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WELDABILITY AND BRAZEABILITY OF FORMABLE SHEET TITANIUM ALLOYS.(U)

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WELDABILITY AND BRAZEABILITY OF FORMABLE SHEET TITANIUM ALLOYS

Structural Metals Branch
Metals and Ceramics Division

September 1977

TECHNICAL REPORT AFML-TR-77-165

Final Report for Period June 1970 to December 1976

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AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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Donald W. Becker

D. W. BECKER
Project Monitor

FOR THE COMMANDER

Nathan G. Tupper

N. G. TUPPER
Acting Chief, Structural Metals Branch
Metals and Ceramics Division
Air Force Materials Laboratory

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Three metastable beta titanium alloys were evaluated for their weldability and brazeability. The alloys were Ti-8V-7Cr-3Al-4Sn-1Zr, Ti-8V-4Cr-2Mo-2Fe-3Al, and Ti-15V-3Cr-3Al-3Sn. The material evaluated was in the form of .100 inch sheet and was processed by hot rolling and also hot plus cold rolling. The weldability was evaluated by longitudinal bead on plate weld tensile specimens. Lap shear tensiles prepared with Al3003 filler metal were used to determine the braze strength. The rating for the alloys according to weldability and in order of performance was determined to be Ti-8V-7Cr-3Al-4Sn-1Zr, Ti-15V-3Cr-3Al-3Sn,

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and Ti-8V-4Cr-2Mo-2Fe-3Al. Normal brazing practice was found to be acceptable for all three titanium alloys.

FOREWORD

This report was prepared by Mr. D. W. Becker, Structural Metals Branch, Metals and Ceramics Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. The research was performed under Task Number 24180402, "Welding of High Strength and High Temperature Aerospace Alloys."

The report covers work performed during the period from June 1975 to December 1976.

The author wishes to express his appreciation to Robert Leese, University of Dayton, for conducting the welding studies and to Vince Vidoni, University of Dayton, for conducting the brazing tests.

TABLE OF CONTENTS

SECTION		PAGE
I	INTRODUCTION	1
II	EQUIPMENT	2
III	MATERIAL	4
IV	WELDABILITY TESTS	9
V	BRAZING TESTS	11
VI	RESULTS	16
	1. Welding	16
	2. Brazing	27
VII	DISCUSSION - WELDING	29
VIII	DISCUSSION - BRAZING	34
IX	CONCLUSIONS	35
X	REFERENCES	36

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Centorr Cold Wall Vacuum Furnace with Power and Control Panel	3
2	Ti-8V-7Cr-3Al-4Sn-1Zr Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing	6
3	Ti-8V-4Cr-2Mo-2Fe-3Al Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing	7
4	Ti-15V-3Cr-3Al-3Sn Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing	8
5	Longitudinal Weld Tensile Configuration	9
6	Critical Portion of Braze Thermal Cycle	12
7	Brazed Lap Shear Tensile Specimen	13
8	Brazing Platen with Assembled Braze Coupons	14
9	Base Metal Tensile Specimen Configuration	14
10	Tensile Properties of Ti-8V-3Al-4Sn-1Zr Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging	17
11	Tensile Properties of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging	18
12	Tensile Properties of Ti-15V-3Cr-3Al-3Sn Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging	19
13	Fusion Zone of Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500.	20
14	Near Heat Affected Zone in Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500.	20

LIST OF ILLUSTRATIONS (CONTINUED)

FIGURE		PAGE
15	Far Heat Affected Zone in Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500.	21
16	Fusion Zone Transgranular Failure in Ti-8V-7Cr-3Al 4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Seven Hours. X80.	21
17	Fusion Zone of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1050°F (566°C) for Four Hours. Etchant: Krolls Reagent. X500.	23
18	Fusion Zone of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1250°F (677°C) for 16 Hours. Etchant: Krolls Reagent. X500.	23
19	Fusion Zone Fracture Surface of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1050°F (566°C) for Four Hours. X160.	24
20	Heat Affected Zone Fracture Surface of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1150°F (621°C) for Eight Hours. X160.	24
21a	Fusion Zone of Ti-15V-3Cr-3Al-3Sn Alloy. Post Weld Aged at 1150°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500.	25
21b	Near Heat Affected Zone of Ti-15V-3Cr-3Al-3Sn Alloy. Post Weld Aged at 1150°F (566°C) for Eight Hours. X500.	25
22a	Fusion Zone of Ti-15V-3Cr-3Al-3Sn Alloy. Post Weld Aged at 1150°F (621°C) for Eight Hours. Etchant: Krolls Reagent. X500.	26
22b	Fusion Zone of Ti-15V-3Cr-3Al-3Sn Alloy. Post Weld Aged at 1250°F (677°C) for 16 Hours. Etchant: Krolls Reagent. X500.	26
23	Summary of Best Post Weld Treatment Conditions for the Three Alloys Evaluated	33

LIST OF TABLES

TABLE		PAGE
1	Mill Annealed Tensile Properties of the Three Alloys of Interest	5
2	Welding Conditions	10
3	Braze Lap Shear Strength	27
4	Braze Lap Shear Strength After Salt Exposure	28
5	Effect Braze Cycle on Base Metal Properties	28
6	Summary of Weldment Performance	32

SECTION I

INTRODUCTION

Formable sheet titanium alloys are metastable beta alloys. This class of titanium alloys is of special interest because of its good fabricability and because of its good aging response to high strength levels and high toughness.

Three formable sheet titanium alloys were recently evaluated on the basis of formability, formageability,and uniformity of properties under USAF Contract F33615-74-C-5063. The envisioned use of these alloys pointed to the need for an evaluation of their brazeability and weldability.

A program intended to evaluate primarily the weldability and to a lesser extent the brazeability of these alloys was undertaken within the Joining Technology Group of the Air Force Materials Laboratory.

SECTION II

EQUIPMENT

The two major pieces of equipment utilized in this program were a vacuum furnace for heat treating and brazing and the automatic welding equipment used in preparing the welded test samples.

The vacuum furnace used in this program was the cold wall Centorr furnace shown in Figure 1. The furnace temperature is regulated by a single thermocouple located in the platen. Three additional thermocouples are used to monitor the temperature distribution in the furnace. The control panel of the Centorr furnace is equipped with a Data Trak card reader, providing the capability for programmed thermal cycles.

Automatic welding equipment consisting of a Sciaky power supply and welding torch with an Airline welding fixture were used for this program. The power supply was used in the constant current mode and is capable of delivering 400 amperes of current. The welding torch was a conventional gas tungsten arc torch with a 1/8-inch diameter, 2% thoriated tungsten electrode. The electrode was ground to a point with a 30° included angle.

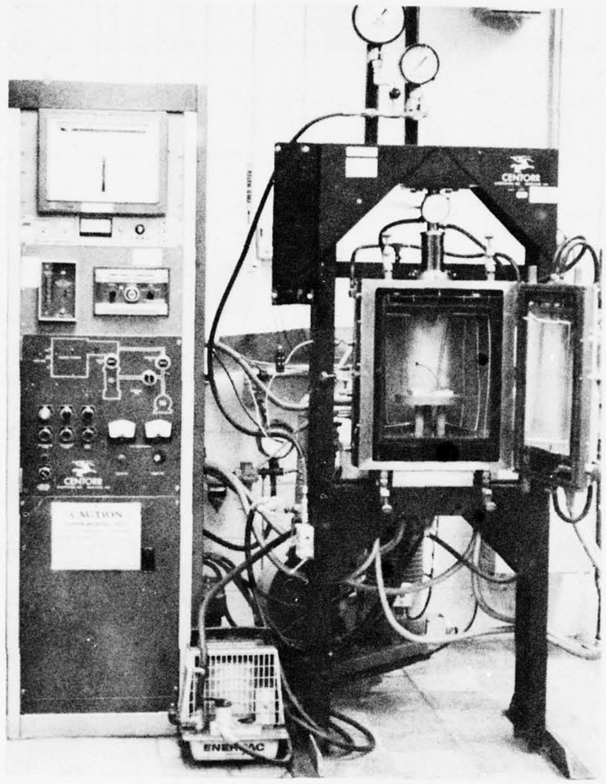


Figure 1. Centorr Cold Wall Vacuum Furnace with Power and Control Panel

SECTION III

MATERIAL

The three formable sheet titanium alloys evaluated in this program were Ti-15V-3Cr-3Al-3Sn, Ti-8V-4Cr-2Mo-2Fe-3Al, and Ti-8V-7Cr-3Al-4Sn-1Zr. These alloys were supplied by Titanium Metals Corporation of America in the form of .100 inch sheet. The sheet had been processed by either hot rolling at 1750°F (954°C) to final thickness, or by hot rolling to .250 inches and cold rolling to final gage thickness. A final annealing treatment for both conditions consisted of an air anneal at a temperature and time which varied for each alloy in order to develop a uniformly recrystallized microstructure. The annealing conditions are given in Table 1. Material for both processing conditions was made available for the three alloys of interest. The hot rolled material was selected for the braze evaluation work with mill annealed Ti-6Al-4V included as a control material. The weldability tests were restricted to the hot plus cold rolled material.

