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JOINING TECHNIQUES FOR FABRICATION OF COMPOSITE AIR-COOLED TURBINE BLADES AND VANES

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TURBINE BLADES AND VANES

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ABSTRACT

NASA contract results from activated diffusion brazing studies by the General Electric Company and gas pressure welding studies by the Battelle Memorial Institute for joining Udimet 700 and TD NiCr finned shells to B1900 and René 80 struts are presented. These results include shear, tensile, and stress rupture data at 1750° F. Effects of oxidation exposure and thermal cycling are also discussed. Problems and advantages associated with applying each of these joining methods to various composite blade or vane cooling configurations are evaluated.

INTRODUCTION

Some of the most effective methods for cooling turbine blades and vanes for advanced airbreathing engines require internal cooling configurations beyond the present state-of-the-art of casting. In order to utilize these methods on a production basis, the blades will have to be fabricated in separate segments and joined together. In this study, two joining processes, activated diffusion brazing and gas pressure welding, were investigated for composite blades operating with metal temperatures of 1750° F or higher.

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The gas pressure welding process consists of placing the parts to be joined within an evacuated, lightweight container and then joining by means of temperature and pressure in a high temperature, high pressure autoclave. In activated diffusion brazing, a braze material is used whose composition closely matches that of at least one of the parent materials and includes a melting point depressant such as silicon or boron. Brazing is done under a low pressure and at a temperature below the incipient melting points of the parent materials. These joining techniques were selected because they appeared to have more promise for attaining strong, reliable joints with high temperature nickel or cobalt base superalloys for complex blade shapes and internal configurations than other processes such as conventional brazing, fusion welding, explosive welding, and hot pressure welding with dies.

The purposes of this investigation were threefold: first, to develop joining parameters and conditions for the candidate base material combinations (TD nickel chromium or Udimet 700 to B1900 or René 80 whose compositions are shown in table I); second, to study the joint strengths at elevated temperatures including effects of thermal cycling and oxidation exposure; and third, to evaluate the fit-up and other fabrication problems involved in applying these joining techniques to actual or simulated airfoil shapes.

The geometries of the specimens and the application of the joining techniques were based on a convection cooled shell, containing integral fins, attached to an internal strut. Joint strength evaluation consisted of shear tests, burst tests, stress rupture tests, thermal cycling, and oxidation exposure. Simulated blade configurations were also fabricated.

Preliminary conclusions are drawn as to the applicability of each of the joining processes to various types of composite cooling configurations.

EXPERIMENTAL MODEL

In order to rigorously evaluate the gas pressure and activated diffusion joining processes, specimen geometries were chosen that provided a difficult fabrication problem and were representative of joining problems that would be encountered in advanced finned blade configurations. Such a configuration, which is shown in figure 1, consists of a finned shell joined to a hollow strut. In this configuration, air enters a central cavity formed by the hollow strut and flows through holes at the leading edge of the strut to impingement cool the blade leading edge. The air then circulates through the chordwise channels between the finned shell and strut and discharges through slots in the trailing edge. Alternative variations to this scheme are to continue the fins around the leading edge or to use spanwise fins with air ejection through the tip. The advantage to machining the fins integral with the shell rather than with the strut is that the joints will be at cooler temperatures and, therefore, stronger than if they were on the inside surface of the shell. In the latter case, a small unwelded area could result in catastrophically high shell temperatures, whereas at the strut surface such an unwelded area could probably be tolerated.

Composite construction affords an opportunity to tailor the material properties to the structural, oxidation, or corrosion problems associated with different parts of the blade by the use of different materials for the shell and strut or between different regions of the shell. The cast

nickel-base superalloys, B1900 and René 80, were selected as strut materials. The shell materials which were used in this investigation were Udimet 700, one of the strongest of present-day blade materials in the 1400° to 1800° F range available in sheet metal, and TD nickel-chromium (TD NiCr), a thoria dispersion strengthened superalloy used in vanes for its excellent oxidation resistance and strength characteristics above 1800° F.

Two fin geometries are shown in figure 1. All of the test results reported herein, except for butt joint tests, were for specimens with fin geometries of configuration A. The dimensions of these specimens are given in table II. The 0.012 inch thick fins of configuration A present a more severe joining problem than the 0.036 inch thick fins of configuration B because the pressure that can be applied during welding before fin collapse occurs is more limited, and because the total fin contact area would be smaller due to the greater number of corners rounded off during machining. However, both configuration A and configuration B fin specimens were used in developing the gas pressure welding parameters since the relatively large unsupported shell span between fins in configuration B could limit the internal gas pressure because of buckling considerations.

