ADVANCED CONCEPTS IN COMPONENT FABRICATION

by

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Introduction

The aerospace systems of today, whether intended for civil or military applications, face the problem of cost credibility. While in the minds of we in the aerospace industry, the cost of today's systems is justified in terms of the technological state of advancement coupled with an outstanding safety record, we do still strive to reduce costs wherever possible. It is also mandatory, but not as frequently cited, that direct and indirect customer cost demands be reconciled with the need for further technological advancement consistent with both military preparedness and civil safety requirements.

The above, now somewhat trite statements, must be further analyzed to determine how aerospace scientists and engineers should redefine and redirect their efforts to satisfy today's ambitious and ambiguous demands. Following a logical analysis of our current problem, it is obvious that the field of component fabrication provides answers which satisfy the current demands. In amplifying this point, it will be first necessary to review the advantages and disadvantages of final part processing. With this background, it becomes possible to identify areas where increased current and future emphasis is required.

Prior to a discussion of fabrication, it is first required that the terms be defined. Fabrication for purposes of this presentation will concentrate principally on welding processes with welding defined as any bonding method wherein a metallurgical joint is formed. Other important final fabrication processes such as metal removal and coating techniques will also be only briefly cited as related to the welding process. Other conventional final fabrication processes such as bolting and riveting do not involve the overall metallurgical aspects of the system and thus have not been included in the following discussion.

A facet of component fabrication, which will be frequently mentioned, is the ever present concern for the total interaction and effect of all processing steps on the performance capability of the final part. A fabricated part consists of a group of segments, each of which may have been individually processed, formed and heat treated and will finally be assembled into a complex structure designed and made to perform a function. Individual segments frequently possess differing compositions, microstructures and properties, all of which are then joined and finally heat treated. It will hopefully be made clear that as materials and component sophistication increases, greater care and understanding are required to assure compatibility of processing and joining sequences with performance need. In particular, development of materials will also require more emphasis on the fabricability than ever before.

Design Considerations for Fabricated Hardware

The principal advantage of fabricating gas turbine components by welding as opposed to monolithic construction is product form flexibility which results in direct cost benefits not obtainable by other fabrication methods. The repair capability during manufacture and following service degradation enjoyed with many welded structures such as Hastelloy 'X' alloy combustion chambers has been secondary consideration but is of ever increasing importance. The reduced quantity and more acceptable form of scrap generated, while not a prime reason for welding, is nonetheless a further process benefit. As unique materials such as dispersion strengthened superalloys are introduced into production, it will become necessary to fabricate components in a manner designed to optimize materials utilization

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of these strategic or expensive alloys.

The major impediment to welding critical structures is a general lack of sufficient background data and/or experience to substantiate weldment properties. Contrasted to the vast accumulation of data on candidate wrought alloys, little systematically assimilation weld property data exist. This insufficiency of data results in reduced design confidence and therefore a tendency to continue the use of monolithic structures or to overdesign joints where no practical alternatives exist. Overcoming this attitude will require a concentrated effort by all concerned to develop fundamental design data at a more rapid rate.

The microstructural differences and the implied mechanical property variations associated with fusion welding and to a lesser extent with solid-state welding processes so concern many designers that unnecessary roadblocks to welding are instituted. These factors coupled with inspection unknowns have resulted in warranted and unwarranted restrictive use of welding technology. These additional restraints, while warranting extensive study in their own right, can best be resolved in an application sense through the generation of reliable design data as noted above.

Finally, the problem of dimensional control in fabricated structures has long been of concern. However, in this area, tremendous advances in process technology have been realized through the use of fixturing and metallurgical development of minimal stress relief cycles. With current technology parts such as large fusion-welded INCO 718 cases and inertia-bonded drum rotors, it is apparent that the problem of dimensional stability can be controlled on an individual component design basis.

Two types of fabricated structures typify what is being made today for gas turbine engines. The first is the large welded case. It is typically more than 30 inches in diameter, is non-moving and a flexing heat-resistant pressure vessel. Welds are required for repairs, attachments, penetrations and segment assembly. It is often of a heat-resistant alloy such as A-286 or Inconel 718. The second structure is more advanced in character and is a rotating member. This is a drum rotor. The integrity, dimensional control, and performance requirements for this rotating structure are much more stringent than for a static structure. Thus, the full structure uses more advanced materials such as high strength titanium and high gamma prime fraction superalloys. The process and joining techniques applied here are subjected to more rigid controls due to the nature of the structure, materials used and processes applied. Further advancement in performance and cost savings are possible in this more complex structure.