Base metal tensile strength data of the three alloys and two processing conditions can be found in Table 1 and Figures 2, 3, and 4. These data were extracted from AFML-TR-76-45 so that a proper comparison of base metal and welded properties can be made.

TABLE 1

MILLED ANNEALED TENSILE PROPERTIES OF THE THREE ALLOYS OF INTEREST

Hot Rolled - 1750°F (954°C)

		Anneal			Tensile Properties		
Alloy	Nominal Ga., In.	Temp, F (C)	Time, Mins.	Test Dir.	UTS, Ksi	YS, Ksi	El %
Ti-8V-7Cr-3Al-4Sn-1Zr	.100	1400 (760)	20	L	124	120	19
Ti-8V-4Cr-2Mo-2Fe-3Al	.100	1500 (816)	20	L	121	117	22
Ti-15V-3Xr-3Al-3Sn	.100	1450 (788)	20	L	111	107	21

Hot Plus Cold Rolled

		Anneal			Tensile Properties		
Alloy	Nominal Ga., In.	Temp, F (C)	Time, Mins.	Test Dir.	UTS, Ksi	YS, Ksi	El %
Ti-8V-7Cr-3Al-4Sn-1Zr	.100	1400 (760)	10	L	121	119	23
Ti-8V-4Cr-2Mo-2Fe-3Al	.100	1500 (816)	10	L	124	119	19
Ti-15V-3Cr-3Al-3Sn	.100	1450 (788)	10	L	110	106	24

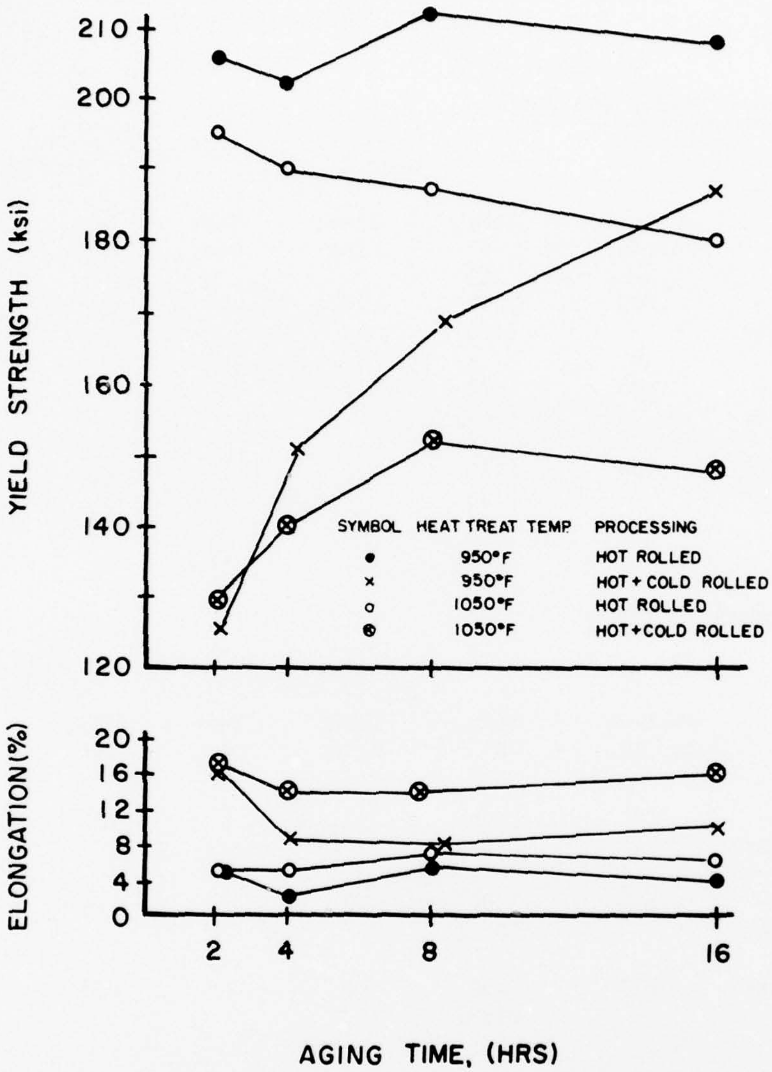


Figure 2. Ti-8V-7Cr-3Al-4Sn-1Zr Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing

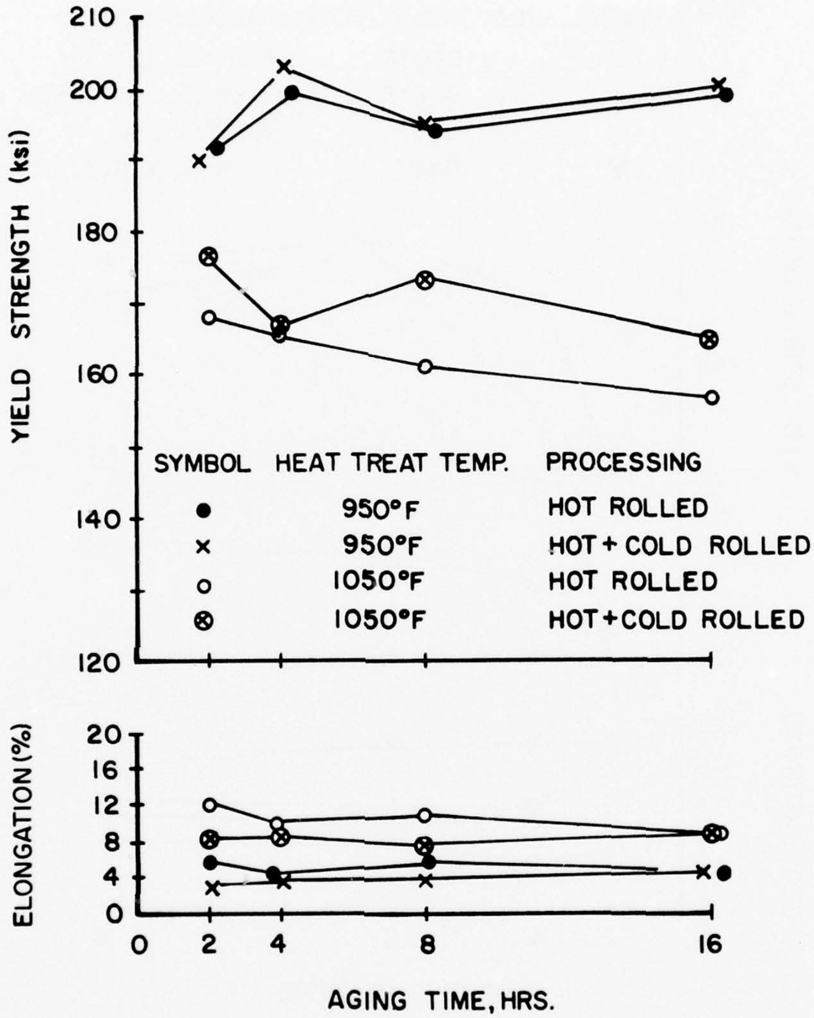


Figure 3. Ti-8V-4Cr-2Mo-2Fe-3Al Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing

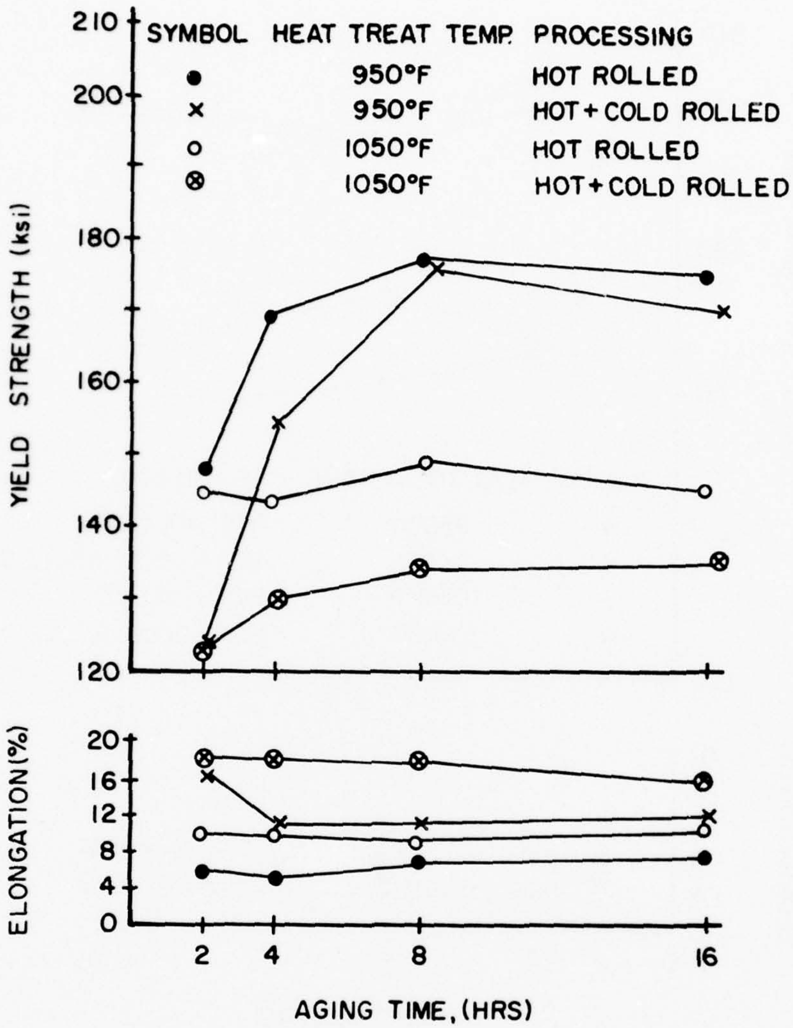


Figure 4. Ti-15V-3Cr-3Al-3Sn Alloy Aged at 950°F (510°C) and 1050°F (566°C) with Hot Rolled and Hot + Cold Rolled Processing

SECTION IV

WELDABILITY TESTS

The object of this portion of the study was to determine the weldability of each of the three formable sheet alloys. There are many material properties which can be determined to aid in making such a decision. The relative importance of these properties is determined by the specific application of the material. Since these alloys are likely to be a source of lower cost titanium sheet, the tensile properties of the welded material serve as an adequate indicator for weldability. Had the principal application been in thick sections, therefore requiring thick section weldments, fracture toughness would have been a more suitable screening parameter.

The test specimen selected for this study was the longitudinal weld tensile specimen shown in Figure 5. The annealed test samples were welded according to the conditions identified in Table 2. All the welds were autogeneous bead on plate welds.

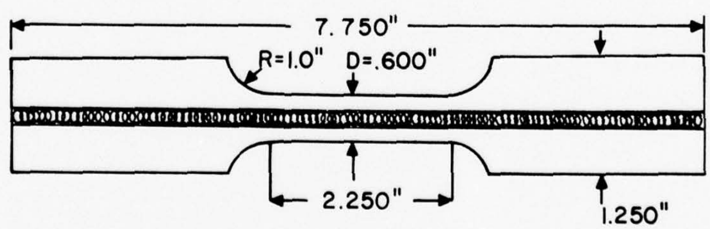


Figure 5. Longitudinal Weld Tensile Configuration

TABLE 2

WELDING CONDITIONS

MODE:	Direct current, straight polarity
POTENTIAL:	10V
CURRENT:	155 amps
TRAVEL SPEED:	6.0 in/min.
TORCH GAS:	argon, 15 CFH
TRAILING GAS:	argon, 30 CFH
BACK-UP GAS:	argon, 15 CFH

The samples were aged in the Centorr vacuum furnace previously described following welding. A range of heat treatment temperatures and times was selected in order to identify the post weld heat treatment which would offer the best combination of strength and ductility. The aging temperatures selected were 1050°F (566°C), 1150°F (621°C), and 1250°F (677°C) for 4, 8, and 16 hours.

SECTION V

BRAZING TESTS

Although it was not anticipated that there would be any brazing problems unique to these metastable beta titanium alloys, a brief program was initiated to confirm this. A wide range of braze filler alloys could have been used in such a study including the titanium base, aluminum base and silver base alloys. Since the base metal alloys to be evaluated were metastable beta alloys and heat treatable to high strengths, the flow temperature of the filler metal selected must be compatible with that of the substrate mechanical property requirements. Too high a flow temperature could cause excessive overaging or rapid beta grain growth. The low alpha-beta transus of the substrate alloys and rapid grain growth which occurs above this transus eliminated the high melting point braze alloys. This leaves the aluminum braze and the silver base braze alloys. Since the corrosion problems of the aluminum base braze alloys is less severe than the silver base alloys, an aluminum braze was selected. The final selection of Al 3003 was made because of the significant amount of data available in the Boeing reports associated with the SST program. The composition of this alloy is aluminum and 1.2% manganese, with a liquidus of 1210°F (954°C).

It was reported in a Boeing Aerospace Company report that it was necessary to control the titanium-aluminum intermetallic by controlling the brazing thermal cycle. Figure 6 illustrates the degree of control recommended. A three hour thermal program, compatible with the recommended thermal cycle, was placed on a card for the Data Trak card reader. This offered excellent reproducibility in the brazing thermal cycle. It was assumed that the substrate alloys under consideration, if used in a brazed assembly, would be brazed in the STA condition. The metastable beta titanium alloy coupons were therefore aged at 950°F (510°C) for 8 hours before brazing.

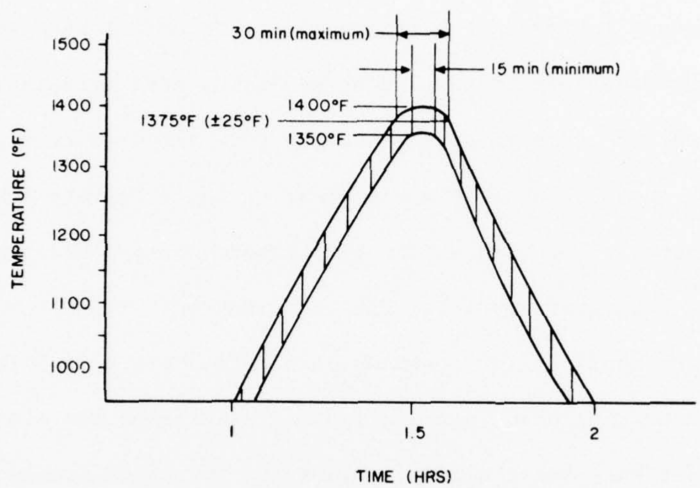


Figure 6. Critical Portion of Braze Thermal Cycle

The brazed specimen configuration used in this study was the lap shear tensile specimen shown in Figure 7. These test specimens were made by performing the brazing operation on a fixturing furnace platen. The platen was designed to maintain a constant braze coupon overlap distance of .375 inches. The braze specimens were prepared by first cutting rectangular shaped base metal coupons, 1.25 inches by 5 inches. These were then pickled in a solution of 35% HNO_3-5%HF-60%H_2O. Two narrow strips of .002-inch thick titanium foil were spot welded to the surface of one of the base metal coupons.