The mechanical stresses from the applied loads that the joints would have to withstand are relatively small for a blade and insignificant for a vane. In the design of a finned shell-strut blade with a hub-tip diameter ratio of 0.75, a tip speed 1250 feet per second, and with chordwise fins covering the full strut perimeter, the joint shear stress from the centrifugal loading was under 2000 psi. Assuming that the strut carried the whole weight of the shell, the maximum bending stresses at the joints were

about 5000 psi for fin configuration A and 1700 psi for fin configuration
B. Although these stresses are not too serious by themselves, it is
desirable to have high joint efficiencies to allow for thermal stresses.
Joint efficiency is defined herein as the percent of the joint strength
to the strength of the weaker of the two base materials for a particular
time to failure. Lower joint efficiencies can be tolerated in a blade with
spanwise fins where there are no fin bending stresses or in a vane where
the mechanical stresses are so low that even a local failure due to thermal
strains may not affect the overall structural integrity of the finned shell-
strut configuration.

JOINING PROCESSES

The activated diffusion brazing and gas pressure welding processes
are illustrated schematically in figure 2. The joining temperatures,
bearing stresses at the fins from the application of external pressure,
exposure times at these conditions, and post weld heat treatments for the
shell-strut material combinations are also shown. The bonding parameters
in figure 2 show that activated diffusion brazing requires only nominal
joining pressures, while gas pressure welding requires very high pressures
but several hundred degree lower temperatures.

Activated diffusion brazing is a development of the General Electric
Company in which the braze alloy consists of a high strength superalloy
composition in powder form to which a small amount of a melting point
depressant such as boron or silicon is added. The braze material used
in this investigation was essentially René 80 with 5 percent silicon
preformed from powder and a binder to 0.003 inch tape. This tape was

placed on the René 80 strut specimen after the joining surfaces had been ground to about 16 RMS finish and degreased. The finned specimen was then brought into contact with the René 80 and joined in a vacuum furnace using the appropriate bonding parameters.

Gas pressure welding, which was developed at Battelle Memorial Institute, joins parts encapsulated in a metal container by subjecting them to a high inert gas pressure at an elevated temperature. The welding is performed in a high pressure autoclave containing a resistance heater. Surface preparation is more critical in gas pressure welding than in activated diffusion brazing. All surfaces to be joined were initially cleaned by degreasing, abraded with grit paper, soaked in a detergent, and rinsed in alcohol and hot water. The fin surfaces were also etched in a solution of ferric chloride, hydrochloric acid, and nitric acid after abrading with grit paper. A 0.0002 to 0.0003 inch thick layer of nickel was applied to the B1900 surface by vapor deposition as a diffusion aid in joining the Udimet 700 finned specimens.

The finned shell-strut specimens were assembled and placed in a close-fitting, thin stainless steel container which was sealed by electron beam welding in a vacuum chamber at a pressure of 10^{-5} Torr. The assemblies were then welded at the desired temperature in the autoclave with a gas pressure which imposed the required bearing stress at the fin surfaces while the container maintained a vacuum environment for the parts being welded. It was found that both fin configuration A and fin configuration B could withstand the high gas pressure without the use of internal tooling in the channels to prevent collapse of the fins. No difficulty was encountered in removing the stainless steel container since the bearing stress at the

container surface was much lower than at the fins and it was insufficient to weld the container to the specimen.

DISCUSSION OF RESULTS

Activated Diffusion Braze Strengths

Stress rupture tests results at 1750° F in tension on butt joints and in shear on finned lap joints are shown in figure 3 for TD NiCr-René 80 specimens and in figure 4 for Udimet 700-René 80 specimens. These are compared to base material properties and to average short-time shear and tensile strengths of the joints.

The short-time TD NiCr-René 80 joint efficiencies in shear and tension are almost 100 percent as shown on the extreme left of figure 3. In stress rupture, however, the joint efficiencies drop sharply. Based on the stresses required for failure in 100 hours of the butt joints and of TD NiCr in tension, the efficiency is only about 35 percent. Electron photomicrographs of some brazed TD NiCr-René 80 specimens exhibited thoria agglomeration in the TD NiCr at the joint and a thoria depleted zone adjacent to it. The material in both the thoria agglomerated and depleted regions is just as strong in short-time properties as normal TD NiCr but considerably weaker in stress rupture.

An unusual feature of figure 3 is that the joint stress rupture strengths appear to be similar in shear and in tension. The explanation for the relatively high shear strengths probably lies in the nature of the braze flow around the joint. A photomicrograph of a typical TD NiCr-René 80 brazed joint is shown in figure 5. The flow of the braze material up the sides of the fins improves the shear strength by providing a form of mechanical locking

against a transverse load and by the addition of more shear area. The gray spots at the bottom of figure 5 are caused by concentrations of silicon remaining in the brazed area instead of diffusing into the base materials.

Another factor in improving the joint efficiency in shear stress rupture may be the increase in the ratio of shear to tensile base material strengths with rupture time which is apparent in figure 3. In short-time base material tests the shear strength was about 43 percent of the tensile strength while at 400 hours the shear stress to rupture was about 65 percent of the tensile stress to rupture.

No significant effect on the joint shear strength of the fin direction with respect to the load was found. There is also no evidence shown in figure 3 of a deterioration in the joint strengths of tensile specimens from previous oxidation exposure for 100 hours at 1750° F. Rupture generally occurred around the joints with the fracture wandering in and out of the braze and the adjoining TD NiCr.

