

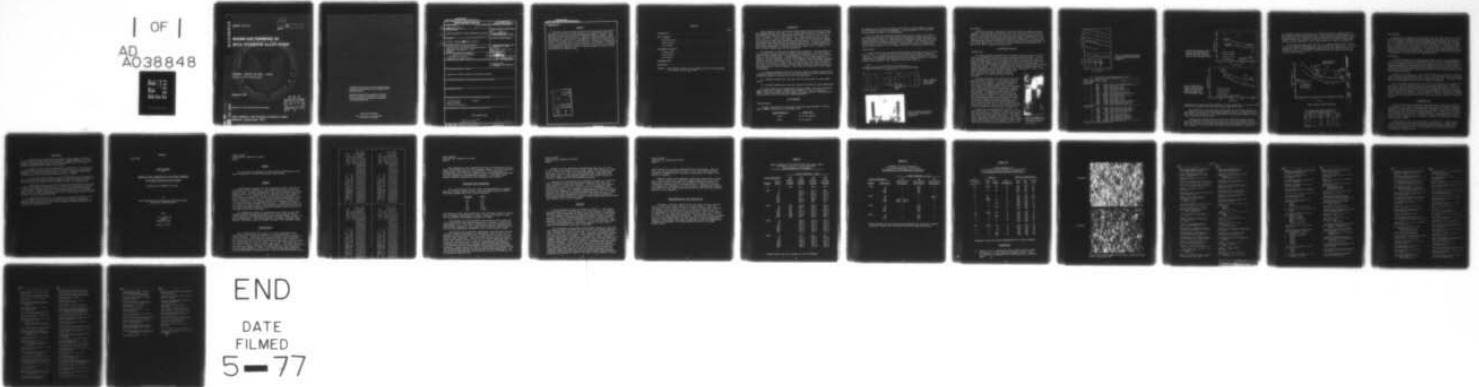
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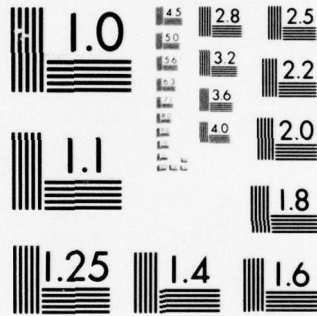
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WARM-DIE-FORMING OF BETA TITANIUM ALLOY STRIP.(U)
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WARM-DIE-FORMING OF BETA TITANIUM ALLOY STRIP

STUART V. ARNOLD and PAUL J. DOYLE
MATERIALS APPLICATION DIVISION

December 1976

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ABSTRACT

Continuous strip of Ti-8Mo-8V-2Fe-3Al was investigated for possible application in the nose cap for the main rotor blade of the Heavy Lift Helicopter as part of the Advanced Technology Component Program. Aging response of strip solutionized in a continuous vacuum annealing furnace and subsequently cold rolled was determined as functions of time and temperature for several levels of cold reduction. Tensile and fatigue properties of strip produced by selected practices were measured. Feasibility of creep forming solutionized-and-cold-rolled strip to nose cap contours during aging was explored. Warm die forming and aging of strip to those same contours was demonstrated.

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INTRODUCTION

During conduct of the recent Heavy Lift Helicopter Advanced Technology Component Program (HLH-ATC) nose caps for the leading edge of main rotor blades for the developmental aircraft were creep formed from blanks of Ti-6Al-4V alloy strip 40 feet x 32 inches x 0.060 ± 0.003 inch in size. Creep forming was done at 1600 F over a male die in a car-bottom furnace. Interaction with air during the lengthy cycle resulted in alpha-case formation requiring removal of 0.004 inch of contaminated metal from each surface of the blank by chem-etching. Fatigue properties of mill-product strip after forming and chem-etching were less than anticipated and below design requirements. Because the blade was weight-critical, recourse to Ti-6Al-4V strip of heavier gage was not permissible.

Two approaches to resolving the problem were undertaken: (a) modification of Ti-6Al-4V strip rolling practice to produce textured material with directionally higher fatigue strength, and (b) investigation of Ti-8Mo-8V-2Fe-3Al alloy (Ti-8823) strip as a possible alternate. Because technology for the former approach was thought to be more advanced at time of the ATC program, blade development proceeded using the textured (directional) strip. This report describes the second approach which was carried out as a lower priority backup measure using funds provided by the office of the Project Engineer, HLH-ATC, Army Air Mobility Research & Development Laboratory, Ft. Eustis, Virginia. There were three objectives of the subject investigation:

(a) Determine whether cold rolling could be used to accelerate aging response of solution-annealed Ti-8823 strip in a controlled fashion to produce material with mechanical properties suitable for the nose cap application.

(b) Determine whether nose cap radii could be creep formed at aging temperatures.

(c) Determine whether nose cap radii could be die formed at aging temperatures.

The first objective was accomplished in part by TIMET, a division of Titanium Metals Corporation of America under Contract DAAG46-74-C-0030 (see Appendix). AMMRC, using strip produced by TIMET, measured fatigue properties corresponding to selected aging cycles and conducted forming experiments.

