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APPLICATIONS OF COMPOSITE GAS TURBINE COMPONENTS

Semi-Annual Technical Progress Report, Phase I

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March 1981

Work Performed Under Contract No. AC01-80ET17005

General Electric Company
Gas Turbine Division
Schenectady, New York

U. S. DEPARTMENT OF ENERGY

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ABSTRACT

Heavy-duty, air-cooled gas turbines utilize relatively large superalloy buckets and nozzle guide vanes. These large components, particularly buckets, must demonstrate a variety of properties. The airfoil vane requires excellent surface stability with high creep and low-cycle fatigue (LCF) strength. The dovetail requires excellent tensile strength and low-cycle fatigue (LCF) properties. Conventional buckets are fabricated as one single casting or forging in which compromises in these properties are inevitable, and the full capabilities of the superalloys used are rarely optimized along each individual line.

A unique approach toward improved performance in key properties is to integrate the best material for each part of a hot section bucket or nozzle into a bonded "composite" component, or a "hybrid" component. A hybrid bucket is a superalloy part composed of a variety of alloys bonded into one integral part. Each segment is tailored to perform a specific function with greater reliability and performance than possible with contemporary monolithic parts. An example is a directionally-solidified (DS) airfoil vane bonded to a dovetail section of forged/PM superalloy.

Phase I of this program evaluates several nickel base superalloy combinations which have been diffusion bonded using hot isostatic pressing (HIP). This technique enables large gas turbine buckets to be fabricated using materials with improved creep and low cycle fatigue life for the airfoil and greater high temperature tensile strength in the dovetail.

The program will specifically investigate three directionally solidified airfoil alloys and two powdered metal dovetail alloys. This effort will include heat treat studies, physical metallurgy and high temperature tensile testing for all 5 alloys in their HIP bonded condition. In parallel with these tasks will be studies on alternate bonding techniques and mechanical design considerations for adopting composite bucket technology into the Gas Turbine product line.

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PROGRAM DESCRIPTION

OBJECTIVE

The overall objective of the program is to maximize the potential for durability, reliability and performance for heavy duty gas turbine hot-stage parts. This effort is being undertaken in a multi-phased program.

Phase I, the current effort, is specifically directed to develop the technology for a composite gas turbine bucket comprised of airfoil vanes made from materials optimized for creep/rupture properties and dovetail members of high tensile and fatigue properties. Primary emphasis is placed on validating a bonding technique for joining the airfoil to the dovetail.

Upon the successful completion of the Phase I effort and the availability of funding, the proposed objective of the next step in the program, Phase II, will be to process and fabricate full size gas turbine buckets for testing in the laboratory and subsequent demonstration in a gas turbine. Subsequent phases will take the demonstrated composite gas turbine bucket concept and complete the essential operation of applying effective and superior oxidation/corrosion protective claddings and coating to the airfoil vanes.

The successful completion of these efforts is intended to demonstrate the technology and principles of composite hardware and verify the reliability and durability required by electrical utility and industrial markets. Accordingly, it is the initiation and successful completion of all phases that can result in bringing the accomplishments of the program to commercialization and subsequent benefit.

OVERALL APPROACH

Until now, buckets for heavy-duty gas turbines have been constructed of large single metal castings or forgings. Improvements in materials for these monolithic designs have demanded simultaneous considerations of all essential property requirements. These properties include high temperature tensile strengths, rupture strength, low cycle fatigue strength, corrosion resistance, oxidation resistance and ductility. Simultaneous improvement in all these areas rarely occurs. Instead, trade-off positions in which one property is improved at the expense of another is the generally accepted practice.

The performance of a gas turbine, as measured by both output and efficiency, is strongly influenced by the gas temperature at which it operates. The higher the operating temperature the greater the efficiency and output. As an example, a monolithic bucket fabricated with materials that can operate with equivalent stresses at higher metal temperatures would be offset by the same material's poor oxidation and hot corrosion resistance in the airfoil area and lower high temperature yield strength in the dovetail.

One method of achieving improved properties for both the dovetail, airfoil, and hot gas path surfaces is to match different materials together. This approach toward improved performance in key properties is to integrate the best material for each part of a hot section bucket or nozzle into a bonded "composite" component, or a "hybrid" component. A hybrid bucket is a superalloy part composed of a variety of alloys bonded into one integral part. Each segment is tailored to perform a specific function with greater reliability and performance than possible with contemporary monolithic parts. Such a structure would consist of a strong low temperature dovetail material, a strong high temperature airfoil material, and a high reliability hot corrosion resistant skin material. These three dissimilar materials would then be bonded together to form a homogeneous structure with each material responding to the specific service conditions applied to it. The success of such a structure would be totally dependent on the ability to adequately bond claddings to airfoil surfaces, and airfoil structures to dovetails. Currently, there are programs in place within the General Electric Company Gas Turbine Division to evaluate claddings bonded to airfoil materials. Phase I of the overall program addresses bonding airfoil and dovetail selected materials.

PHASE I DEFINITION

The Phase 1 effort consists of process development, composite mechanical performance and mechanical design. Tasks in the program are an evaluation of bonding techniques, the physical metallurgy of the candidate alloy combinations and their bondlines, and the mechanical performance of airfoil and dovetail materials separately and as bonded composite structures. In addition, studies are being made on how best to incorporate the details of bonding (shape, location, strength requirements) into full scale hardware.

The Phase I effort requires the coordinated efforts from the following organizations:

- Advanced Materials Systems (AMS)
- Mechanics of Materials (MM)
- Materials and Processing Laboratory (M&P)
- Gas Turbine Mechanical Design

Advanced Materials Systems is responsible for airfoil and dovetail alloy selection, procurement of material for all tasks, preliminary high temperature tensile testing of all unbonded and bonded materials, and the physical metallurgy of all candidate materials.

Mechanics of Materials is responsible for all long term creep testing of the prime airfoil material and low cycle fatigue testing of the dove tail and airfoil material as well as the prime airfoil to dovetail bonded combination. Utilizing the results of the test programs and specimen analysis, recommendations will be made regarding the desired configuration of bond geometry as well as methods for determining composite bucket life.

The Materials and Processing laboratory is supporting AMS studies and evaluating alternate bonding techniques. Bonding studies conducted by AMS will use hot isostatic pressing to achieve a diffusion bond between the airfoil and dovetail materials. Alternate bonding techniques, using processes like Activated Diffusion Bonding (ADB), will be pursued by the M&P Lab. Airfoil and dovetail materials to be used in alternate bonding studies will be recommended by AMS.

Mechanical Design Engineering is evaluating the requirements for a composite bucket to be used in full scale hardware. Areas being addressed include bondline geometry, location and strength requirements. In addition, consideration will be given to alternate bucket dovetail and shank designs so as to simplify its fabrication.