The Udimet 700 - Rene 80 results in figure 4 demonstrate tensile joint efficiencies of 60 to 65 percent for 100 hours stress rupture life compared to a 75 percent efficiency in short time testing. Shear stress rupture strengths were only slightly lower than tensile stress rupture strengths. Shear specimens loaded transverse to the fins tended to have somewhat lower strengths than specimens loaded parallel to the fins and always failed in the braze joint.

The butt joint data in figure 4 indicate that the joint strengths improve slightly after 100 hours exposure to oxidation in an air atmosphere at 1750° F. The additional time at elevated temperature probably promotes further diffusion of silicon from the braze into the parent materials.

The effects of thermal cycling on the short transverse tensile strengths at 1750° F of activated diffusion brazed TD NiCr-René 80 joints are presented in figure 6. All the thermal cycling consisted of 10 to 13 cycles from 70 to 1750° combined with 200 hours oxidation exposure at 1750° F. The noncycled specimens were not subjected to oxidation exposure. Testing was conducted by applying loads through René 80 grips which were joined to both the finned and nonfinned surfaces of the TD NiCr specimens.

The results show that the thermal cycling has caused a reduction in strength of approximately 50 percent. Metallurgical inspection of other thermal cycled specimens which were not tensile tested revealed that cracks occurred in the vicinity of the joints from the thermal cycling before any mechanical load was applied. However, a similar test of a TD NiCr specimen joined to 0.090 inch René 80 instead of to a bulky grip showed little sign of thermal cracking. This indicates that thermal cycling should be less of a problem with a thin, flexible strut.

Thermal cycling tests of Udimet 700 - René 80 brazed joints show either no decrease in strength compared to noncycled specimens or a slight improvement due to further silicon diffusion. It can, therefore, be concluded that activated diffusion brazing will provide satisfactory joint strengths for a Udimet 700 finned shell-René 80 strut blade and, probably, for most other composite blade constructions.

Gas Pressure Weld Strengths

Strengths of TD NiCr-B1900 joints were determined from burst tests of curved specimens which simulated an airfoil curvature at midchord. Figure 7 shows a specimen with half the test section cut away to reveal the interior

of the specimen and the friction welded pipe attachment. A number of curved specimens were subjected to 10 thermal cycles from 70° F to 1750° F and 200 hours exposure to oxidation in an air atmosphere at 1750° F before burst testing.

The burst test results at 1750° F are presented in figure 6. All of the thermal cycled specimens show deterioration in strengths compared to the uncycled specimens. However, all of the cycled specimens with axial fins and half of those with circumferential fins failed in the TD NiCr fins outside any diffusion affected zone near the joint. Some specimens which were inspected immediately after being subjected to thermal cycling exhibited cracks in the fins or near the joints as shown in figure 8. The low strengths of the thermal cycled specimens at 1750° F probably resulted from the stress raising effects of the cracks when mechanical loads were applied. These results seem to indicate that TD NiCr and B1900 are not thermally compatible even though some of the literature show an excellent match in thermal expansion coefficients. As an example of this, reference 1 gives the mean coefficient of thermal expansion from 70° to 1800° F as 8.84 in./in./°F for B1900 while reference 2 gives the comparable thermal expansion coefficient for TD NiCr as 8.8 in./in./°F. It is probable that the thermal expansion characteristics of TD NiCr have not been accurately established up to the present time.

The somewhat smaller decline in strengths due to thermal cycling shown by the TD NiCr-René 80 joints in figure 6 may signify that René 80 is slightly more compatible with TD NiCr than B1900. It should be emphasized that the strengths shown in figure 6 for the curved specimens represent only partial fin or joint failure since all tests were terminated due to

leakage problems at the braze seal around the edges of the test specimens
or the weld between the B1900 and the pipe attachment (see figure 7).
Many of the lower strength specimens could probably have taken greater
pressures before complete failure occurred in the test section.

The thermal cycling results of figure 6 indicate that neither Rene 80
nor B1900 are suitable strut materials for use with a TD NiCr shell attached
to a rigid strut. The uncycled TD NiCr joint strengths are probably adequate
for a vane provided that a strut material is used which has a closer thermal
expansion match to the shell or the strut is flexible enough to absorb the
thermal cycling without cracking. For most vane applications, TD NiCr
itself can be used as a strut as well as shell material.

Shear tests results at 1750° F of flat Udimet 700 - B1900 finned
joining specimens are presented in figure 9. Four experiments were con-
ducted in order to evaluate the reproducibility of the joint strength from
different autoclave runs and different Udimet 700 sheets. In each experi-
ment, a 2 X 2 inch finned shell-strut assembly was gas pressure welded and
then cut into 0.4 X 0.4 inch shear specimens. The specimens were tested
in compression induced shear to evaluate the effect on the joint strength
of fin direction with and without thermal cycling. Each scatter band in
figure 9 represents an average for 3 specimens.