TEST PROCEDURE

Fatigue Testing

Solution-treated-and-35%-cold-rolled 0.060-inch strip provided by TIMET was aged at AMMRC according to the following cycles:

<u>Aging Temperature</u>	<u>Aging Time</u>
1110 F	30, 60, 120 minutes
1150 F	30, 60 minutes

The composition of the ingot from which this strip was rolled appears on page 2 of the Contractor's report (see Appendix). Photomicrographs of the strip material are shown in Figure A-1 of the Appendix.

After the aged strip material had been chem-etched to remove 0.001 inch of metal from each surface it was fashioned into longitudinal fatigue specimens of the design shown in Figure 1. This design was intended to reduce edge-initiating fracture and avoid fretting associated with pin-loading. Six specimens for each aging condition were tested to failure or run-out (10^7 cycles) in alternating (15 Hz) tensile stress, $R = 0.10$, using a 20 kip MTS closed-loop fatigue system.

Creep Forming

A simple fixture was constructed which provided a horizontal pin of 0.25-inch radius over which a length of strip could be balanced with weights attached to each end. This apparatus was placed in an electric furnace and raised to selected temperatures to determine whether creep would bring about conformity with the pin radius within acceptable time/temperature cycles (see Figure 2).

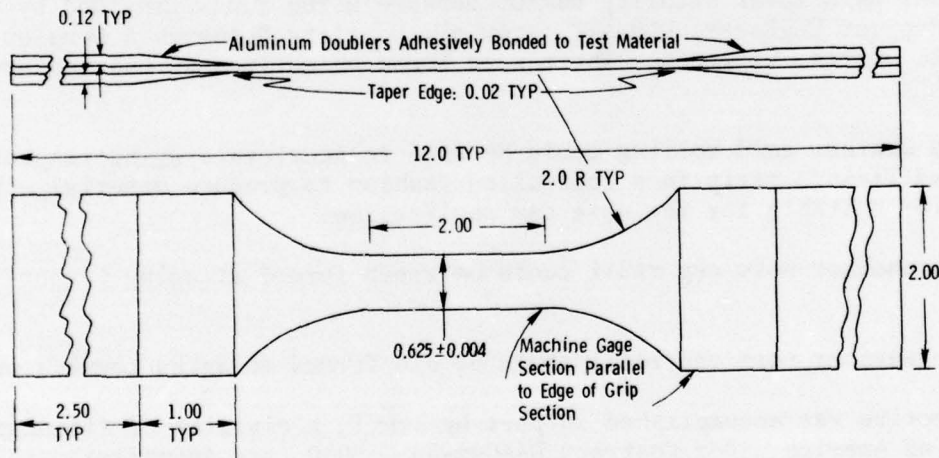


Figure 1. Fatigue test specimen design for sheet materials.

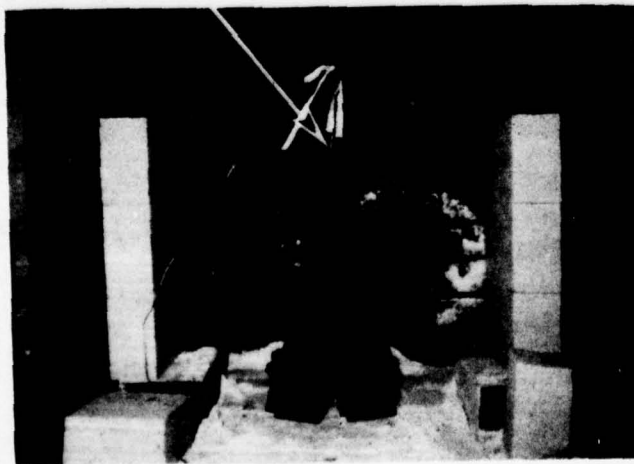


Figure 2. Apparatus for creep forming Ti-8823 strip over 1/2-inch-diameter pin (see arrow).

Die Forming

Several die fixtures, see Figure 3, were constructed to simulate nose cap contours. The nose radii of these dies were 0.25, 0.50, and 0.75 inch, corresponding to the range of radii at various stations along the length of the nose cap. As-received (solution-treated plus 35% cold-rolled) Ti-8823 strip was cold formed in these dies, then removed and checked for spring-back. Strip was also cold formed and retained in the dies, which were placed in a furnace and held for the desired aging cycle. Strip was also warm formed at aging temperature and held in the dies to complete the aging cycle.

DISCUSSION OF RESULTS

Fatigue Tests

The fatigue specimen designed for this program avoided the problem of fretting, as was intended, but did not prevent edge-initiating fractures. Indeed, trial specimens disclosed that fractures were prone to start in the radius just beyond the gage length. This was thought to result from a change in cutting conditions at this point during the numerically controlled milling operation. Increased care in edge preparation alleviated (but did not eliminate) this difficulty in the test series. It may be remarked that for fatigue testing Boeing-Vertol Company (contractor for the HLH-ATC program) uses a rectangular 12 inch \times 2 inch strip specimen with doublers cemented on each end. This latter design is much simpler to machine, but it results in a portion of edge-initiating fractures.

The aging treatments for the fatigue test series were selected on the basis of tensile data shown in Table III of the Appendix. Longitudinal properties are shown plotted against aging time in Figure 4. Since aging of solution-treated Ti-8823 strip requires 4 to 8 hours, 35% cold reduction has accelerated response considerably and in a controllable, reproducible fashion. It appears that yield and tensile strengths fall off logarithmically with aging time while ductility increases. It should be noted that the spread between longitudinal and transverse properties of the aged strip is quite moderate. Since no property advantage accrued from the 480-minute cycle, shorter cycles (30, 60, and 120 minutes) were selected for the test series on the premise that these would cut production time and reduce contamination.