The program was initiated with AMS identifying, selecting and procuring airfoil and dovetail alloys. Subsequently, the M&P Lab began its alternate bonding studies on a pre-selected combination. After the HIP bonded trials and tests have been completed, M&M will begin to evaluate the prime airfoil and dovetail combination by conducting long term creep and low cycle fatigue tests. Design Engineering studies will be conducted in parallel with the mechanical testing portion of the program.

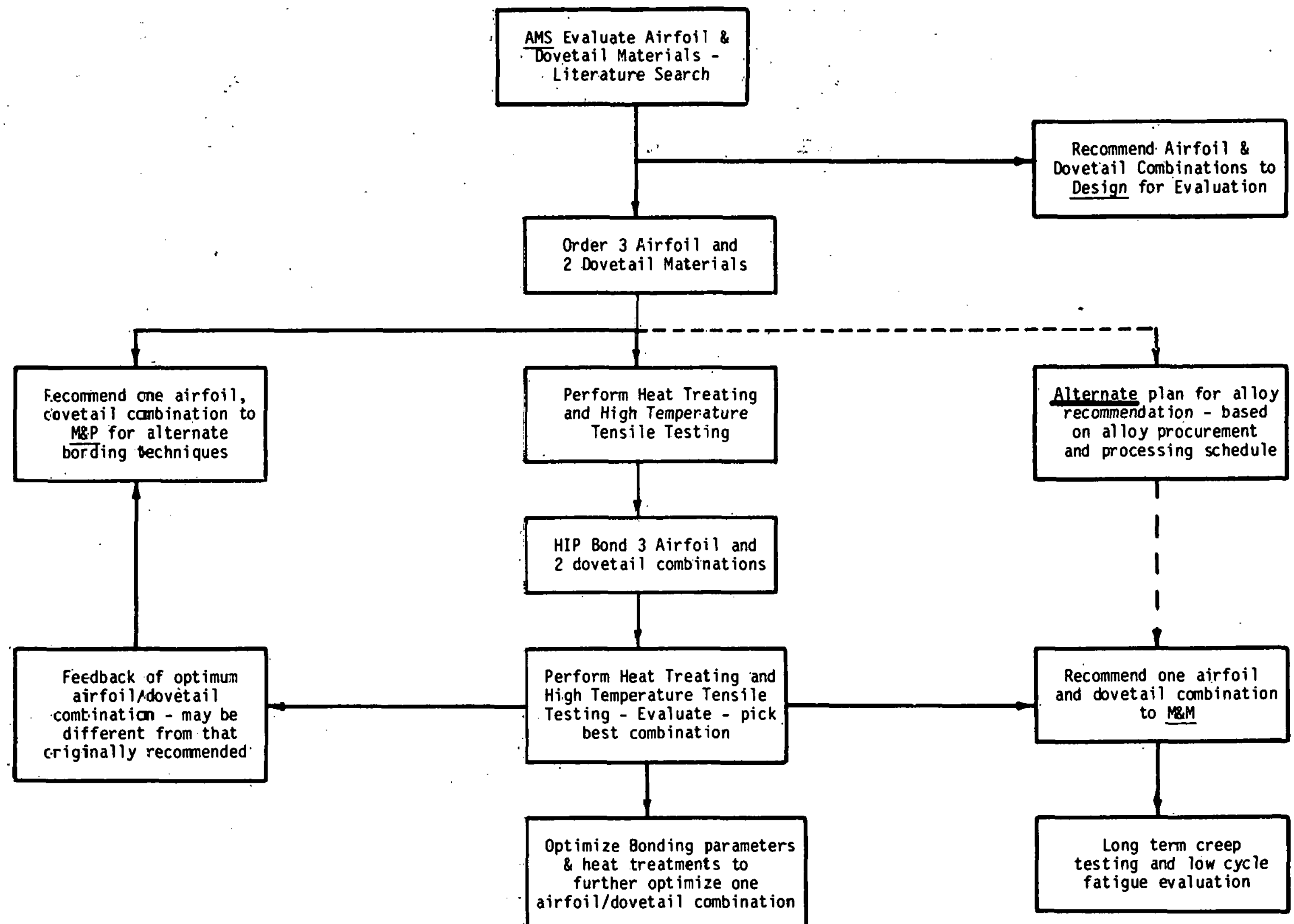
Since the program's inception, changes in the Phase I strategy have taken place. Table 1 shows a block diagram for the progression of events scheduled to occur in the program. The major change in this schedule has been the decision to recommend the airfoil and dovetail alloy which M&M will evaluate prior to the HIP bond evaluation by AMS.

Reasons for the change are based on the need to maintain compositional compatibility, schedule limitations and costs. Compositionally, each of the five alloys being studied is quite complex. Small changes in their composition would significantly alter the material's physical metallurgy and mechanical properties. For this reason it is important that an alloy's composition during preliminary high temperature tensile testing be exactly the same as that used for long term creep and low cycle fatigue testing. In this regard, it is desirable that a master heat of each alloy be made at the start of the program even though only one airfoil/dovetail combination will be extensively tested. However, costs to provide a master heat of all five alloys are prohibitive. Also, on a schedular basis, directional solidification of the airfoil alloys had to be completed by March 1981 or extensive delays (3 to 4 months) would be encountered. For these reasons, the internal conduct of the program events were redirected to provide alternate inputs to Mechanics of Materials activities as indicated by the dotted line shown in Table 1.

ALLOY SELECTION CRITERIA

This program is directed toward a composite bucket which can replace conventional monolithic design in large size heavy-duty gas turbines. Accordingly, mechanical property improvements are compared to conventionally cast superalloys (ie IN738, U500). Dovetail alloys should have ductilities and high temperature yield strengths greater than currently used materials while the airfoil material should have substantial improvements in creep and low cycle fatigue life.

TABLE 1
SCHEDULED EVENTS FOR THE COMPOSITE BUCKET PROGRAM



In addition to improvements in mechanical properties, other criteria include the following:

- minimal processing restrictions
- "off-the-shelf" material selection
- Heat treat compatibility
- Oxidation and hot corrosion behavior

In order to achieve the greatest benefit in increased mechanical properties, new processes were considered. By selecting a new superalloy composition in a conventionally cast form, only moderate increases in performance could be realized. In anticipation of a significant increase in performance, the following processes were selected. For the airfoil, directionally solidified (DS) structures will be used while powdered metals (PM) were selected for the dovetail. Directional solidification provides a significant improvement in stress rupture performance over that of currently used superalloys, Figure 1. Hot isostatic pressing of PM superalloys produces a very fine grain size which provides ductilities, Figure 2, and high temperature yield strengths and ultimate strengths, Figure 3, which are greater than those of conventional superalloy investment castings. As a result of the significant improvements associated with DS and PM, alloys selected for this program must be capable of being processed using these techniques.