As expected, the joints with fins transverse to the load were generally
somewhat weaker than joints with fins parallel to the load. Thermal cycling
appears to have a more adverse effect on the transverse fins than on the
parallel fins. This may result from localized crack initiation during
thermal cycling which would be more likely to cause premature failure under
transverse loading because of the added bending component. No definite

conclusions can be drawn from figure 9 on the effect of thermal cycling when the fins are parallel to the load. The mean thermal expansion coefficients from 70° F to 1800° F from reference 1 are 9.65 in./in./$^{\circ}$F for Udimet 700 and 8.84 in./in./$^{\circ}$F for B1900. These values would lead one to expect a greater effect of thermal cycling on the Udimet 700 - B1900 joints than on the TD NiCr - B1900 joints (fig. 6) which is contrary to the actual results. However, it is possible that the thermal cycling effects on the TD NiCr - B1900 joints were exaggerated because of the greater susceptibility of burst specimens to premature failure from localized cracks.

Most of the shear specimens failed in the Udimet 700 parent material away from the joints. A photomicrograph is shown in figure 8 of a Udimet 700 - B1900 joint in which new grains have nucleated in the interface region. This type of grain growth occurred in the higher strength joints whereas lower strength joints all showed sharp bond lines separating the two materials.

A comparison of the average short time shear test results at 1750° F for the gas pressure welded Udimet 700 - B1900 joints (fig. 9) with the activated diffusion brazed Udimet 700 - René 80 joints (fig. 4) show average shear strengths for fins transverse to the load direction were about 27,000 psi with gas pressure welding and 21,000 psi with activated diffusion brazing. The shear strengths for fins parallel to the load were about 35,000 psi with gas pressure welding and 33,000 psi with activated diffusion brazing. However, the data scatter from gas pressure welding was considerably higher than the brazing results and included specimens which fell apart upon application of load as well as specimens whose strengths exceeded the initial capability of the test fixture which was a shear stress of about

40,000 psi. In the latter case, strengths of 40,000 psi were assumed for the purpose of averaging the shear data. The shear test results of figure 9 also demonstrate significant differences in strength levels between the different groups of specimens. Further gas pressure welding development is desirable to improve the joint strength reproducibility.

Composite Blade Fabrication

As a final test of the activated diffusion brazing process, simulated blade configurations were fabricated by brazing finned shells to the airfoils of René 80 production blades with airfoil span lengths and chord widths of about 2 and 1.4 inches, respectively. The parts of one of these blade assemblies are shown in figure 10. Each shell was formed in three segments; a nonfinned leading edge, a finned pressure side, and a finned suction side. These segments were formed with dies to a tolerance of 0.002 inch between the airfoil and matching fin surfaces. A bearing stress of about 120 psi was applied to the joints by the use of mechanical pressure through close-fitting dies at the shell pressure and suction surfaces. Although only 10 psi bearing stress was used in brazing the flat specimens, additional pressure was required to force complete contact between the curved surfaces of the shell and strut. The seams near the leading edge between the shell segments and the junction between the shell and the blade platform were also brazed. Metallurgical inspection revealed, generally, good quality joints.

Applicability of Joining Processes

From the experience gained in this program, a number of conclusions have been reached as to the advantages and limitations of the candidate joining processes. It is evident that, where it is applicable, activated

diffusion brazing is preferable from a cost consideration. Although gas pressure welding would probably be more competitive on a production basis, the process is inherently expensive because of the costs of autoclave operation, specimen canning, and the requirement for internal tooling to support portions of the shell or strut in many applications. However, there are some conditions under which activated diffusion brazing is not practicable and gas pressure welding would be a more feasible joining technique.

In table III, the two joining methods are evaluated as to their applicability to three composite blade constructions. The finned shell construction lends itself to activated diffusion brazing using dies if the joints extend over a midchord region of shallow curvature. In this case, the use of dies has the advantage of applying pressure only over a local area whereas the use of gas pressure would require support against collapse of nonfinned areas of the shell. On the other hand, dies could not apply pressure normally to every part of a highly curved surface such as a leading edge region or a midchord region of a highly cambered airfoil. Joining of finned shells to struts at these locations would require either gas pressure welding or a combination of activated diffusion brazing with gas pressure or some other form of hot isostatic pressing. The use of isostatic pressure to force fitup and to apply the bearing stress needed for joining may necessitate the support of the strut as well as unfinned parts of the shell by internal tooling.

Another composite construction shown in table III consists of a nonfinned shell attached to strut webs. If the shell were smooth, activated diffusion brazing would be advantageous because the pressure could be localized to the vicinity of the webs. However, brazing could be a problem with

a porous shell because of the tendency of the braze to flow and clog pores. Whether gas pressure welding would have any advantage over electron beam welding in attaching a porous shell would depend on the shell thickness, density, and weldability as well as the web contact area and spacing.

A third possibility for a composite construction which has been considered by some turbine blade designers is to fabricate the shell in two or more parts from different materials. In the two-part shell illustrated in table III, the leading edge would be fabricated from a material resistant to thermal fatigue while the remainder of the blade would be fabricated from a stronger or lower cost material. Activated diffusion brazing would be suitable for joining segments of a shell. Care should be taken, however, that the spanwise joints are far enough removed from the leading edge so that they will not be critical in low cycle fatigue since the ability of the joints to withstand plastic straining is limited.