These shims controlled the joint gap and were located in a region which was machined off during final specimen preparation. The braze alloy was .004 inch thick foil which was prepared for brazing by light abrasion. The braze alloy was preplaced in the braze joint area between the two titanium foil shims. The brazing platen containing the final assembled braze coupons is shown in Figure 8. This method of brazed test coupon preparation differs only slightly from the AWS standard procedure.

The brazing test matrix was designed to determine the as-brazed shear strength, the shear strength after salt exposure, and the effect of the braze thermal cycle on base metal properties. The lap shear tensiles exposed to the salt after final specimen machining. The salt exposure consisted of coating the brazed area with a slurry of NaCl and placing them in a furnace at 500°F (260°C) for 200 hours.

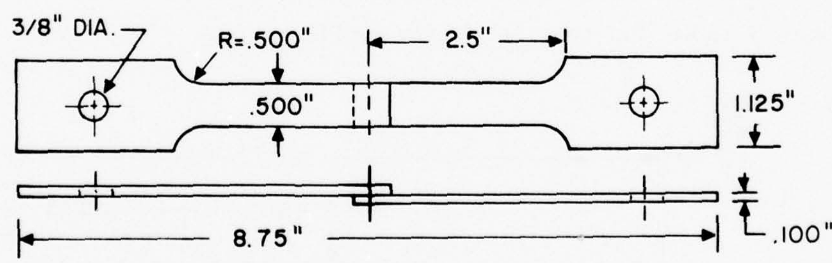


Figure 7. Brazed Lap Shear Tensile Specimen

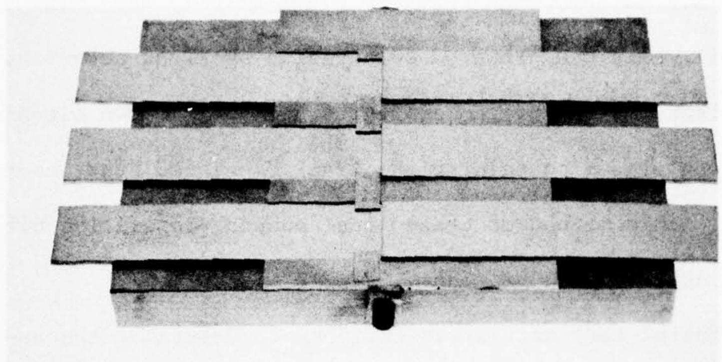


Figure 8. Brazing Platen with Assembled Braze Coupons

The effect of the braze thermal cycle on the substrates mechanical properties was determined by tensile testing the substrate alloys in the STA condition and in the STA condition plus a simulated braze thermal cycle. Each alloy received the proper solution or annealing treatment plus the 950°F (510°C) age for 8 hours and half of the base metal tensile specimens received an additional thermal cycle identical to the braze thermal cycle. Figure 9 shows the tensile coupon configuration.

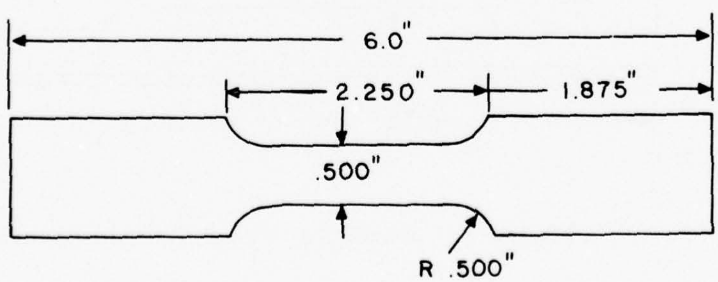


Figure 9. Base Metal Tensile Specimen Configuration

The brazed lap shear tensiles and the base metal specimens which received a simulated braze cycle were tested in the as-brazed condition on an Instron tensile machine with a cross head speed of .02-inches per minute.

SECTION VI

RESULTS

WELDING

The tensile test data for the welded samples is summarized in Figures 10, 11, and 12. Each point in these figures is the average of duplicate tests. Following tensile testing, metallographic sections were cut from the grip sections of the samples; and the fracture surfaces were examined on a scanning electron microscope. In describing these results,the terms near and far heat affected zones will be used to refer to regions in the heat affected zones relative to the fusion zone.

Ti-8V-7Cr-3Al-4Sn-1Zr

Metallographic examination of the Ti-8V-7Cr-3Al-4Sn-1Zr welded samples which were aged at 1050°F (566°C) for 8 hours showed a fairly uniform precipitation of alpha in the fusion zone and the near heat affected zone. In the far heat affected zone the alpha precipitation was concentrated more at the grain boundaries. This can be seen in Figures 13, 14, and 15. Aging at 1150°F (621°C) and 1250°F (677°C) produced microstructures which had fewer, and increasingly course alpha precipitates with increasing grain boundary alpha precipitation.

The fracture surface of the samples aged at 1150°F (566°C) appeared to be principally dimpled transgranular failure in the fusion zone (Figure 16) with increasing amounts of ductile appearing intergranular fracture occurring further away from the fusion zone. Examination of the fractured samples aged at 1150°F (621°C) and 1250°F (677°C) revealed increasing amounts of intergranular fracture with increasing aging temperature and time. This correlates well with the noted grain boundary alpha precipitation.

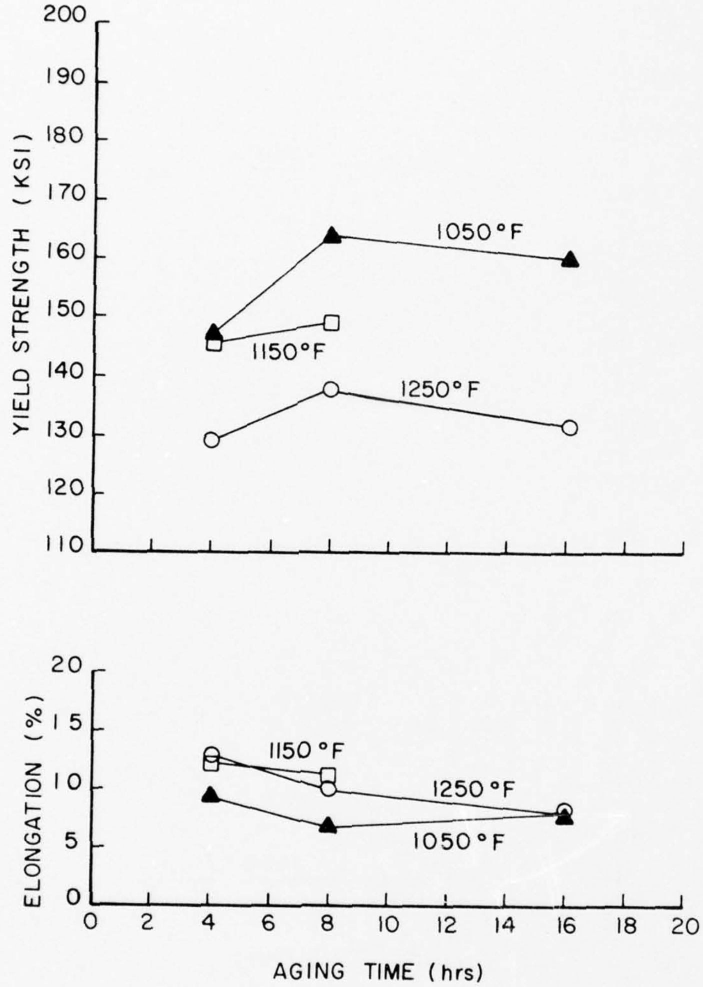


Figure 10. Tensile Properties of Ti-8V-7Cr-3Al-4Sn-1Zr Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging

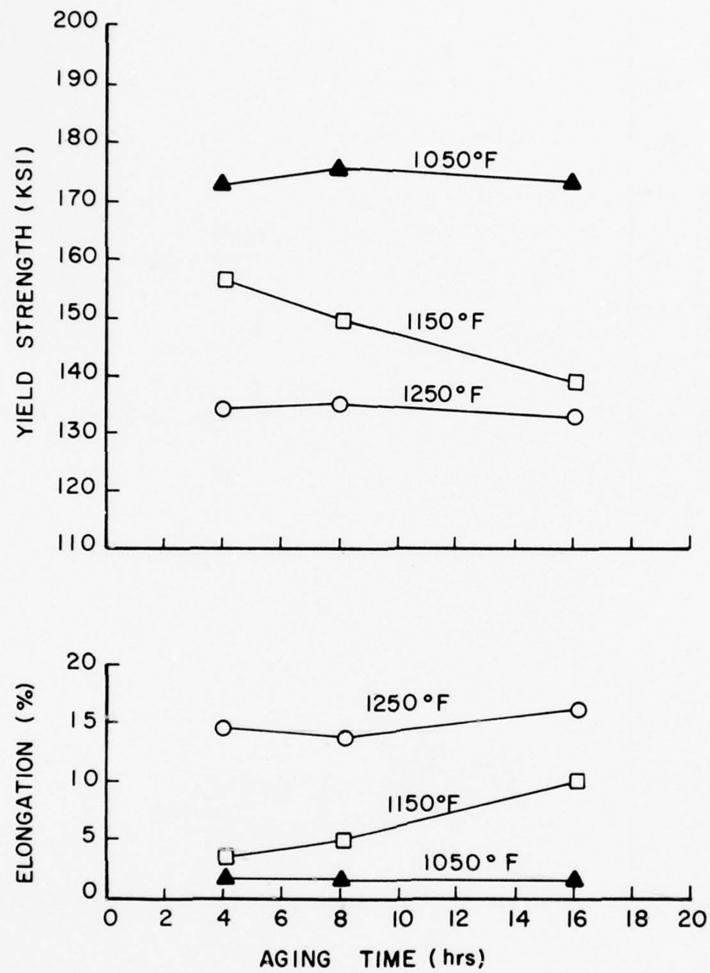


Figure 11. Tensile Properties of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging

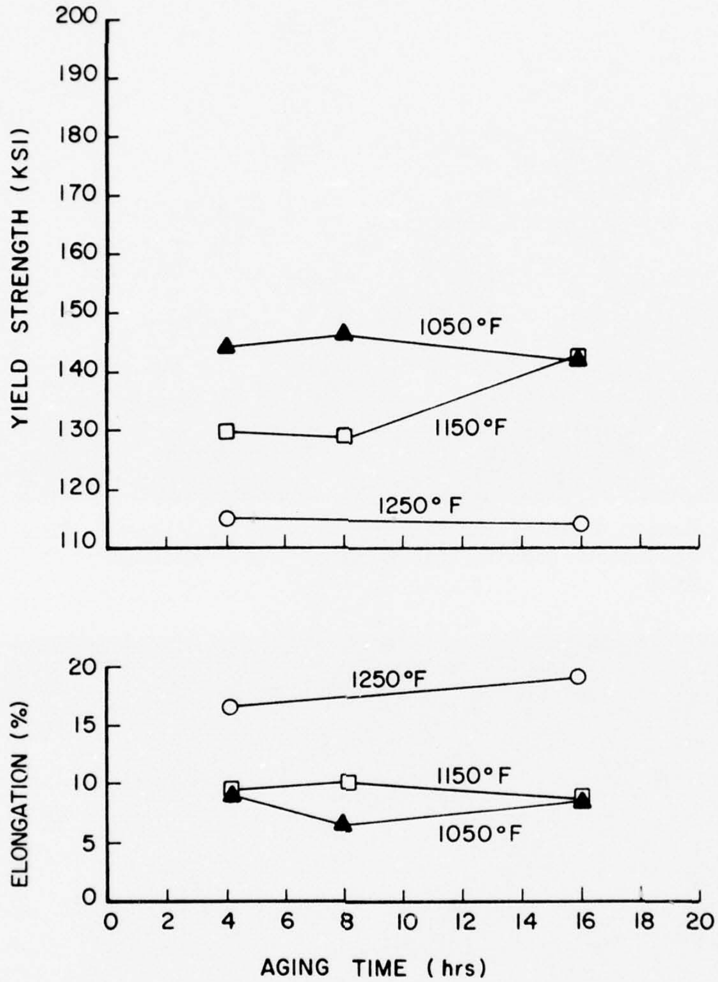


Figure 12. Tensile Properties of Ti-15V-3Cr-3Al-3Sn Alloy Processed by Hot Plus Cold Rolling, Welding, and Aging

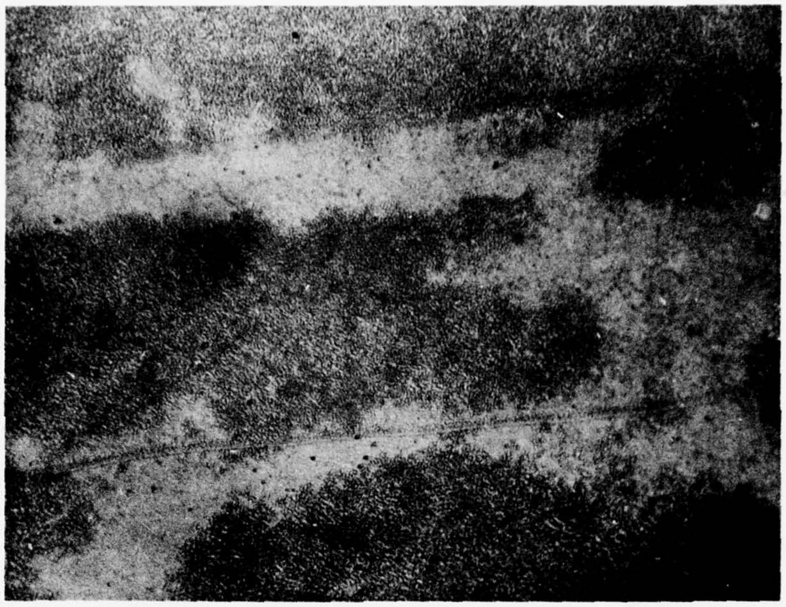


Figure 13. Fusion Zone of Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500

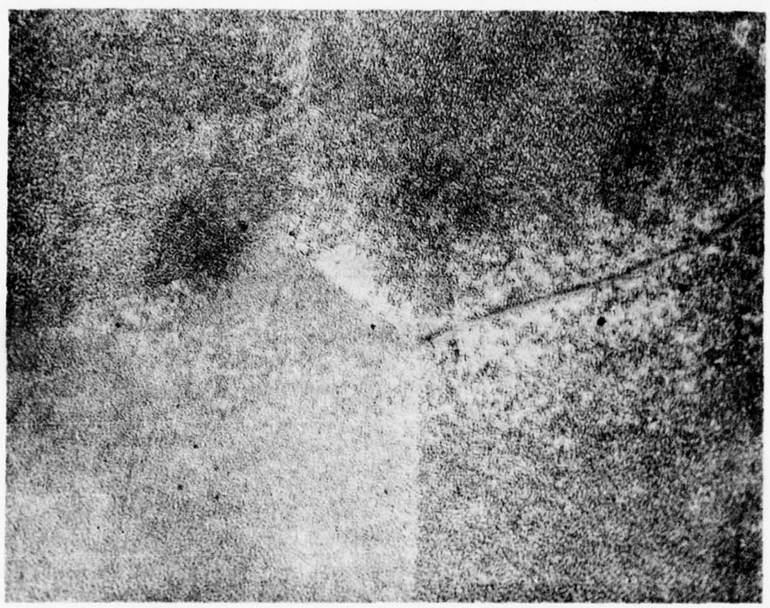


Figure 14. Near Heat Affected Zone in Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500

Figure 15. Far Heat Affected Zone in Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Eight Hours. Etchant: Krolls Reagent. X500

Figure 16. Fusion Zone Transgranular Failure in Ti-8V-7Cr-3Al-4Sn-1Zr Alloy. Post Weld Aged at 1050°F (566°C) for Seven Hours. X80

Ti-8V-4Cr-2Mo-2Fe-3Al

The microstructure of the fusion zone and heat affected zone of the samples aged at 1050°F (566°C) for 4 hours consisted of a uniform fine dispersion of alpha precipitates with very little grain boundary alpha precipitation (Figure 17). After aging at 1150°F (621°C) grain boundary alpha precipitation became more evident while the uniform dispersion of alpha precipitates remained quite small. The precipitates became very large with a prominent grain boundary alpha phase (Figure 18) after aging at 1250°F (677°C).