The program plan is designed to evaluate metallurgical compatibility, with alloy selection limited to existing compositions. No attempts will be made to alter compositions in order to optimize such characteristics as hot corrosion resistance, oxidation resistance and γ' strengthening. Off-the-shelf alloys, and their established compositions have been used. Once it has been established that strong, homogeneous bonds can be developed, then alternate chemistries, materials, heat treats, etc. may be considered for optimization of bondline performance.

Heat treat compatibility is the remaining characteristic which influenced the alloy selection. In order to successfully join two nickel base superalloys,it is important that the HIP temperature and heat treat cycle for each alloy be as compatible as possible. A typical cycle for these alloys includes a high temperature solution, followed by some high temperature coating cycle and then aging. High temperature solutioning for both airfoil and dovetail sections is expected to be achieved during the HIP bonding operation. Subsequent heat heating would depend upon the coating method selected; for example, plasma spraying, cladding, etc. Aging for the bonded structure will be chosen so as to optimize properties in the airfoil while simultaneously trying to maintain some minimum high temperature strength (120 to 130 KSI) in the dovetail. Possible aging cycles for strengthening the airfoil and dovetail sections include:

- aging at higher airfoil temperature with subsequent overaging in the dovetail,

- aging at the lower dovetail temperature with subsequent airfoil aging taking place during high temperature service operation,

- slow cooling from the high temperature coating cycle to the dovetail aging temperature, then aging at the lower temperature.

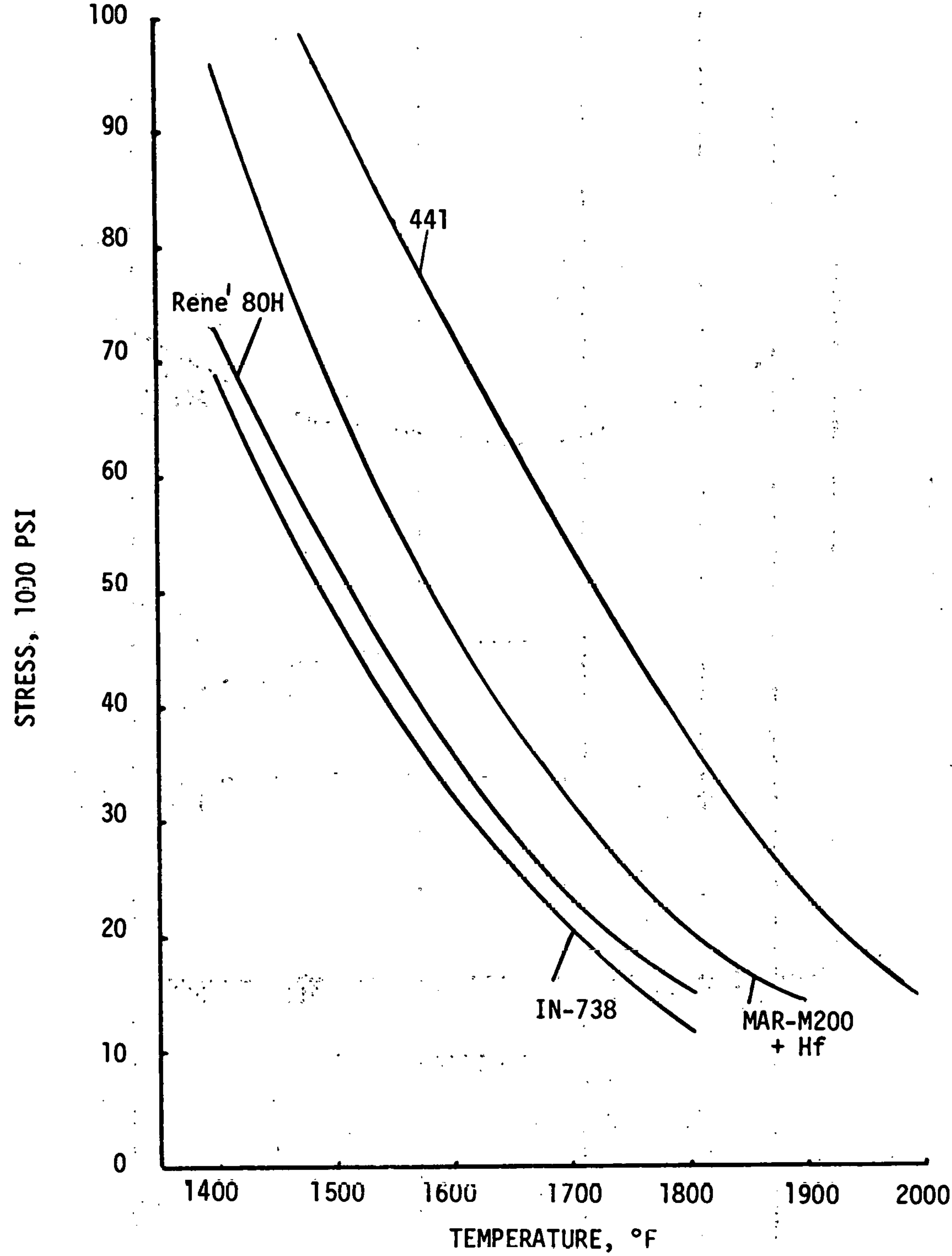


Figure 1. Airfoil Alloy 1000 Hour Stress Rupture Life (Average Data)