Another factor that could influence the choice of a joining method is the possibility of adverse metallurgical changes in the parent materials. An example of this is the detrimental effect on the TD NiCr properties of silicon which is used as a melting point depressant in activated diffusion brazing. The composite configurations and material combinations which have been discussed illustrate the problems involved in and the advantages to be derived from utilizing activated diffusion brazing and gas pressure welding. Neither of these joining processes can be said to be superior to the other. Both processes are expected to find application in joining of simple and complex configurations of turbine blades and other high temperature components.

REFERENCES

1. Anon., "High Temperature High Strength Nickel Base Alloys," 1964, International Nickel Company, Inc.

2. Anon., "TD NiC - A New Dispersion Strengthened Alloy," 1966, DuPont Metal Products.

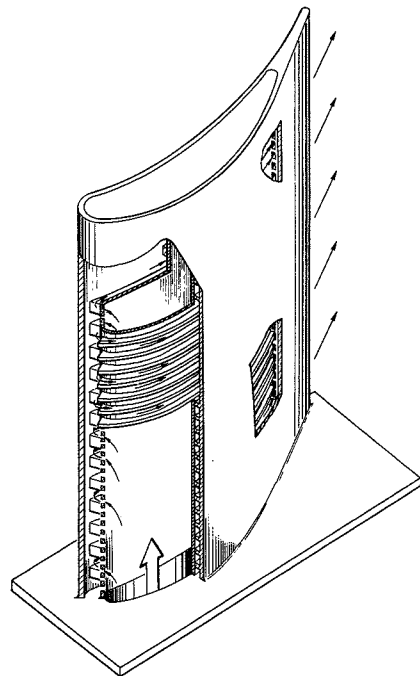TABLE I. - ALLOY NOMINAL COMPOSITIONS

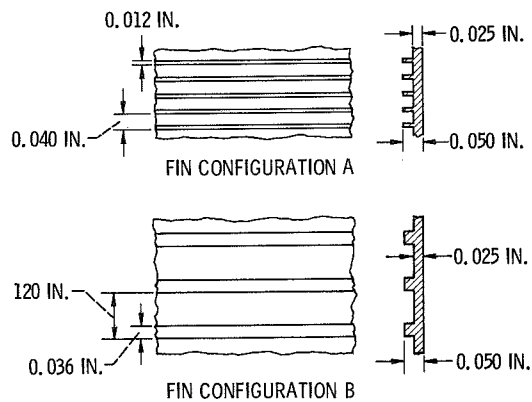| Alloy	Nominal chemical composition, wt., percent													
	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Fe	Ti	Al	B	Zr	Other
B1900	.10	0	0	8.0	Bal	10.0	6.0	0	0	0	1.0	6.0	.015	.10	4.0 Ta
Rene 80	.17	.2	.2	14.0	Bal	9.5	4.0	4.0	9.5	.2	5.0	3.0	.015	.03	0
TDNiCr	0	0	0	20.0	Bal	0	0	0	0	0	0	0	0	0	2.0 ThO$_2$
Udimet 700	.08	0	0	15.0	Bal	18.5	5.2	0	0	0	3.5	4.3	.03	0	0

TABLE II. - TEST SPECIMENS

JOINING PROCESS	SPECIMEN TYPE AND SIZE
ACTIVATED DIFFUSION BRAZING	 TENSION, NO FINS SHEAR, FINNED TENSION, FINNED
GAS PRESSURE WELDING	 SHEAR, FINNED BURST, FINNED

TABLE III. - APPLICATION OF JOINING PROCESSES TO COMPOSITE BLADE CONFIGURATIONS

| COMPOSITE CONFIGURATION	CONFIGURATION CROSS-SECTION	PROCESS APPLICABILITY	
		ACTIVATED DIFFUSION BRAZING	GAS PRESSURE WELDING
FINNED SHELL TO STRUT (A) FINS AT MIDCHORD REGION (B) FINS AT LEADING EDGE		(A) VERY GOOD (B) NOT APPLICABLE UNLESS GAS PRESSURE IS USED	(A) OR (B) GOOD BUT SHELL NEEDS SUPPORT IN NONFINNED REGION (A) AND (B) COMBINED VERY GOOD
NONFINNED SHELL TO STRUT WEBS (A) SOLID SHELL (B) POROUS SHELL		(A) VERY GOOD (B) NOT APPLICABLE BECAUSE BRAZE CLOGS PORES	(A) OR (B) GOOD BUT SHELL NEEDS INTERNAL SUPPORT
SHELL SEGMENTS WITH SPAN-WISE JOINTS		GOOD	NOT APPLICABLE

(A) COOLED TURBINE BLADE.