Fatigue test data are presented in Table 1 and plotted in Figure 5. Reference to Figure 5a will show that specimens aged 120 minutes at 1100 F were marginally better than those aged 30 minutes at that temperature; those aged 60 minutes were poorer. Run-out at 40 ksi alternating stress may be projected for specimens aged either 30 minutes or 120 minutes at 1100 F. Figure 5b shows that specimens aged 30 minutes at 1150 F

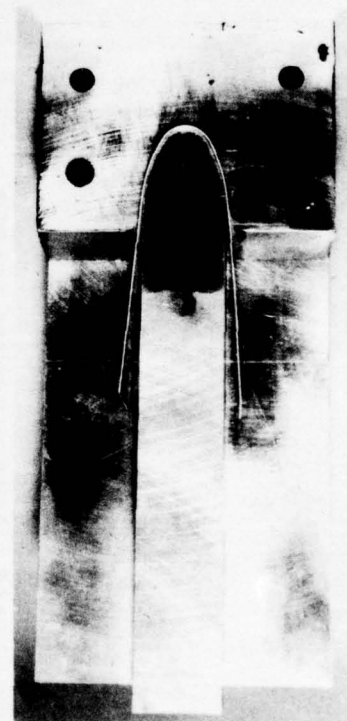


Figure 3. Disassembled die for warm forming Ti-8823 strip to simulated nose cap contour.

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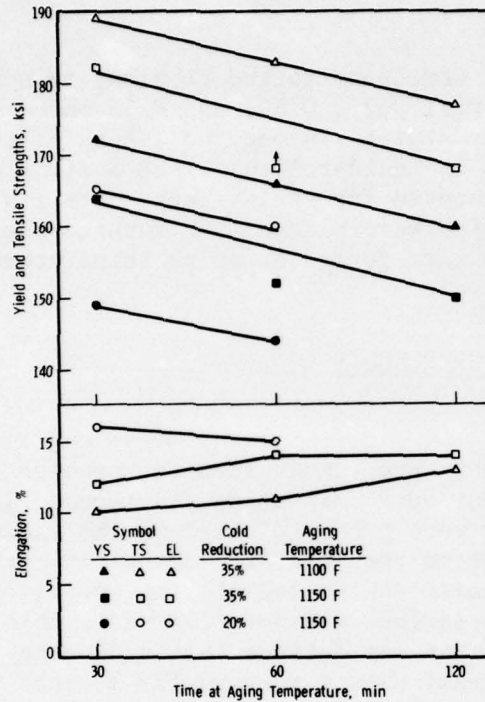


Figure 4. Longitudinal tensile properties of solution-treated-cold-rolled and aged Ti-8823 strip.

Table 1. FATIGUE BEHAVIOR OF SOLUTION-TREATED-AND-COLD-ROLLED Ti-8823 STRIP, 0.060 INCH THICK, TESTED IN ALTERNATING TENSION, R = 0.10

Aging Time, min	Specimen Number	Alternating Stress, psi	Cycles to Failure	Remarks
a. Aged at 1100 F				
30	1	40,000	(3,643,000)*	Specimen holder broke, bending specimen.
	2	50,000	28,000	Break in outer third gage length (GL), central origin.
	3	45,000	(51,200)	Break outside GL in radius.
	4	40,000	(34,400)	Break outside GL in radius.
	5	40,000	10,124,300	No break, specimen removed.
	6	42,500	28,900	Break in outer third GL, edge origin.
60	1	40,000	(77,200)	Break outside GL in radius.
	2	40,000	40,500	Break in outer third GL, edge origin.
	3	30,000	(6,585,300)	Broken in bending by surge of testing machine.
	4	35,000	10,210,000	No break, specimen removed.
	5	40,000	364,500	Break in outer third GL, central origin.
	6	37,500	10,435,000	No break, specimen removed.
120	1	40,000	(40,500)	Break outside GL in radius.
	2	40,000	(67,400)	Break outside GL in radius.
	3	40,000	(6,553,200)	Broken in bending by surge of testing machine.
	4	50,000	500,100	Break in middle third GL, central origin.
	5	45,000	26,900	Break in middle third GL, central origin.
	6	45,000	40,200	Break in outer third GL, central origin.
b. Aged at 1150 F				
30	1	40,000	10,583,200	Break in outer third GL, central origin.
	2	50,000	24,100	Break in outer third GL, central origin.
	3	45,000	(1,874,400)	Broken in bending by surge of testing machine.
	4	45,000	54,500	Break in outer third GL, central origin.
	5	45,000	19,800	Break in outer third GL, central origin.
	6	42,500	(6,504,300)	Break in outside GL in radius.
60	1	40,000	2,063,500	Break in outer third GL, edge origin.
	2	50,000	15,000	Break in outer third GL, edge origin.
	3	45,000	2,800	Break in middle third GL, central origin.
	4	37,500	1,445,900	Break in outer third GL, edge origin.
	5	42,500	67,600	Break in middle third GL, edge origin.
	6	35,000	10,000,000	No break, specimen removed.

*Parenthetical values are questionable, see "Remarks".