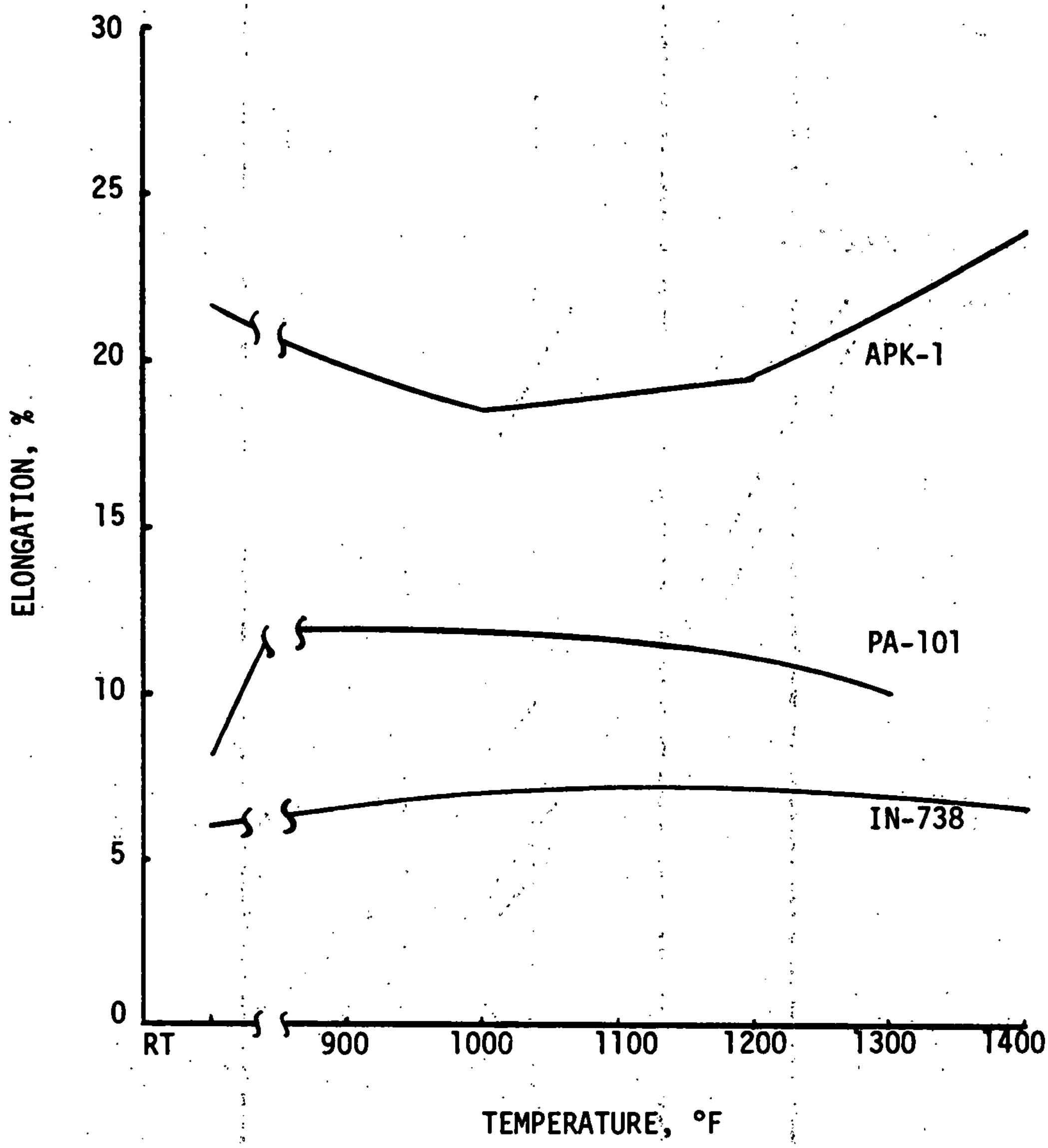


Figure 2. Dovetail Elongation Values
(Average Data)

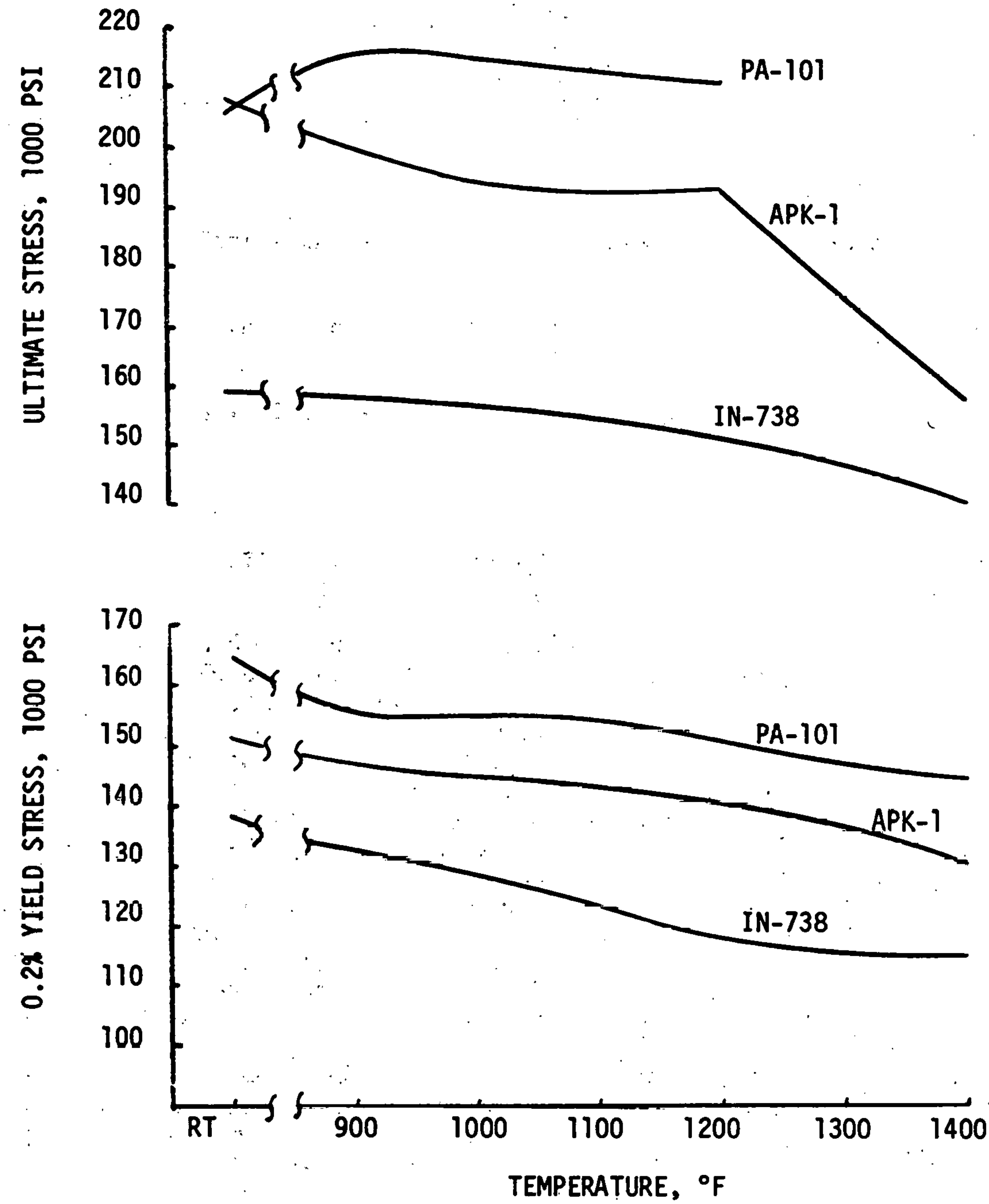


Figure 3. Dovetail Alloy Tensile Values
(Average Data)

Airfoil aging would then take place during high temperature service. Details of the heat treat cycle for this composite structure are being worked out in preparation for the HIP bonding runs. Table 2 lists the typical heat treatment cycles for each material while Table 3 lists alternatives to these cycles.

TECHNICAL ACTIVITIES

Technical activities in the supporting functional areas are as summarized below:

Advanced Materials Systems

Advanced Materials Systems work completed to date includes the following:

- Selection of the material process by which airfoil and dovetail material will be made.
- Selection of 3 airfoil and 2 dovetail materials for evaluation.
- Receipt of all alloys
- Completed preparations for machining, heat treating, bonding, and tensile testing candidate alloys.