0.012 IN.

0.040 IN. ⎯

FIN CONFIGURATION A

0.025 IN.

0.050 IN.

120 IN. ⎯

0.036 IN. ⎯

FIN CONFIGURATION B

0.025 IN.

0.050 IN.

(B) FIN CONFIGURATIONS INVESTIGATED.

Figure 1. – Composite finned shell-strut configuration.

ACTIVATED DIFFUSION BRAZING

BRAZE ALLOY
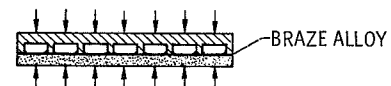
MATERIALS	TEMPER-ATURE, °F	BEARING STRESS, PSI	TIME, MIN	POST WELD HEAT TREATMENT
UDIMET 700-RENÉ 80	2210	-10	20	1950° F/4 HR, 1550° F/24 HR, 1400° F/16 HR
TD NiCr-RENÉ 80	2225	-10	20	2000° F/4 HR, 1925° F/4 HR, 1550° F/16 HR

GAS PRESSURE WELDING

STAINLESS STEEL CONTAINER
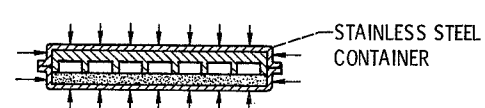
MATERIALS	TEMPER-ATURE, °F	BEARING STRESS, PSI	TIME, MIN	POST WELD HEAT TREATMENT
UDIMET 700-B1900	1900	-10,000	60	2135° F/4 HR, 1975° F/4 HR, 1550° F/24 HR, 1440° F/16 HR
TD NiCr-B1900	2000	-10,000	60	NONE

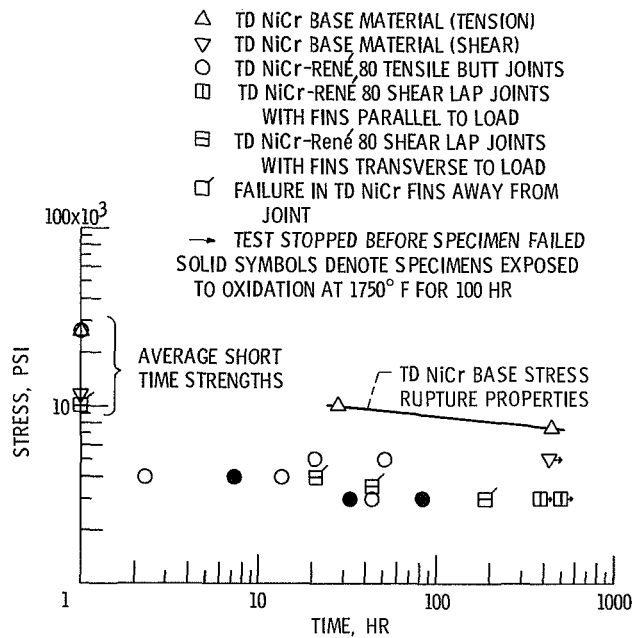Figure 2. – Joining processes for finned shell-strut composite blades.

△ TD NiCr BASE MATERIAL (TENSION)
▽ TD NiCr BASE MATERIAL (SHEAR)
○ TD NiCr-RENÉ 80 TENSILE BUTT JOINTS
⊡ TD NiCr-RENÉ 80 SHEAR LAP JOINTS
    WITH FINS PARALLEL TO LOAD
⊟ TD NiCr-René 80 SHEAR LAP JOINTS
    WITH FINS TRANSVERSE TO LOAD
◁ FAILURE IN TD NiCr FINS AWAY FROM
    JOINT
→ TEST STOPPED BEFORE SPECIMEN FAILED
SOLID SYMBOLS DENOTE SPECIMENS EXPOSED
TO OXIDATION AT 1750° F FOR 100 HR

Figure 3. - Activated diffusion brazed TD NiCr-René 80 joint
stress rupture strengths at 1750° F.

△ UDIMET 700 BASE MATERIAL (TENSION)
○ UDIMET 700-RENÉ 80 TENSILE BUTT JOINTS
⊡ UDIMET 700-RENÉ 80 SHEAR LAP JOINTS
    WITH FINS PARALLEL TO LOAD
⊟ UDIMET 700-RENÉ 80 SHEAR LAP JOINTS
    WITH FINS TRANSVERSE TO LOAD
SOLID SYMBOLS DENOTE SPECIMENS EXPOSED
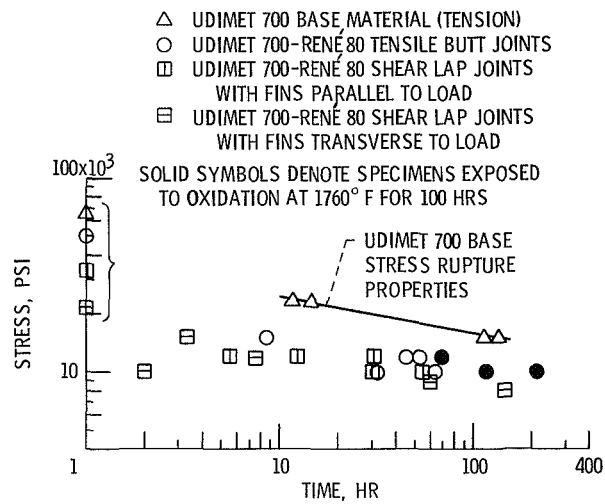TO OXIDATION AT 1760° F FOR 100 HRS