Figure 5a. Fatigue behavior of solution-treated-and-cold-rolled Ti-8823 strip, 0.06 inch thick, tested in alternating tension, $R = 0.10$, after aging at 1100 F.

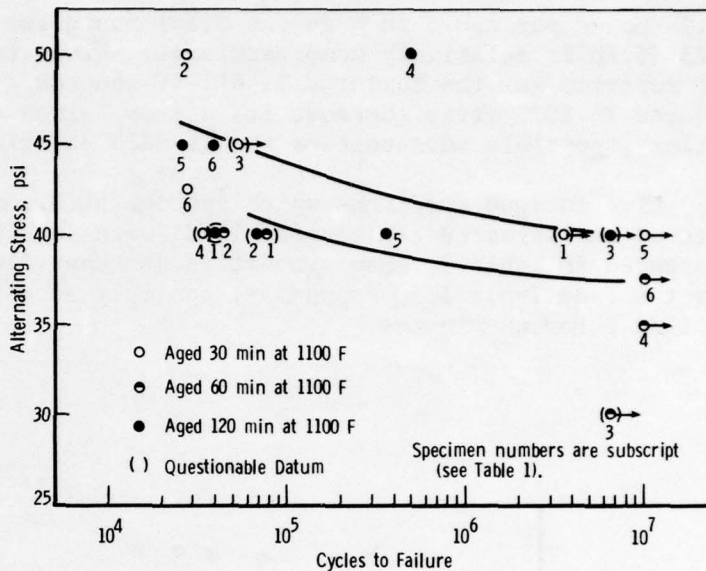
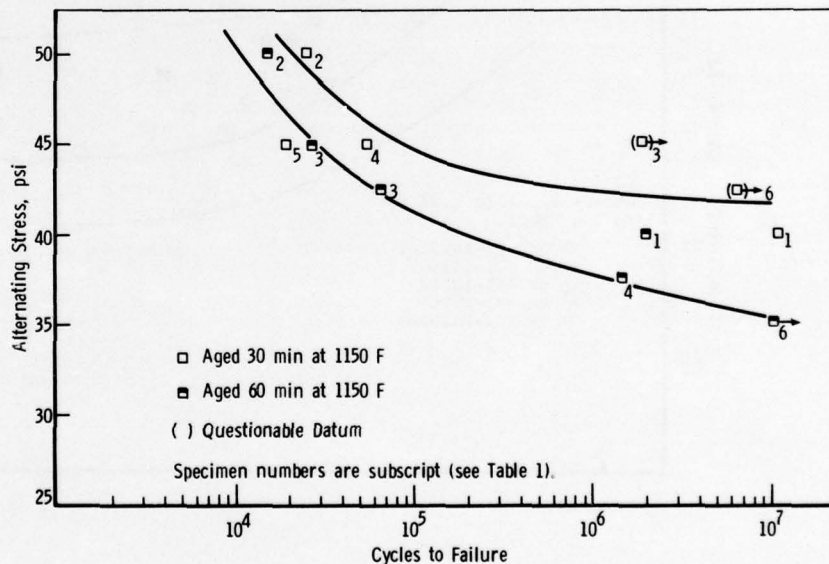


Figure 5b. Fatigue behavior of solution-treated-and-cold-rolled Ti-8823 strip, 0.06 inch thick, tested in alternating tension, $R = 0.10$, after aging at 1150 F.



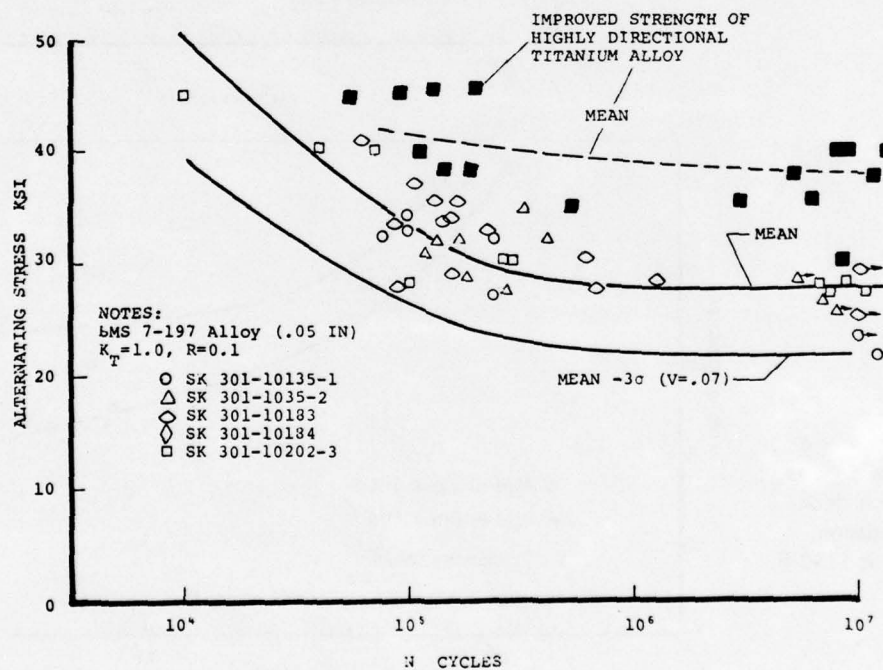
performed better than those aged 60 minutes at this temperature. A run-out stress of 42.5 ksi is projected for 30 minutes aging treatment at 1150 F.