Alloys selected for the airfoil in DS form include Rene' 80H, MAR-M200+Hf and alloy 441. For the dovetail, two powdered alloys were chosen, PA-101 and APK-1. As part of the alloy selection criteria, 1000 hour stress rupture strength vs. temperature characteristics were used to select the DS alloys while high temperature tensile and elongation characteristics were used to select the powder alloys. All alloys, except 441, are commercially available and considerable data is available in the open literature. Directionally solidified MAR-M200+Hf has been in use in the aircraft industry for the past 10 years. Rene' 80H, though not currently in use, represents an alloy with excellent castability for future aircraft applications. For the airfoil alloys, three different levels of improved stress rupture performance were selected. As shown on Table 4, for equivalent stress levels, the increase in operating temperature over alloy 738 can range from approximately 25 to 30°F for Rene' 80H to greater than 200°F for 441.

Alloy 441 is actually Rene' 150 with Vanadium removed to improve oxidation and hot corrosion resistance. Though this alloy is still in the experimental stages, it represents the current upper limit on improved stress rupture performance for DS nickel base superalloys. Mechanical property and chemical composition data along with optimum heat treating cycles are available for 441, and have been utilized in this program.

Both powder alloys selected have low carbon content (.02 to .04 wt %). The purpose of the low carbon composition is to minimize the precipitation of MC type carbides on prior particle boundaries during hot isostatic pressing.

Table 2
Typical Heat Treat Cycles for Candidate Alloys

Cycle \ Alloy	441	MAR-M200 + Hf	René 80H	APK-1	PA-101
Solution	2300°F/2 hr	2200°F/2 hr	2175°F/2 hr	2120°F/2 hr	2050°F/2 hr
Coating*	1975°F/4 hr	1975°F/4 hr	1925°F/4 hr	1975°F/4 hr	2052°F/2 hr
Age	1650°F/16 hr	1600°F/32 hr	1600°F/16 hr	1200°F/24 hr 1400°F/8 hr	1250°F/16 hr 1400°F/16 hr

* Typical Coating Cycle - this will be altered for plasma spray type coatings.

Table 3
Possible Heat Treat Cycles for Bonded Airfoil and Dovetail Combinations

		Airfoil Alloys			Dovetail Alloys	
Cycle \ Alloy		Rene 80H	MAR-M200 + Hf	441	APK-1	PA-101
Combined HIP + Solution		2150 to 2200°F/ 2 Hours	2150 to 2200°F/ 2 Hours	2200 to 2250°F/ 2 Hours	2150 to 2250°F/ 2 Hours	2150 to 2250°F/ 2 Hours
Coating Cycle		1975°F/1 Hour	1975°F/1 Hour	1975°F/1 Hour	1975°F/1 Hour	1975°F/1 Hour
Possible Aging Cycles	1	1600°F/16 Hr	1600°F/32 Hr	1650°F/16 Hr	1600-1650°F/ 16-32 Hr	1600-1650°F/ 16-32 Hr
	2	1200°F/24 Hr 1400°F/8 Hr	1200°F/24 Hr 1400°F/8 Hr	1200°F/24 Hr 1400°F/8 Hr	1200°F/24 Hr 1400°F/8 Hr	1200°F/24 Hr 1400°F/8 Hr
	3	Slow Cool From 1975 to 1200°F 1200°F/24 Hr 1400°F/8 Hr	Slow Cool From 1975 to 1200°F 1200°F/24 Hr 1400°F/8 Hr	Slow Cool From 1975 to 1200°F 1200°F/24 Hr 1400°F/8 Hr	Slow Cool From 1975 to 1200°f 1200°F/24 Hr 1400°F/8 Hr	Slow Cool From 1975 to 1200°F 1200°F/24 Hr 1400°F/8 Hr

Table 4
Comparison of Temperature Improvements and Mechanical Properties for Conventionally Cast and Directionally Solidified Airfoil Alloys

a) TEMPERATURE IMPROVEMENTS

Alloy	Operating Temperature (T)	Applied Stress (KSI)	ΔT (°F)	Operating Temp. (T)	Applied Stress (KSI)	ΔT (°F)
738	1500°F	48	0	1700	20	0
René 80H	1525	48	+25	1735	20	+35
MAR-M200 + Hf	1595	48	+95	1800	20	+100
441	1735	48	+235	1925	20	+225

b) MECHANICAL PROPERTIES @ 1600°F

Property / Alloy	Ultimate (KSI)	% Change from 738	Yield (KSI)	% Change from 738	Elongation (%)	% Change from 738
738	112	0	82	0	11	0
René 80H	94	-16	65	-21	26	+136
Mar-M200 + Hf	132	+18	111	+35	7	-36
441	127	+12	106	+29	6	-45

This prior particle boundary (PPB) film, once formed, cannot be elilminated and provide a path for easy fracture in consolidated parts.

Alloys APK-1 and PA-101 are better recognized as low carbon Astroloy or low carbon U700 and IN792 with Hf respectively. Typical compositions are shown in Table 5. High temperature tensile property improvements over conventionally cast IN738 are shown in Table 6.

Directional solidification of all three airfoil alloys was completed at the GE Corporate Research and Development Center. This insured close control over the process. Directional Solidification facilities at CR&D allow for a maximum bar size of 1 5/8" diameter by six to seven inches long. Alloys 441 and MAR-M200+Hf were made from raw materials at CR&D while cast Rene' 80H bar stock was received from GE, Evendale. Typical compositions for the five alloys, as determined by x-ray fluorescence, are shown in Table 5. All materials are cast into 2" diameter bar stock. Lengths of bar stock are cut so as to provide a DS'ed bar having dimensions of 1 5/8" diameter x 6" long. All melting, pouring and subsequent DS'ing is done in argon. All material is induction melted in a ceramic crucible to 1635°C. The material is then poured into ceramic tubes having dimensions of the finished DS bar. These tubes are positioned in a vertical furnace operating at the melting temperature 1635°C. The fixed end of the ceramic tube is connected to a chill plate which is drawn down through the furnace at a rate of 12 inches per hour in order to produce the elongated grain structure shown in Figure 4. To date all required Rene' 80H and 441 DS'ed bars have been made. Work is continuing to produce the required number of MAR-M200+Hf bars.

To insure clean, useable powder for the program, certain requirements were placed on its production. These included vacuum melting, argon atomizing, and inert gas screening. To minimize accidental introduction of inclusions during manufacturing and subsequent handling, a maximum allowable powder particle size of -325 mesh was stipulated. Screening out the larger powder will help to remove any large size foreign inclusions that may have been introduced during powder production. All APK-1 powder was screened to -325 mesh (less than 44 microns); however, due to increased raw material costs with PA-101, it was not possible to purchase just -325 mesh powder. Instead the total product of a 100 pound run was purchased and screened into categories of +60 (250 microns) , -60 +270 (250 to 53 microns), -270 +400 (53 to 37 microns) and -400 mesh (less than 37 microns). The amount of powder in the -60 +270 mesh size is large enough to provide enough material to perform the preliminary tensile testing and bonding studies required for this program. The size difference between APK-1 (-325 mesh) and PA-101 (-60 +270 mesh) should not present a problem in high temperature tensile testing of HIP consolidated material. However, differences could occur in long term high temperature creep rupture or LCF tests where foreign inclusions associated with larger particle sizes could reduce material performance. If these two powders are to be compared for their creep rupture and LCF performance, then the -270 +400 mesh PA-101 would be consolidated and tested. Tap densities for both powders was specified to be equal to or greater than 4.95 gm/cm^3. All powders have been received.