Figure 4. - Activated diffusion brazed Udimet 700-René 80
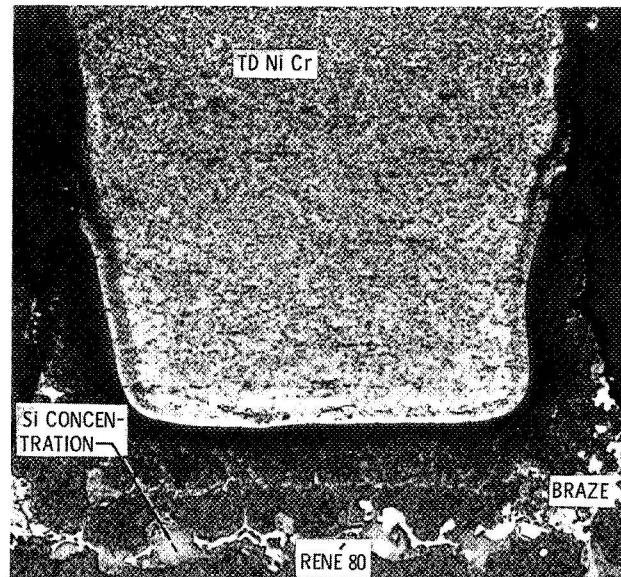joint stress rupture strengths at 1750° F.

Figure 5. - Photomicrograph of activated diffusion brazed TD Ni Cr finned shell - René 80 strut joint. X200.
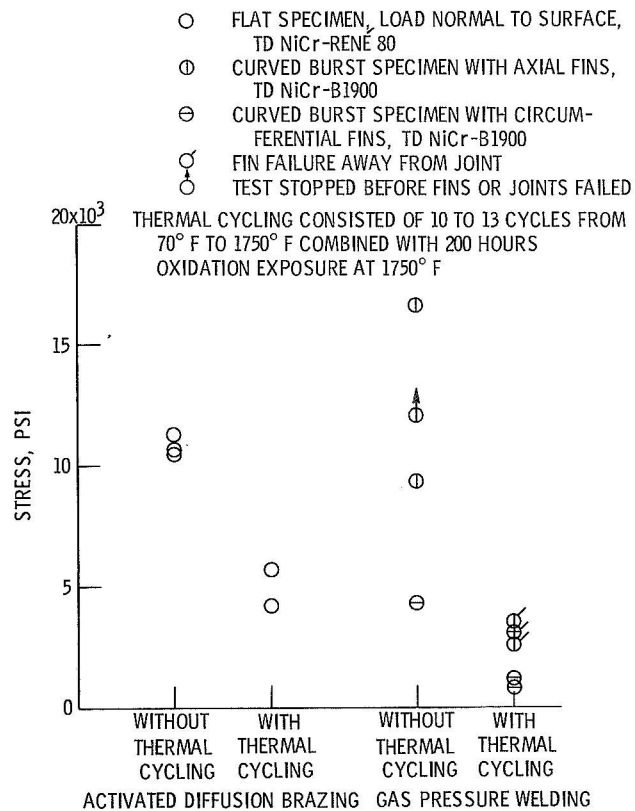

○   FLAT SPECIMEN, LOAD NORMAL TO SURFACE, TD NiCr-RENÉ 80

⊕   CURVED BURST SPECIMEN WITH AXIAL FINS, TD NiCr-B1900

⊖   CURVED BURST SPECIMEN WITH CIRCUM-FERENTIAL FINS, TD NiCr-B1900

♂   FIN FAILURE AWAY FROM JOINT

⊗   TEST STOPPED BEFORE FINS OR JOINTS FAILED

THERMAL CYCLING CONSISTED OF 10 TO 13 CYCLES FROM 70° F TO 1750° F COMBINED WITH 200 HOURS OXIDATION EXPOSURE AT 1750° F

Figure 6. - Effect on short transverse tensile strengths at 1750° F of thermal cycling of TD NiCr-René 80 and TD NiCr-B1900 finned specimen joints.