Some difficulties were experienced with control of the fatigue testing machine which in several instances promoted premature failure in compression (see data marked "questionable"). Other questionable data represent failures initiating in the radii of the specimens.

Although these projected run-out values are considerably higher than the mean for standard Ti-6Al-4V annealed strip, they are not substantially better than those of highly directional (textured) strip of that same alloy (see Boeing data, Figure 6). It is well to note, moreover, that Ti-8823 has a density of

0.175 pound per cubic inch versus 0.161 pound for Ti-6Al-4V. However, the Ti-8823 strip is relatively nondirectional. Since transverse fatigue properties are not reported for the textured Ti-6Al-4V and could not be obtained from the cold-reduced Ti-8823 strip (because its narrow 6-inch width precluded specimen preparation), possible advantage of the Ti-8823 material is a matter of conjecture.

Five fatigue specimens which ran out (i.e., remained unbroken after 10^7 cycles at the selected alternating load) were submitted for tension test. The data, presented in Table 2, show properties somewhat lower than reported by the contractor (see Table III, Appendix), possibly excepting the single specimen aged at 1150 F for 60 minutes.



THE BOEING COMPANY
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 CHECKED BY: R. Sandford
 DATE: 9-28-73
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Figure 6. S-N data for 6Al-4V titanium alloy.

Table 2. RESIDUAL TENSILE PROPERTIES OF SOLUTION-TREATED, COLD-ROLLED, AND AGED Ti-8823 STRIP, 0.060 INCH THICK, PREVIOUSLY TESTED* TO RUN-OUT IN ALTERNATING TENSION, R = 0.10

Aging Temp (deg F)	Aging Time (min)	Specimen No.	Yield Strength (ksi) 0.2% Offset	Tensile Strength (ksi)	Elong. (%)	Elastic Modulus (psi)
1100	30	1	161.4	172.8	12.0	16.1×10
1100	30	5	161.4	173.5	12.5	16.5
1100	60	4	155.2	169.8	10.0	15.2
1100	60	6	162.2	174.3	10.0	16.1
1150	60	6	154.9	165.6	15.0	15.4

*See Table 1.

Creep Forming

Experiments were undertaken with the hope that conformity with the 0.25-inch-radius pin could be obtained by creep forming during the aging cycle. This did not prove possible, although symmetrical loading of 15 pounds per inch per side (i.e., 15 pounds on each end of a 1-inch-wide specimen) was sufficient to achieve the 0.75-inch radius in 120 minutes at 1100 F (see Figure 2). Most of the deformation occurred within a few minutes, but then aging set in and relatively less change took place with increasing time. Increase of edge loading beyond the 15 lb/inch/side value was deemed unattractive, because of space limitation and problems of attachment in the actual nose cap forming operation.

Die Forming

It had been hoped by creep forming during aging to avoid a high temperature cycle such as that necessary to creep form Ti-6Al-4V strip to nose cap contours. Since high temperature creep forming of titanium alloys leads to costly removal of oxygen-contaminated surface metal and would likely give rise to quality control problems in production, experimental die forming of Ti-8823 strip to simulated nose cap contours was undertaken to explore this possibility as an alternative low temperature forming process.

Attempts to cold form 0.75-, 0.50-, and 0.25-inch nose radii from 1-inch-wide samples of the strip revealed that the 0.75- and 0.50-inch radii could be achieved, but considerable spring-back occurred on removal from the dies. The samples broke before cold conformity with the 0.25-inch radius was obtained.

When cold formed and then aged in the dies (by placing the die assemblies in an electric furnace), samples displayed no spring-back upon removal. Similarly, when samples were placed between dies already at aging temperature (1100 F) all three nose radii were easily achieved and no spring-back occurred after aging and removal from the die assembly. It would appear, therefore, that warm die forming could be employed to fashion the nose cap section. However, construction of equipment for such an operation would be very costly and present a number of technical problems.

RECOMMENDATIONS

Whereas the HLH nose cap presents unusual forming and fabrication difficulties because of its length, shorter nose caps (for other helicopters) and various airframe structures should be considered for advantages to be realized through application of warm-die-formed Ti-8823 sheet and strip. Results of this investigation suggest that parts could be formed and aged in warm dies using cycles possibly as brief as five minutes. By proper choice of aging temperature, a wide range of useful properties may be obtained, including, as demonstrated, high specific fatigue strength.

Another factor worthy of investigation is material cost. Ti-8823 strip, solution treated and cold reduced for rapid aging response, is readily producible by continuous rolling and continuous vacuum-heat-treatment operations. Accordingly, it may prove to be a less expensive mill product than strip or sheet of other titanium alloys.

CONCLUSIONS

1. Cold rolling has been shown to accelerate aging response of solution-treated Ti-8Mo-8V-2Fe-3Al alloy (Ti-8823) strip. Several combinations of cold reduction and aging appear useful for obtaining reproducibly a wide range of mechanical properties with limited directionality.

2. Strip of Ti-8823 solution-treated and cold-rolled 35% to 0.060 inch in thickness displayed a run-out value of 42.5 ksi when tested in tension-tension fatigue ($R = 0.10$) after aging 30 minutes at 1150 F. Comparable values were determined for similar strip aged 30 and 120 minutes at 1100 F.