The fracture surfaces of the samples aged at 1050°F (566°C) revealed that the fusion zone failed by a combination of transgranular cleavage and intergranular failure (Figure 19). The intergranular fracture surfaces showed a very fine structure characteristic of a low ductility fracture. The heat affected zone failed intergranularly with similar appearing fracture surfaces as in the fusion zone but with a finer grain size. The samples aged at 1150°F (621°C) failed primarily by intergranular fracture both in the fusion zone and in the heat affected zone (Figure 20). Dimple formation at the grain boundaries, although small, was more clearly defined at this aging temperature than it was at 1050°F (566°C). At the highest aging temperature, 1250°F (677°C), the fracture was transgranular and ductile.

Ti-15V-3Cr-3Al-3Sn

The microstructure of the fusion zone and near heat affected zone of the 1050°F (566°C) aged samples is shown in Figure 21. The far heat affected zone had moderately larger and more widely spaced precipitates with some grain boundary alpha precipitation. At the 1150°F (621°C) and 1250°F (677°C) aging temperature the precipitate spacing became successively larger and the grain boundary alpha film more pronounced (Figure 22).

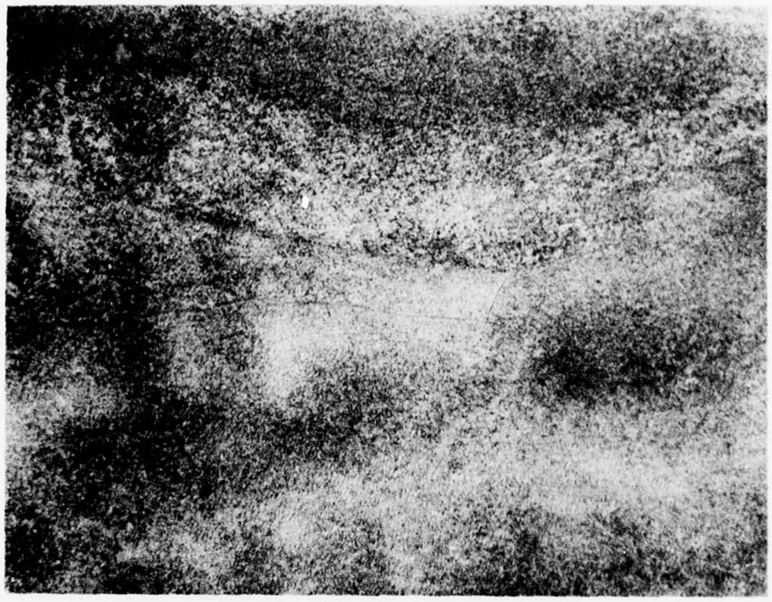


Figure 17. Fusion Zone of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1050°F (566°C) for Four Hours. Etchant: Krolls Reagent. X500

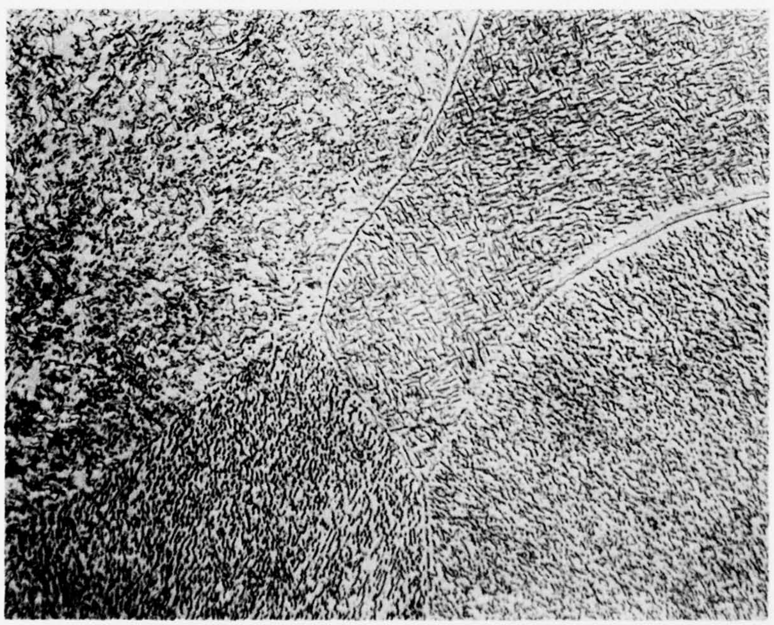
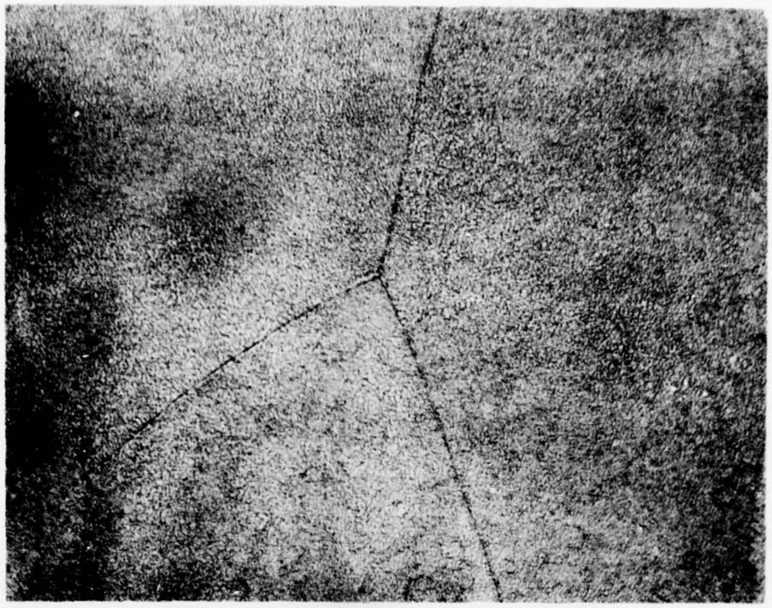


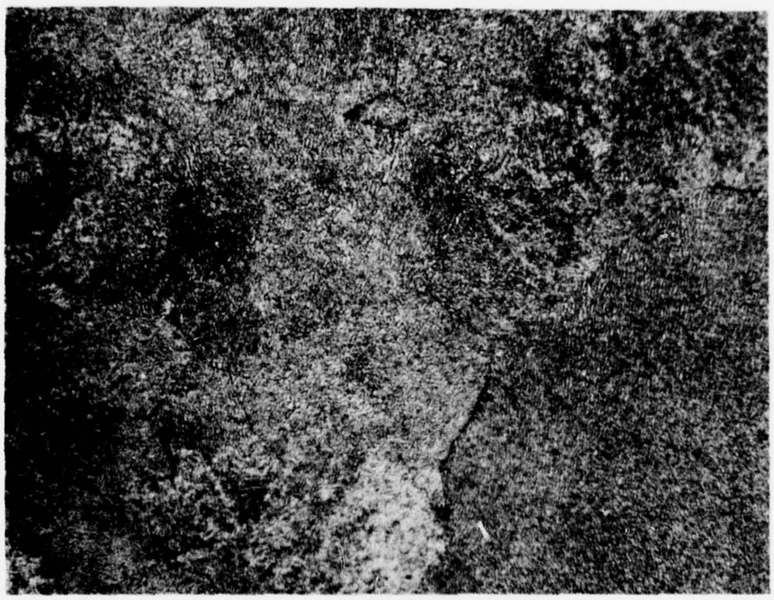
Figure 18. Fusion Zone of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1250°F (677°C) for 16 Hours. Etchant: Krolls Reagent. X500

Figure 19. Fusion Zone Fracture Surface of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1050°F (566°C) for four hours. X160

Figure 20. Heat Affected Zone Fracture Surface of Ti-8V-4Cr-2Mo-2Fe-3Al Alloy. Post Weld Aged at 1150°F (621°C) for Eight Hours. X160