TD Ni Cr
FINNED
SHELL

CUTAWAY TEST
SECTION

B1900 STRUT
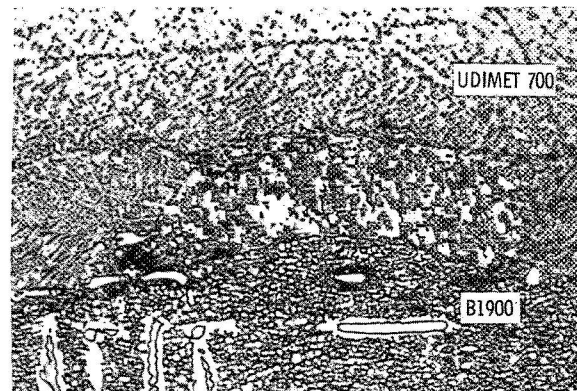
RENÉ 41 PIPE
ATTACHMENT

CM
0   1   2.5
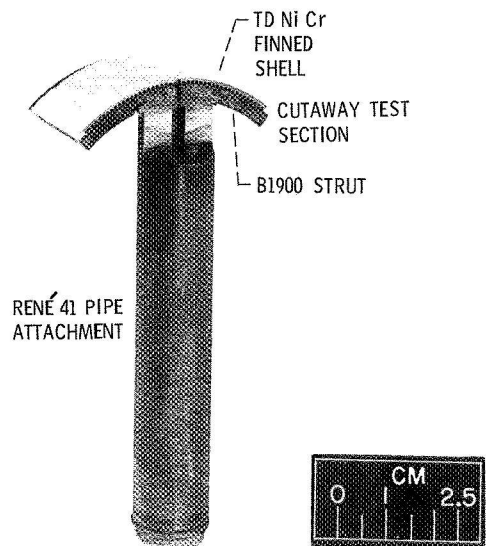
C-70-1781

Figure 7. - Gas pressure welded TD Ni Cr - B1900 curved
burst test specimen.
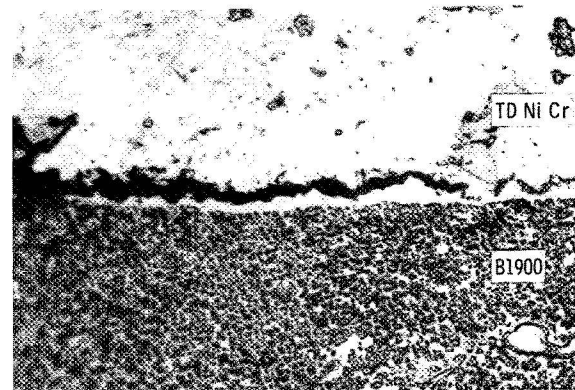
(a) TD Ni Cr - B1900: failure in thermal cycled specimen.

(b) Udimet 700 - B1900: grain growth through joint.

Figure 8. - Photomicrographs of gas pressure welded finned
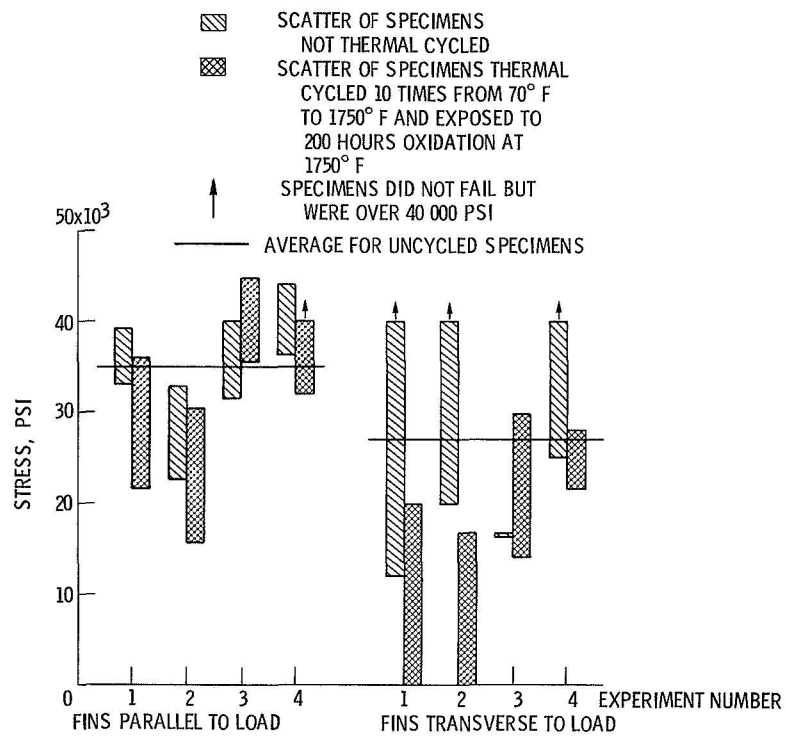shell-strut joints. X750.

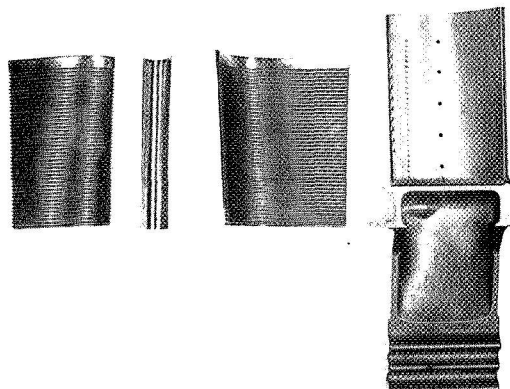Figure 9. – Gas pressure welded flat Udimet 700-B1900 finned specimen joint shear strengths at 1750° F.

Figure 10. – Shell segments and strut of composite blade.