3. On the basis of these results, solution treated/35% cold rolled/aged Ti-8823 strip 0.060 inch thick satisfies fatigue strength requirements for the nose cap of the main rotor blade of the developmental heavy lift helicopter HLH.

4. Creep forming the nose cap section from solution-treated/35% cold-rolled Ti-8823 strip during the aging cycle is not possible with edge loads equivalent to those used in production of prototype nose caps under the HLH-ATC program. Since recourse to higher edge loads is considered undesirable, the alloy does not appear to be a suitable alternate material if this creep forming practice were to be used in quantity production of HLH.

5. Warm die forming the nose cap section from solution-treated/35% cold-rolled Ti-8823 strip is possible, but could require equipment development. Warm-die-formed sections would offer the advantages of minimal spring-back and negligible surface contamination.

APPENDIX.

Item A002

FINAL REPORT
on

EFFECT OF COLD REDUCTION ON THE AGING RESPONSE
OF Ti-8Mo-8V-2Fe-3Al ALLOY STRIP

Contract No. DAAG46-74-C-0030

to

Army Materials and Mechanics Research Center
Watertown, Massachusetts

from

G. A. Lenning
TIMET
Toronto, Ohio

July 2, 1974

FINAL REPORT
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Page 1

OBJECT

To determine the effect of cold rolling reduction on the aging response of Ti-8Mo-8V-2Fe-3Al alloy strip.

SUMMARY

Considerable promise for the approach of cold rolling to accelerate aging response of the Ti-8Mo-8V-2Fe-3Al alloy was demonstrated. Several combinations of cold reduction and aging appear useful and reproducible for developing a wide range of strengths. In the range of 145 to 180 Ksi yield strength it would appear possible to develop reproducible properties within what is known of the range of current control on forming and sizing variables. As strength level aim increases control of the variables would become more critical. Additional study of the effect of heat-to-heat, penultimate reduction-anneal cycles and aging variables would be required before control limits on strength could be established.

An unexpected range of instability was found in the cold reduction-aging temperature-aging time range examined where reproducibility is questionable even with laboratory control of aging temperature. The data obtained, however, indicate that process variables could be chosen to avoid this unstable range.

INTRODUCTION

The Ti-8Mo-8V-2Fe-3Al alloy is an age hardenable beta titanium alloy readily produced as a unidirectionally rolled strip material. Normally, beta alloy materials are supplied in the cold rolled plus solution annealed 1450F, 788C condition. The fabricator hot or cold forms the desired shape and then ages the formed part at 1000 to 1100F, 538 to 593C for times up to 16 hours in dies to retain the formed shape. Cold work following the solution anneal is known to accelerate the aging reaction in most age hardenable alloys, and preliminary data indicate this acceleration of aging exists in the Ti-8Mo-8V-2Fe-3Al alloy.

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The purpose of this investigation was to determine if the aging characteristics of cold reduced material can be controlled sufficiently for practical application. The advantages of accelerated aging would be lowered costs by decreasing age time and the expense of contamination removal. The three prior reports covered preparation and hardness test results.

MATERIALS AND PROCEDURES

The starting material for this investigation was approximately 0.150-in. gage x 36-in. wide hot band rolled at 2050F. The ingot number was K5055 which analyzed:

<u>Element</u>	<u>Wt, %</u>
Mo	8.0
V	8.2
Fe	2.0
Al	3.0
O ₂	0.14
N ₂	0.011

The material from this particular coil had been rolled to strip and thoroughly evaluated at 0.060, 0.040, and 0.020-in. gage for an internal development program at TIMET.

The material for the present investigation was rolled as short panels without tension applied on a 2-high, 4-high Fenn laboratory mill. This mill is normally used for research and development studies on new alloys and processes before application to the production Zendzimir mill in the Toronto Plant.

The electrical resistance laboratory furnace used for the solution anneal treatments of 1450F-8mins has a cycle of $\pm 7F$ around the control point which is less than the cycle for production type furnaces. This same furnace was used for aging where the thermal cycle in the 1100 to 1250F range was plus or minus 15F, but again less than for conventional production furnaces used for aging. Furnace temperatures were measured with chromel-alumel thermocouples and a semi-precision potentiometer. Aging times are time at temperature as measured with the thermocouple resting on top of the pieces being aged. All aging was by placing the cold material in a hot furnace so as to minimize heat-up time.

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Levels of cold reduction investigated were 35, 50, and 58 per cent with aging at 1100, 1150, 1200, and 1250F for times of 5, 30, 60, 120, 240, 480, and 960 minutes. An additional reduction level of 20% was also examined for 1150F aging for the times above. Penultimate reduction was varied to give a 0.060-in. gage final at all reduction levels.

Hardness was determined on a section through the 0.060-in. sheet thickness using the elongated indenter with the long axis parallel to the sheet surface. The five hardness impressions were all placed in a line at the mid thickness level through the sheet. The hardness tester was calibrated prior to use on this program by a factory representative, and the single operator who took the readings checked the machine with a calibrated test block immediately prior to starting the program. The tensile machine used is a screw driven Riehle having multiple load ranges up to 120,000 pounds.