Review of Joining Fabrication Processes

Fusion welding in gas turbine powerplants has in the past concentrated on the gas tungsten arc (GTAW), electron beam (EBW) and resistance seam welding (RSW) processes. Plasma arc welding (PAW) has more recently reached production status. The electron beam, plasma arc and, potentially, laser welding are the current key processes wherein further process evolution will lead to increased powerplant fabrication applications.

The electron beam welding process gained general acceptance because of its applicability to reactive metals systems together with small heat-affected zone sizes and the related benefit of minimal part distortion. The very factors which have resulted on the large scale use of electron beam welding also limit its future potential. The need for vacuum chambers to utilize the process properly and the cost of pre-weld part preparation to assure fit-up become liabilities to the process in many applications. Therefore, while electron beam welded usage will undoubtedly broaden in scope, it is doubtful that revolutionary growth in this area will again occur.

The plasma arc welding process has similarities to the EBW and GTAW processes. The PAW process is an arc welding process in which coalescence is produced by heating with the arc constricted between the tungsten electrode and the workpiece. Shielding is provided by an inert gas flowing at the orifice and may be supplemented by an auxiliary shielding. The major difference between the GTAW and PAW process is the latter's constriction of the arc column which results in significantly greater energy concentration. The narrow, high velocity arc column impinges on the workpiece melting a hole completely through the workpiece. The hole so produced, designated the "keyhole", is moved and the surface tension of the molten metal flowing around the edges closes the hole behind itself as metal melts ahead of the hole. Penetration is apparent when the keyhole extends through the metal thickness during welding. The through penetration characteristic of PAW marks a similarity to the EBW. The energy concentration of a plasma arc is lower than an electron beam but significantly higher than the unconstricted arc of the GTAW process. The plasma weld process has been shown to yield a lower porosity defect level in titanium than competitive fusion welding processes. This low defect level is believed to be associated with the solidification mechanics associated with the keyhole welding method.

Other technical advantages of the PAW process include low propensity for arc deflection on improved tolerance for joint misalignment, elimination of the tungsten inclusion problem, and weld energy constancy. Economic rationale for the PAW process are low initial capital cost, simple or no weld preparation, single pass weld capability, and simple fixturing.

Based upon the excellent technical experience to date, operational simplicity and low total cost, it is apparent that the PAW process will gain wide future acceptance.

Laser welding, being relatively new as a potential fusion welding process, remains undefined in potential scope and cost effectiveness. The ability of the laser beam to be transmitted in air for large distances constitutes a unique form of deep penetration welding not previously available. Inert gas coverage may be incorporated by simple means for reactive metals welding. For thin gage section joining, it appears practical to produce joints at the rate of hundreds of inches per minute. In the near term, continued evaluation of laser welding is warranted. The results of these studies will indicate the extent to which laser welding capability should be expanded in terms of production applications.

Solid-state joining methods produce very highly desirable joints with parent metal properties theoretically achievable; however, aside from inertia bonding, it has not found widespread application predicted. The reason for this lack of acceptance is directly attributable to the cost of manufacturing and problems of inspecting high integrity diffusion bonded joints. Nonetheless, diffusion bonding incorporating various interlayer materials has been successfully demonstrated. The use of nickel plate interlayers on nickel-base alloys to prevent oxidation has resulted in the successful diffusion bonding of applications such as combustion liners. The use of melting point depressants such as boron and/or silicon have also been demonstrated as capable of bonding solid solution and gamma prime strengthened nickel-base alloys. Similar systems incorporating melting point depressants have also been developed for titanium alloys. The successful use of the diffusion bonding interlayers is dependent upon the effective and economical application of the interlayers and the development of chemically and metallurgically compatible systems. Metallurgical compatibility in that system may mean suitable remelt temperatures, acceptable mechanical properties, or the establishment of a stable structure.