A

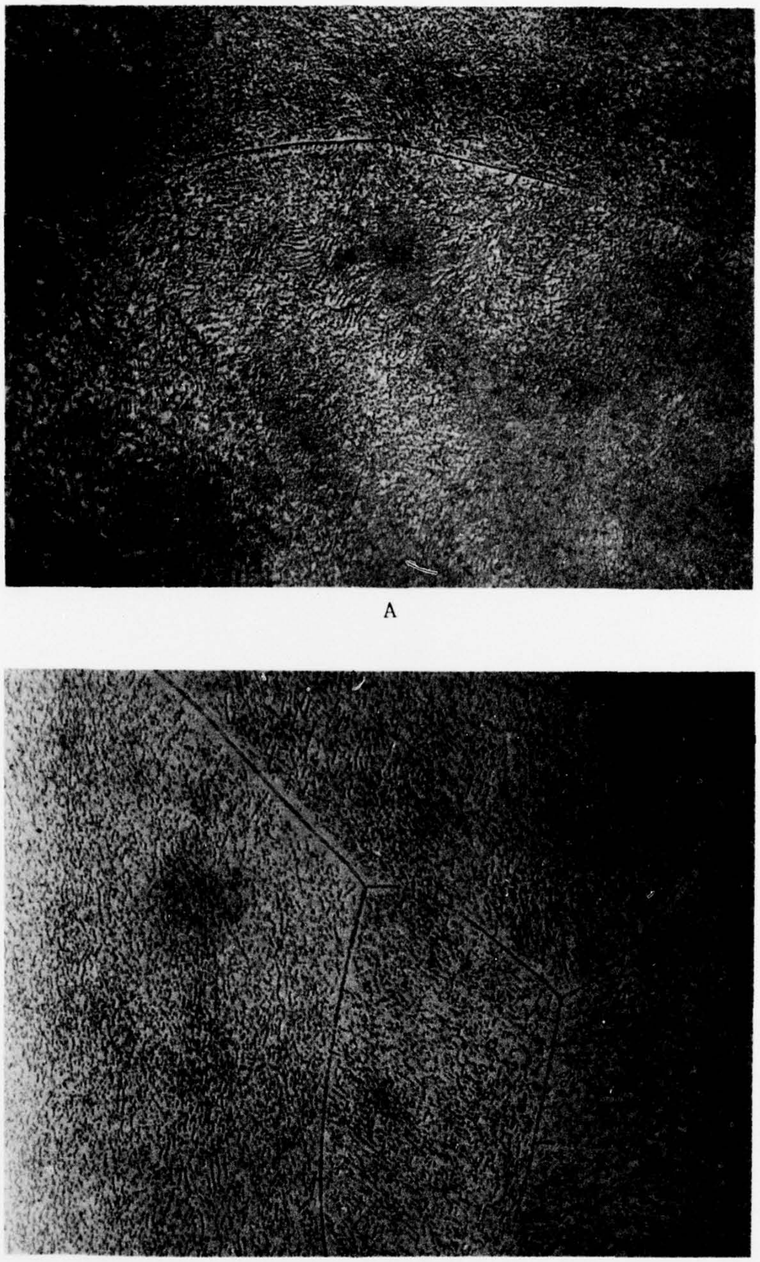


B

Figure 21. Ti-15V-3Cr-3Al-3Sn Alloy. Post Weld Aged at 1150°F (566°C) for Eight Hours. Etchant: Krolls Reagent.

a) Fusion Zone. X500

b) Near Heat Affected Zone. X500



A

B

Figure 22. Fusion Zone of Ti-15V-3Cr-3Al-3Sn Alloy. Etchant: Krolls Reagent.

a) Post Weld Aged at 1150^{o}F (621^{o}C) for Eight Hours. X500

b) Post Weld Aged at 1250^{o}F (677^{o}C) for 16 Hours. X500

Scanning electron microscopy of the fracture surfaces revealed that the samples aged at 1050°F (566°C) failed primarily by a ductile transgranular fracture with considerable secondary cracking at the grain boundaries. The samples aged at 1150°F (621°C) failed by a combination of ductile transgranular fracture and ductile intergranular fracture. The 1250°F (677°C) aged samples failed again by ductile transgranular fracture.

BRAZING

The room temperature shear strength of the lap shear brazed tensiles is summarized in Table 3. The shear stress was calculated by dividing the load at failure by the produce of the gage section width and the overlap distance.

TABLE 3

BRAZE LAP SHEAR STRENGTH

MATERIAL	SHEAR STRENGTH *(lbs/in^2)
Ti-8V-7CR-3Al-4Sn-1Zr	10,130
Ti-8V-4Cr-2Mo-2Fe-3Al	10,070
Ti-15V-3Cr-3Al-3Sn	9,700
Ti-6Al-4V	9,670

The room temperature shear strength of the brazed lap shear tensiles which were given a salt exposure at 500°F (260°C) for 200 hours is presented in Table 4.

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* Average of two tests.

TABLE 4

BRAZE LAP SHEAR STRENGTH AFTER SALT EXPOSURE

MATERIAL	SHEAR STRENGTH *(lbs/in^2)
Ti-8V-7Cr-3Al-4Sn-1Zr	9,300
Ti-8V-4Cr-2Mo-2Fe-3Al	10,300
Ti-15V-3Cr-3Al-3Sn	9,300
Ti-6Al-4V	11,300

The effect of the braze cycle on base metal properties was evaluated by tensile testing the substrate alloys in the STA and STA plus braze cycle conditions. This data is summarized in Table 5.

TABLE 5

EFFECT BRAZE CYCLE ON BASE METAL PROPERTIES

MATERIAL	CONDITION	UTS * (Ksi)	ELONGATION * (%)
Ti-8V-7Cr-3Al-4Sn-1Zr	STA	219	5.7
Ti-8V-7Cr-3Al-4Sn-1Zr	STA + Braze	183	9.5
Ti-8V-4Cr-2Mo-2Fe-3Al	STA	199	5.0
Ti-8V-4Cr-2Mo-2Fe-3Al	STA + Braze	167	14.5
Ti-15V-3Cr-3Al-3Sn	STA	184	9.3
Ti-15V-3Cr-3Al-3Sn	STA + Braze	157	13.5

* Average of two tests.

SECTION VII

DISCUSSION

WELDING

A good correlation between microstructure, fractography, and mechanical properties was found in this study. Since entering into a detailed discussion correlating these test results for all three alloy studied would involve similar comments and logic for all three alloys, only one alloy will be discussed in detail. Ti-8V-4Cr-2Mo-2Fe-3Al will be discussed in detail because of the various combinations of microstructure, properties, and fractographic results exhibited by this alloy.

The aging of this alloy takes place quite rapidly at 1050°F (566°C) as can be seen from the longitudinal weld tensile data presented in Figure 11. After only 4 hours at temperature the material reached its maximum yield strength. The fine dispersion of alpha precipitation gave the material a high yield strength of 173 Ksi and also limited the elongation to only 3 percent. Fractography showed that the fracture was both transgranular and intergranular with the fusion zone columnar structure being very evident (Figure 19). Regardless of which path the fracture took, the appearance of the fracture surface substantiated the lack of ductility. Continued aging at 1050°F (566°C) for times up to 16 hours did not affect the yield strength or the elongation.

The test samples that were aged at 1150°F (621°C) showed an increase in elongation with a decrease in yield strength. The microstructure of the samples aged for 4 hours at 1150°F (621°C) appeared to have only slightly larger precipitates than the samples aged at 1050°F (566°C). When aged for

8 and 16 hours at 1150°F (621°C) precipitate size increased slightly and a continuous grain boundary alpha film was evident; especially in the heat affected zone. This resulted in an intergranular fracture surface in the fusion zone which appeared slightly more ductile than the samples which were aged at 1050°F (566°C) exhibited. In the heat affected zones of the samples aged for 4 and 8 hours at 1150°F (621°C) the failure was of a ductile intergranular mode. This was due to the continuous grain boundary alpha film mentioned previously. When aged for 16 hours the heat affected zone fracture was a mixed ductile intergranular and transgranular failure indicating that some overaging and a decrease in matrix strength was taking place.

Aging at 1250°F (677°C) resulted in an overaged structure with large widely spaced precipitates for all three aging times. This dropped the yield strength still further. Although the grain boundary alpha film was thicker at the 1250°F (677°C) age than with the 1150°F (621°C) age, the fracture path changed from intergranular to transgranular. Presumably this change was caused by the lower matrix strength brought about by the course alpha precipitation.

