solution treated condition of <2T and <3T when stabilized. As shown in Table I, it possesses good uniform elongation, and a low annealed yield strength, which would enable forming of larger parts to be done, or use of smaller presses for equivalent parts.

In summary, it is claimed that the alloy of this invention, Ti-8Mo-V-2Fe-3Al, is superior to the present commercial alloy Ti-13V-11Cr-3Al in the following respects: Speed and control of aging, notch tensile strength, notched fatigue strength, stress corrosion resistance and weldability.

Alloys according to the invention may be produced by admixing titanium sponge with the alloying ingredients in comminuted form, compacting the admixture into a consumable electrode and arc melting in a cold mold furnace such as a water-cooled copper crucible to produce an ingot of the alloy. Homogeneity of the ingot may be improved by utilizing the ingot as such as a consumable electrode and arc-remelting into a cold mold crucible of larger diameter than the first.

For breakdown operation the resulting ingot is heated to about 1860° F. and rolled or forged to a desired shape.

What is claimed is:

1. A titanium base alloy consisting essentially of about: 7 to 9% each of molybdenum and vanadium, 1.5 to 2.75% iron, 2.5 to 3.5% aluminum, up to 0.2% in total amount of carbon, oxygen and nitrogen, balance titanium, characterized in being substantially immune to stress corrosion cracking, in being age hardenable to a yield strength of about 180,000 p.s.i. on solution treating and thereafter

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aging at about 900° F. for about 8 hours, and in having a tensile elongation of at least 5% in the aged condition.

2. An alloy according to claim 1 containing about: 8% each of molybdenum and vanadium, 2% iron and 3% aluminum.

3. A wrought article made of an alloy according to claim 1.

4. A wrought and solution-treated article made of an alloy according to claim 1 characterized by an 0.2% offset yield strength of not more than about 120,000 p.s.i. and a tensile elongation of at least 10%.

5. An age-hardened titanium-base alloy according to claim 1 characterized by an 0.2% offset yield strength of at least 180,000 p.s.i. and a tensile elongation of at least 5%.

References Cited

UNITED STATES PATENTS

2,754,203	7/1956	Vordahl	75—175.5
2,918,367	12/1959	Crossley et al.	75—175.5
3,306,739	2/1967	Evans et al.	75—175.5
3,405,016	10/1968	Jaffee et al.	148—133

FOREIGN PATENTS

659,577	3/1963	Canada.
776,440	6/1957	Great Britain.
782,564	9/1957	Great Britain.

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