RESULTS

Knoop hardness results are shown in Table I. The accelerating effect of cold reduction on aging kinetics is readily apparent from comparison of these data with those in reference 1. For example, the 35% cold reduced material aged to a peak hardness at 1100F sometime between 5 minutes and 60 minutes; whereas, the as-solution annealed material in reference 1 had hardness increasing out to 24 hours. At 50 and 58% cold reduction, maximum hardness at 1100F was reached in less than 30 minutes and possibly less than 5 minutes.

The secondary aging peak at 240 minutes shown for the 35% cold reduced aged at 1150F for 120 minutes and longer condition also occurred for other conditions, e.g. 58% cold reduced and aged at 1150F for 60 minutes. This secondary hardening remains an anomaly outside the scope of the present study. Metallographic examination showed some evidence of recrystallization in samples aged longer than 120 minutes at 1250F for the 58% cold reduced material. The trend toward a secondary peak was reproducible as shown in Table II for this same 35% cold reduced material aged at 1150F and for re-rolled and re-aged material. The hardness level of 333 for the re-rolled and re-aged was somewhat lower than the 357 and 356 values obtained for the original material indicating an unstable region which should probably be avoided in view of the aims of the present program.

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Other areas of the aging temperature-time relations, such as 50% cold reduced and aged at 1100, 1200, and 1250F appeared reasonably reproducible as shown by comparison of Table I and Table II results.

Tensile results for selected conditions are shown in Table III. These values are consistent among themselves; and when yield and tensile strengths are compared against hardness, a reasonable correlation is obtained with all points on a graph of strength vs. hardness in a ± 6 Ksi band. Reproducibility was also good for the 1100F-120minute aging of the 35% cold reduced material (see footnote).

RECOMMENDATIONS FOR FUTURE WORK

Obviously, process capabilities and other factors unknown at this time will weigh heavily on future plans. From the standpoint of the roller, factors needed to establish a process for making cold rolled material to a specific gage would be 1) importance of controlling reduction level, and 2) the effect of reduction and annealing practice from hot band gage, 0.15 to 0.18-in., to the gage for annealing. Fabrication of the finished part is more complicated; but the factors of aging temperature control, aging time, and rate of heating to the age temperature should be considered and investigated relative to process capabilities.

TABLE I

Aging Response of Ti-8Mo-8V-2Fe-3Al Alloy Strip
for Three Levels of Cold Reduction
as Determined by Hardness

<u>Aging Treatment</u>		<u>Knoop Hardness 1.0Kg¹</u>			
<u>Temp, F</u>	<u>Time, Mins.</u>	<u>20% Cold Rolled & Aged</u>	<u>35% Cold Rolled & Aged</u>	<u>50% Cold Rolled & Aged</u>	<u>58% Cold Rolled & Aged</u>
0	0	329	311	314.8	326.7
1100	5		372.3	391.7	388
	30		383.6	373.1	373.8
	60		376.5	368.5	367.8
	120		367	356.8	363.3
	240		357.5	355.7	357.1
	480		354.3	354.3	353.3
	960		345.6	348	346
1150	5	336	345.6	350.8	359.7
	30	334	348.7	357.5	348.4
	60	335	347	344.3	388.8
	120	319	337.9	333.7	370.4
	240	319	357.1	336.6	345.6
	480	316	341.6	331.1	346.7
	960	303	334	328.9	340.6
1200	5		340.6	331.1	327.9
	30		338.9	321.8	318.7
	60		327.9	318.4	313.0
	120		325.7	322.4	304.2
	240		317.8	313.0	298.9
	480		325.4	308.4	317.5
	960		313.3	308.7	321.8
1250	5		316.9	303	323
	30		319	306.7	314.2
	60		311.6	299.7	318.4
	120		309.8	299.7	310.7
	240		309.5	300.2	312.2
	480		298.3	297.5	307.2
	960		299.7	301.4	301.6

¹Values shown are the average of five readings.

TABLE II

Retests for Aging Response
of Ti-8Mo-8V-2Fe-3Al Alloy Strip
for Levels of Cold Reduction Indicated

<u>Aging Treatment</u>		<u>Knoop Hardness 1.0 Kg</u>		
<u>Temp, F</u>	<u>Time, Mins.</u>	<u>35% Cold Rolled and Aged</u>	<u>50% Cold Rolled and Aged</u>	<u>58% Cold Rolled and Aged</u>
1100	5	-	382	-
	30	-	367	-
	120	-	363	-
	480	-	353	-
1150	30	-	-	333.4
	60	-	-	335
	120	348*, 329.9	-	-
	240	356*, 333.1	-	-
1200	5	-	342	-
	30	-	329	-
	120	-	327	-
	480	-	320	-
1250	5	-	314	-
	30	-	311	-
	120	-	312	-

*These values are for same pieces prepared for original results.
Unmarked values are for newly rolled and aged materials.