In terms of solid state welding processes, aside from inertia bonding, it appears that conventional pressure diffusion bonding applications will find limited use. On the other hand, modifications of the diffusion bonding process will probably expand in scope, particularly as viable systems are developed and demonstrated.

Inertia welding is a production process in gas turbine engines. It found initial usage in parts such as steel gears where machining access to bevel gear faces on gear trains was simplified by bonding after machining. Following a parametric study of the process on a series of titanium alloys and full property characterization of the several titanium alloys, inertia welding was applied to production titanium disks. This application of inertia welding to disks enables the use of simple forgings and rolled rings which are subsequently bonded to produce appendages such as spacers or hubs from flat disk forgings. The principal benefit of this fabrication method is the achievement of properties in critically loaded areas which are not readily obtained in the massive forged sections. In this fabrication scheme, the joints are located in areas of reduced stress and therefore do not operate under the conditions wherein critical properties such as low-cycle fatigue are not limiting design factors.

Future applications of inertia welding will require that even higher joint stress capability be demonstrated. In the case of solid solution strengthened titanium alloys (e.g., Ti-6Al-4V) and low volume fraction gamma prime superalloys (e.g., INCO 718), the required design joint properties have been demonstrated. In the case of high strength titanium alloys (e.g., Ti-6Al-6V-2Sn) and high volume fraction gamma prime superalloys (e.g., Astroloy), the required parameters and design data have not been fully developed. In addition, the tooling requirements for the production of a complex component such as a multi-stage compressor rotor have not been adequately defined. This critical area of tooling, from the standpoint of production costs, and dimensional control will ultimately determine the scope of applicability of the inertia welding process.

Brazing as a joining process continues to receive widespread use for many external structures, tube joints and stator assemblies. The braze joints in current use encompass a variety of basic alloys and braze alloy systems. Assemblies such as clustered tube heat fuel/oil exchanges and fuel manifold assemblies would be very difficult to fabricate by any other means. The problems of braze porosity, erosion and lack of fill have over the past decade been satisfactorily resolved through a combination of new braze alloy development and facilities advancements, particularly with regard to vacuum technology. Low braze shear strength, while improved somewhat through alloy development, has been obviated as a problem through design modifications.

Brazing as a production process will continue to be used in most current technology applications. Limited further expansion in the number of brazed components is possible through the development of more viable systems for titanium alloys and, to an even lesser extent, through the development of higher shear strength braze alloys for steel and superalloy systems. A major goal to be achieved is the use of a suitable brazing system for 800 to 1200° service which does not contain gold ($65/oz).

System Integration

A point which cannot be over emphasized is that a fabricated component is a metallurgical mini-system in itself. Each forming, metal removal, metal joining heat treatment and coating operation must be selected and sequenced for optimized properties in the final part and for minimum cost. Material selection must include many factors related to the system being assembled:

- metallurgical compatibility (dissimilar metal structures)
- heat treatment compatibility
- weldability, repairability
- coatability
- formability
- machinability
- dimensional stability

- susceptibility to multiple or redundant process steps

- inspectability

and many others. The design information needed to fully analyze and integrate advanced materials and processes (particularly welding processes) is not always available. With cost as the motive and quality as the inevitable requirement, diligent effort will be required to expand the use of fabricated components to more demanding and critical turbine components.

Summary

Final fabrication has a large impact on cost, performance and reliability of gas turbine engines. Current technology welding processes are used in many static structures and in a more limited manner in dynamic components. Future growth in the areas of plasma arc welding, inertia bonding and in modified diffusion bonding processes appear likely. Laser welding, while at the current level of development holding promise, is as yet undefined in terms of overall potential. Lack of sufficient design data and property correlations to non-destructive test data have been deterrants to further expansion of fusion welding applications.

Environmental protection from erosion, corrosion, oxidation and sulfidation has become a necessity in many powerplant applications. Today's systems, although adequate in terms of flight safety and cost effectiveness compared to unprotected base metal alternatives, still require further development. Protection for highly corrosion prone alloy systems such as refractory metals must be more fully demonstrated for most mission requirements.

Other final fabrication methods such as surface metal removal methods and small passage hole drilling not covered in this review are also pertinent to the problem of cost reduction in current technology powerplants and of even greater importance for the effective utilization of advanced materials and design concepts.