Heat treatments given to nickel base superalloys depend on which properties (fatigue, creep, tensile) are to be optimized. For this program, compromises in heat treating cycles will be made in order to successfully diffusion bond airfoil and dovetail materials together. Tables 3 and 4 list optimum

Table 5
Alloy Compositions

Alloy \ Element w/o	Ni	Ti	Al	Co	Mo	Cb	Ta	W	Hf	Cr	Re	C	B
MAR-M200 + Hf	BALANCE	2.2	4.92	9.48	-	1.04	-	12.0	1.65	9.51	-	0.14	.015
441		-	5.87	11.74	1.1	-	7.11	5.5	1.37	6.58	3.13	0.06	.02
Rene' 80H		4.7	3.1	9.3	4.0	-	-	3.8	.72	13.9	-	.15	.015
APK-1		3.5	3.9	16.9	4.9	-	-	-	-	14.6	-	.022	-
PA 101		4.0	3.5	9.0	2.0	-	4.0	4.0	1.0	12.6	-	.03	.015

Table 6
Comparison of Mechanical Properties for Conventionally Cast and Powdered Metal Dovetail Alloys @ 900°F

Property / Alloy	Ultimate (KSI)	% Increase Over 738	Yield (KSI)	% Increase Over 738	Elong. (%)	% Increase Over 738
738	157	0	132	0	6.5	0
APK-1	200	+27	147	+11	19.8	+204
PA-101	215	+37	155	+17	11	+144

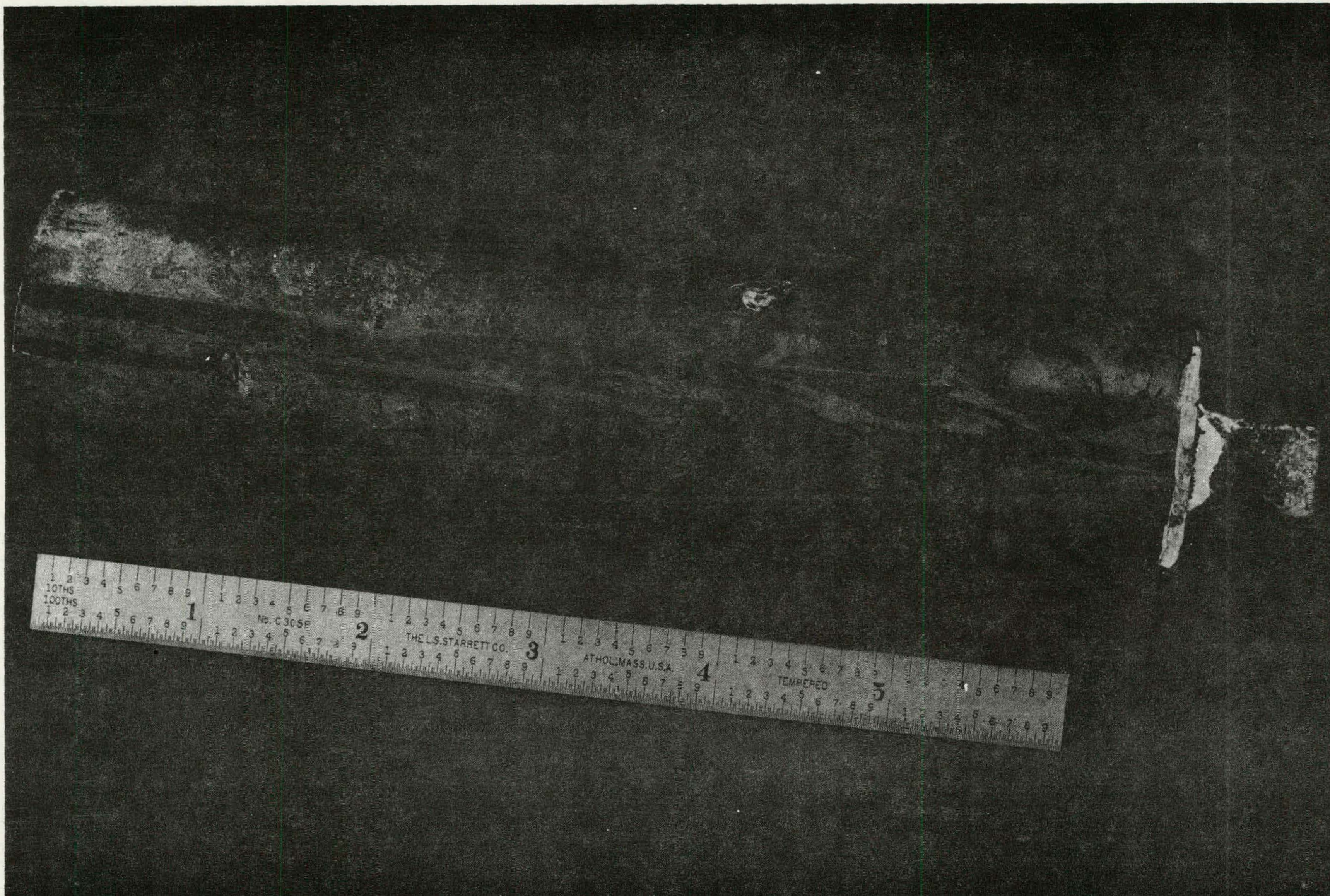


Figure 4. Directionally Solidified Bar of Alloy 441

heat treating cycles for each alloy and a range of treatments which could theoretically be applied in order to best join the two materials together. In all cases, it is anticipated that optimization of one alloy's properties will cause a reduction in the other. However, due to the significant increase in properties over current alloys 3 to 40 ksi in the airfoil and 20 to 30 ksi in the dovetail, Tables 4 and 6, reductions in mechanical properties of either the airfoil or dovetail could be tolerated and still result in an improvement over the monolithic bucket design. The effects of these alternate heat treatments and an assessment of bondline structures will be done during the remaining part of the program.

MATERIALS AND PROCESSING LABORATORY

The laboratory is supporting HIP design, HIP operations and conducting alternate bonding studies on pre-selected alloys. Work to date has centered around can fabrication. HIP densification of powdered nickel alloys will be achieved by using rectangular cans made from mild steel. Joining HIP consolidated powder to DS material will be achieved using two different sizes of thin walled pipe welded together, Figure 5. This design effort and subsequent HIP'ing operations will help support both AMS and M&M in producing the diffusion bonded material needed for mechanical and metallurgical evaluations.