TABLE III

Aging Response of
Cold Rolled Ti-8Mo-8V-2Fe-3Al Alloy Strip
as Determined by Tensile Properties

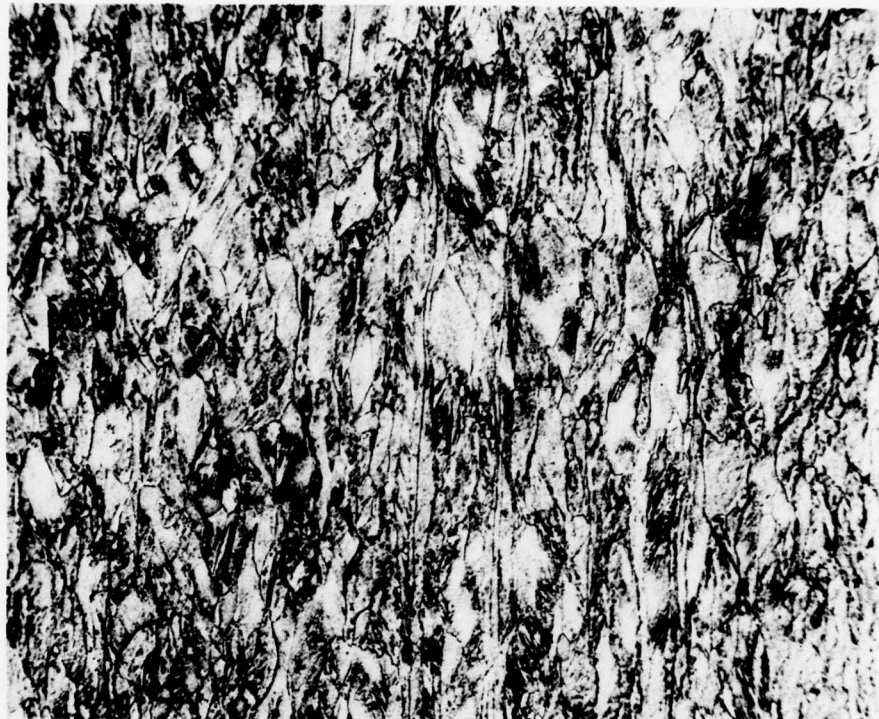
Cold Reduction, %	Aging		Test Direction	Tensile Properties		
	Temp, F	Time, Mins.		UTS, Ksi	YS, Ksi	Elong, %
20	1150	30	L	165	149	16
"	"	"	T	169	157	12
"	"	60	L	160	144	15
"	"	"	T	169	150	12
35	no	-	L	161	145	12
"	no	-	T	165	137	10
"	1100	30	L	189	172	10
"	"	"	T	198	187	7
"	"	60	L	183	165	11
"	"	"	T	194	180	9
"	"	120	L	177	160	13
"	"	"	T	187	174	8
35 ¹	1100	120	L	178	162	13
" ¹	"	"	T	186	174	7
" ¹	"	480	L	171	154	11
" ¹	"	"	"	171	154	12
"	"	"	T	179	165	9
"	"	"	"	179	167	10
35	1150	30	L	182	164	12
"	"	"	T	190	178	8
"	"	60	L	168	152	14
"	"	"	T	173	162	10
"	"	120	L	168	150	14
"	"	120	T	178	165	10

¹Samples rolled and aged independently of prior samples.

REFERENCES

- 1) Hunter, D. B., "Metastable Beta Sheet Alloy Ti-8Mo-8V-2Fe-3Al," Final Technical Report, Part 1, WAL TR 405/2-14 on Contract DA-30-069-ORD-3743, October, 1966.

a. Longitudinal



b. Transverse

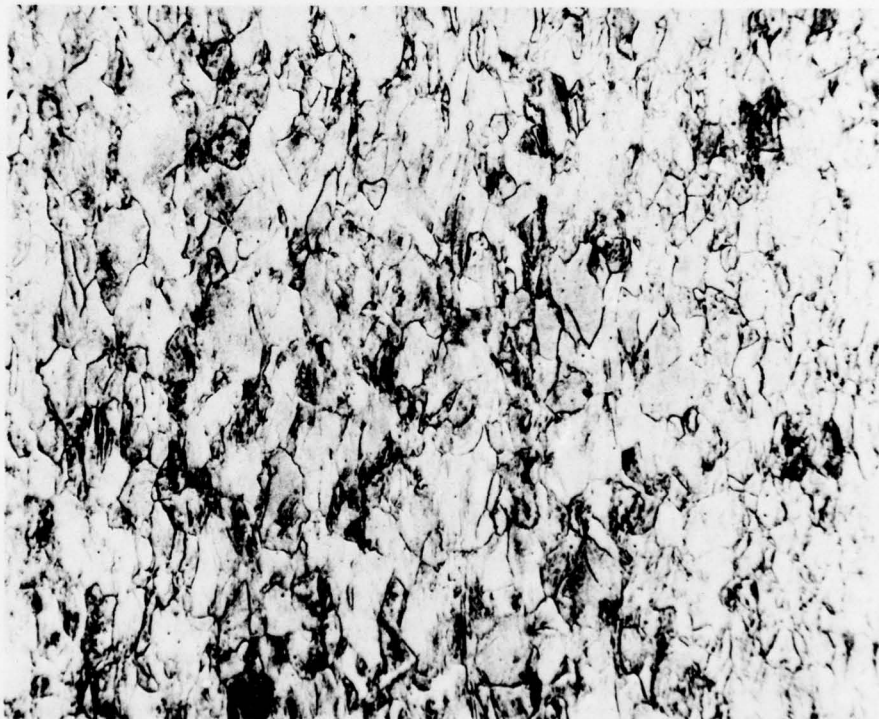


Figure A-1. Microstructures of Ti-8823 strip solution-treated, cold-rolled 35%, and aged 1150 F for 30 minutes. Mag. 100X

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