Selection of the best combination of aging temperature and time must be determined by the yield strength, elongation, and fractographic information. The minimum elongation considered to be acceptable in this study was 6 percent. All combinations of temperature and time which did not exhibit this minimum level of elongation were eliminated from further consideration. For the alloy Ti-8V-4Cr-2Mo-2Fe-3Al, this requirement eliminated all aging times at 1050°F (566°C) along with 4 and 8 hours at 1150°F (621°C). Further screening was done by eliminating all aging conditions which exhibited a brittle transgranular or intergranular failure. In the case of the alloy being discussed, this eliminated no additional aging conditions. Of the remaining conditions, the combination of temperature and time which offered the highest yield strength was selected. Using this methodology the optimum aging condition of Ti-8V-4Cr-2Mo-2Fe-3Al for welded sheet is 1150°F (621°C) for 16 hours.

The optimum combinations of aging temperature and time for the alloy Ti-8V-7Cr-3Al-4Sn-1Zr was identified to be 1050°F (566°C) for 8 or 16 hours. For the alloy Ti-15V-3Cr-3Al-3Sn the combination which proved to be best was 1050°F (566°C) for 4 or 8 hours. The microstructure and fracture surface of this alloy aged at 1050°F (566°C) for 8 hours indicated that the aging temperature may have been too high. The microstructure of the fusion zone and near heat affected zone is shown in Figure 21. Little grain boundary alpha is present in these regions, but in the far heat affected zone a grain boundary alpha film was quite prevalent. Lowering the aging temperature to 1000°F (538°C) would probably reduce much of this with the added benefit of increasing the yield strength since the fusion zone at the 1050°F (566°C) aging temperature failed in a ductile transgranular manner. An increase in yield strength can probably be tolerated without producing a low ductility fracture upon testing. Such an aging temperature also has the advantage of being much closer to the optimum aging temperature 950°F (510°C) of the base metal.

Although the weldability of a material can be described by many different properties, the yield strength of the welded region as determined by the longitudinal weld tensiles will be used for this rating. The mechanical properties of the three alloys are presented in Figure 23 for the aging conditions determined to be satisfactory. From this figure it is clear that on the basis of weldability as determined in this study the order of preference of these alloys must be: Ti-8V-7Cr-3Al-4Sn-1Zr, Ti-15V-3Cr-3Al-3Sn, Ti-8V-4Cr-2Mo-2Fe-3Al.

For the sake of completeness, the joint efficiencies were calculated and are presented in Table 6. These were calculated by dividing the yield strength of the welded and aged samples by the yield strength of the base metal aged at its optimum aging temperature. The base metal aging conditions considered to be optimum are also listed.

TABLE 6

SUMMARY OF WELDMENT PERFORMANCE

ALLOY	AGING TREATMENT	JOINT EFFICIENCY
Ti-8V-7Cr-3Al-4Sn-1Zr	950°F (510°C)/16 Hrs	.89
Ti-8V-4Cr-2Mo-2Fe-3Al	950°F (510°C)/ 8 Hrs	.78
Ti-15V-3Cr-3Al-3Sn	950°F (510°C)/ 8 Hrs	.84

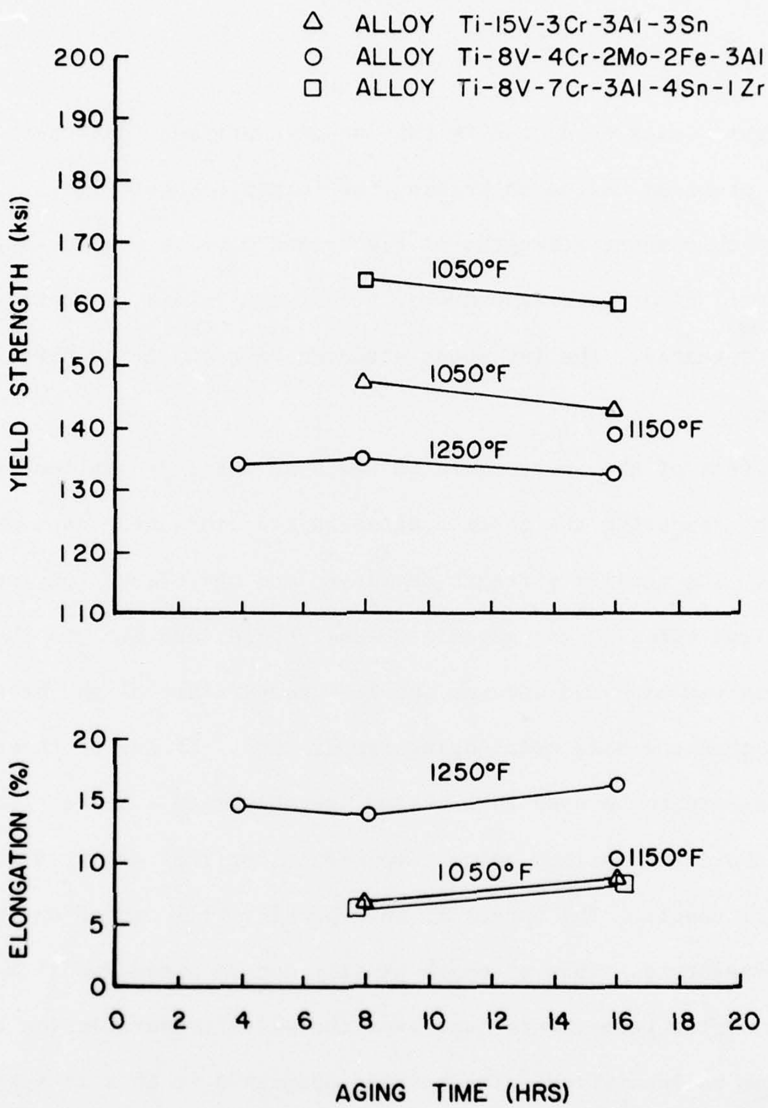

Figure 23. Summary of Best Post Weld Heat Treatment Conditions for the Three Alloys Evaluated

SECTION VIII

DISCUSSION

BRAZING

The braze tests conducted in this study confirmed that there would not be any problems unique to brazing the formable sheet alloys. The room temperature shear strengths of the brazed samples were essentially all the same. After salt exposure of the brazed joints, no corrosive attack was detected. The lap shear strength data confirmed this observation.

The effect of the braze cycle on the base metal properties can be evaluated by comparing the tensile strength and elongation data presented in Table 6. The tensile strength decreased and the elongation increased for each alloy after it was given a thermal cycle identical to the braze cycle. This was expected because the flow temperature of the braze alloy was higher than the base metal aging temperature. If any of these formable sheet alloys are to be used in a brazed assembly with a braze alloy melting point above the optimum aging temperature for that alloy, a strength penalty will result. The extent of this penalty will depend on the actual brazing temperature. This strength penalty can be minimized if a braze alloy with a flow temperature just over the alloy transformation temperature can be identified. The brazing operation in this case would serve as a solution cycle which would be followed by an optimum aging treatment.

SECTION IX

CONCLUSIONS

Welding

1. All of the alloys evaluated were readily weldable in that no deviations from standard welding practice were necessary.

2. The rating of these alloys according to their weldability as determined by longitudinal weld tensiles was in order of preference: Ti-8V-7Cr-3Al-4Sn-1Zr, Ti-15V-3Cr-3Al-3Sn, Ti-8V-4Cr-2Mo-2Fe-3Al.

3. The optimum post weld aging treatment for each alloy is:

Ti-8V-7Cr-3Al-4Sn-1Zr	1050^{o}F (566^{o}C)/8 Hrs.
Ti-15V-3Cr-3Al-3Sn	1050^{o}F (566^{o}C)/8 Hrs.
Ti-8V-4Cr-2Mo-2Fe-3Al	1150^{o}F (621^{o}C)/16 Hrs.

Brazing

1. Adequate brazed joints were obtained using conventional brazing techniques.

2. Brazed joint strengths did not vary significantly for the four titanium alloys tested.

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