In addition to hot isostatic pressing for powder consolidation and composite specimen fabrication, the M&P lab will be pursuing alternate diffusion bonding methods. One such method is activated diffusion bonding. In this method, a thin layer of foil or powder metal is placed between the two superalloy metals to be joined together. Chemical composition of the thin layer, coupled with controlled heat treating and pressure will produce a high integrity bond between the two dissimilar materials. This work at the M&P lab is only now beginning since the material has just recently been made available to them.

MECHANICS OF MATERIALS

The objectives of the Mechanics of Materials efforts are to:

1. Determine the long time creep and LCF behavior of the airfoil alloy and establish the methods for predicting bucket airfoil life.

2. Establish the LCF behavior of the dovetail alloy and define the approaches for predicting dovetail life.

3. Evaluate the structural integrity of the airfoil/shank interface, identify the impact of joint configuration, and provide the methodology for optimizing interface life.

Directionally solidified MAR-M200+Hf has been selected for the airfoil alloy. A total of nine DS MAR-M200+Hf 7/8 inch diameter by 8 inches long bars are being supplied to Mechanics of Materials for evaluation. Up to 9 creep tests will be conducted. These specimens with .505 inch gage diameter and 5 inch long gage length have been found to provide accurate creep response at as low as .1% creep strain. Specimen blanks which are .52 inch diameter by 6 inches long are being supplied for LCF testing. Test conditions for the

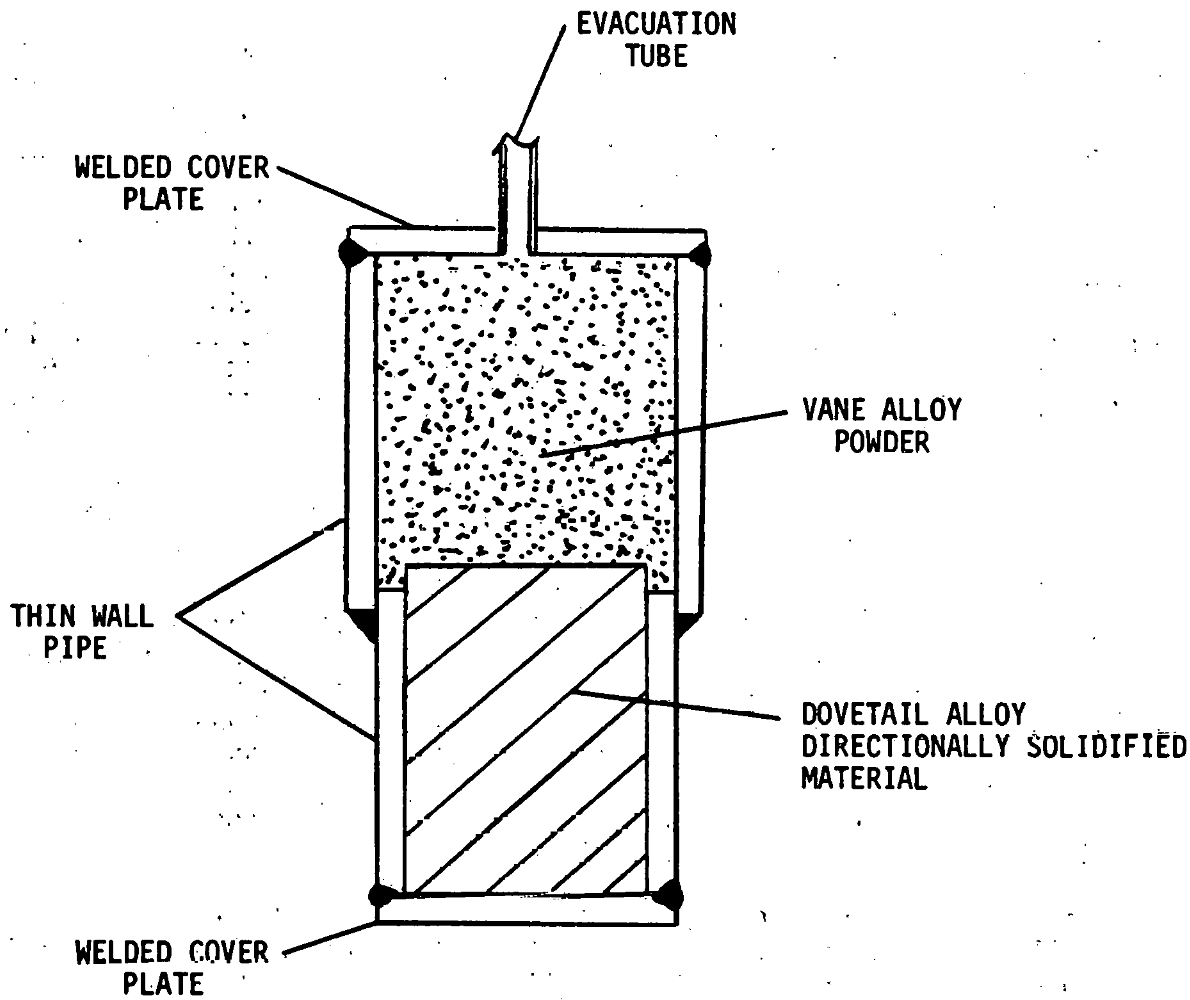


Figure 5. HIP Can Design for Fabricating Bonded Samples of DS Alloy to Consolidated Powder

program have been defined and include temperatures from 1600 to 2000°F and strains from .35 to 1.0%.

HIP'ed APK-1 has been selected for the dovetail alloy. Specimen blanks which are .52 inch diameter by 6 inches long are being prepared for conducting up to 15 LCF tests. Test conditions have been defined and include temperatures from 800 to 1200°F and strains from .8 to 1.25%.

The interface between the bucket airfoil and shank is of prime interest since it contains the diffusion bonded joint of the two dissimilar materials. The behavior of this interface will define the joint configuration required to optimize life and ensure meeting design requirements.

Two bondline configurations will be examined in load controlled LCF testing of shank/airfoil composites. The first will place the bondline normal to the direction of loading and the second will place it at an angle inclined 45° to the direction of loading. This will enable an evaluation of bond fatigue behavior under both normal and shear loading. These results will be utilized with fatigue and fracture mechanics analysis techniques for predicting life of the interface joint and for evaluating potential design configurations.

MECHANICAL DESIGN

For the mechanical design of a composite bucket, one of the first areas under investigation (bondline location) has led to a tentative selection of the radial position of the bondline within the bucket. To maximize the success of the bonded structures, the region immediately below the airfoil platform appears to offer the most advantages. The magnitude of the centrifugal forces acting on the bondline are much less here than further inward locations. This means a reduction of 30-50% in centrifugal forces relative to a location near the dovetail in a typical last stage design. Also, the bonded joint remains in the cooler (less corrosive) environments of the shank.

To facilitate the bonding process, a composite first or last stage bucket will have separate coverplates. While separate coverplates add somewhat to the complexity of the turbine bucket assembly, they are proven and very effective sealing and damping devices. General Electric has successfully applied this design concept in gas turbine engines for over 20 years. As a result, the load carrying sections of the bucket can be simplified and more readily adapted to composite bondline technology needs.

Based on reviews with Aero-Thermo Engineering, preliminary design iterations have begun in order to extend baseline designs towards projected higher allowable stress and temperature environments.

Two distinct categories for bonding geometry are being considered:

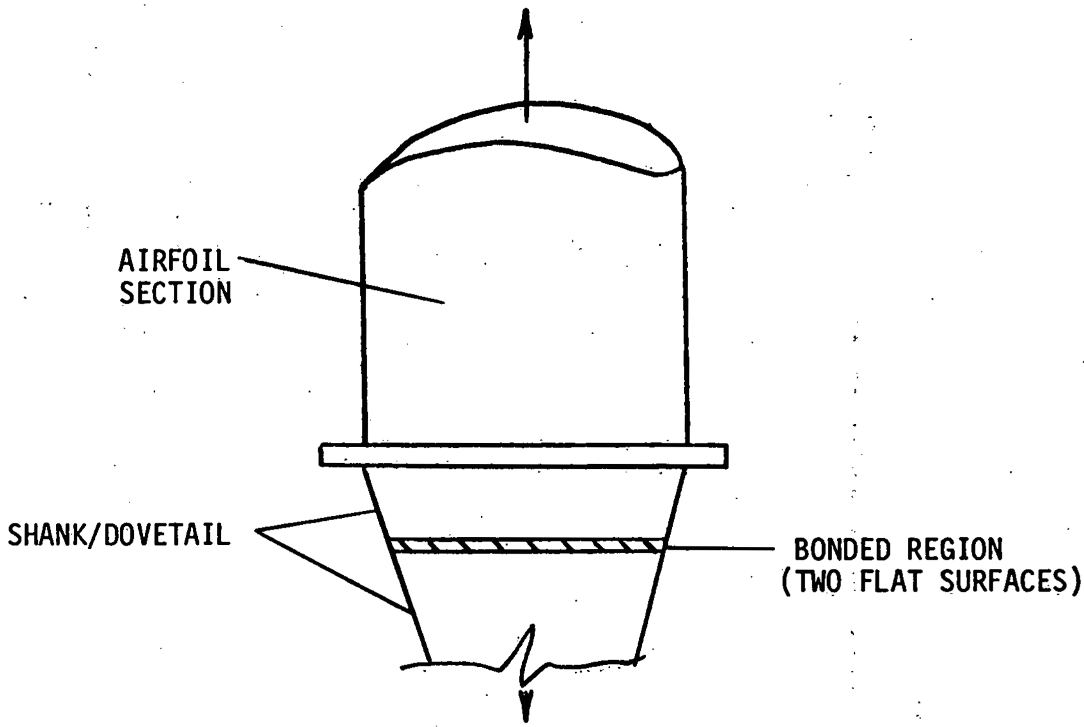
a) direct load geometry (DLG)
b) load sharing geometry (LSG)

The direct load geometry will result in all loads transmitted through the bondline to be in tension. It represents the simplest form of joining the airfoil to shank/dovetail structures by means of two flat surfaces, Figure 6a. A variation of (DLG) being considered is a wedged configuration. Loads will be transmitted both in tension and shear, Figure 6b.

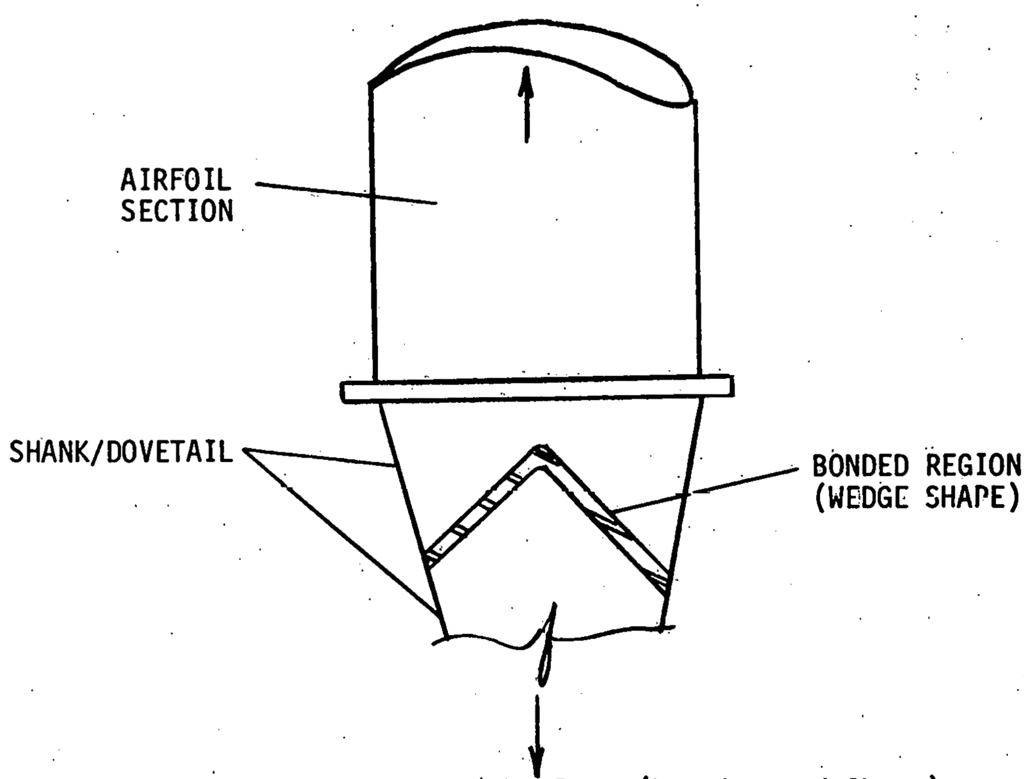
The load sharing geometry will result in loads, at a given radial plane, partly being carried by the bondline and partly through the base material. It represents a "dovetailed" version of the joined structures, and offers the advantage of reducing the strength requirements of the bonded joint.

CURRENT STATUS

- All materials for the airfoil and dovetail have been selected, ordered, and received. Additional bars of DS MAR-M200+Hf for mechanical testing are in process.
- HIP cans for both powder consolidation and diffusion bonding studies have been designed and are being fabricated.
- Discussions are underway with vendors for specimen machining and testing.
- Mechanical Design is evaluating bondline strength requirements, geometry, and location.



a. Direct Load Geometry Bond (Simple Tension)



b. Direct Load Geometry Bond (Tension and Shear)

Figure 6. Shank to Dovetail Bond Geometry

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