

Welding in the Aero Industry

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Background

Rolls-Royce has a large and growing order book with over 54,000 gas turbines in service and has an annual R&D investment in excess of £600 million pounds. The aerospace market is continuing to evolve due to pressures from the need to innovate, from the requirements of legislation, from environmental concerns and of course from the need to reduce costs.

In terms of gas turbine performance, there is a relentless drive to improve the high temperature capability of the turbine in order to improve the overall efficiency of the engine. This means that there is a transition from steels, aluminium and titanium alloys to nickel based materials. This trend to hotter running engines is borne out by looking at the use of materials in aero engines since the 60's: this shows the fall in the usage of steels and aluminium compared to the much increased use of nickel and titanium based materials. Interestingly, there is only a very slow increase in the use of composite materials, as there are significant challenges in using these materials within a gas turbine, but this will probably increase more rapidly in the future. Legislation is requiring the engine to run cleaner and more quietly and this is also forms part of the goal of the company in their pursuit of a more environmentally friendly engine. Finally, cost drivers require constant vigilance on current joining processes to understand how advances in technology or methods of manufacture can reduce the amount of materials consumed or reduce the amount of rework or scrap that occurs. The current and future aerospace welding technologies requirements are reviewed in terms of these drivers.

Welding Processes

Arc Welding

On civil engines, there is currently significant amount of TIG welding that is carried out, particularly on the bearing housings, high and intermediate pressure turbine blade cooling hole closure and combustion chamber. The main challenges for TIG welding within the aeroengine business is to reduce the subsequent distortion of the component by reducing the amount of heat input. In order to do this, activated flux TIG welding is becoming more widely used on thin section materials such as stator vanes and advances such as interpulse technology is employed.

Plasma Welding

Plasma welded joints are proving to have low rates of defects and are becoming more widely used. Previous studies had not proved successful as the power supplies that were used in the 80's were not sufficiently stable for production. However, modern power systems for plasma welding are now capable of reliable operation. A typical new use of plasma welding is the T-joint concept being trialled in a joint venture between Rolls-Royce and Volvo, with much of the development work being carried out by TWI. This process allows the weld to be made from the back face of the joint on either side of a strut to form a T-piece. Very good quality joints can be made as the welding is relatively insensitive to joint fit-up and has the benefit that the weld can be made with easy access. This may become particularly suitable for the welding of intercases.

Electron Beam Welding

Electron beam welding was developed by the Carl Zeiss Company of Stuttgart, West Germany around 1959, following an experiment investigating increased power on an electron microscope which resulted in the vaporising of the specimen under examination. It was found that by regulating the power settings, the specimen would melt and resolidify and it became apparent that this could be utilised as a welding process that

proved to be extremely adaptable to difficult situations. Electron beam welding technology was evaluated within Rolls-Royce in the 1960's, and has been used for at least a generation on components such as compressor drums, bearing housings, stub shafts and casings. The electron beam process requires a large chamber evacuated chamber to house the component. The process is carried out under vacuum and a beam of electrons is generated from a tungsten filament from which electrons are accelerated and focussed to produce very narrow, intense heat source. This creates a keyhole of metal vapour through the component. The process can be used to produce high quality welds in both titanium and nickel based materials in a wide variety of thicknesses. These include Ti6/4 and Ti6246, stainless steel types such as Jethete and nickel based alloys such as Inco 718, Waspaloy and C263.

Current developments include digital high-frequency beam deflection where the beam is manipulated at high speeds from point to point to allow the pre-heating of material. This could provide the means to weld traditionally "non-weldable" alloys such as the new generation nickel-base superalloys which have a significantly higher volume fraction of ?? than conventional superalloys in order to meet the demand for better high temperature properties. These alloys are typically very difficult to weld and are prone to micro-cracking as solidification takes place during welding.

Inertia Welding

Although Inertia welding has been used in Rolls-Royce since the late 1960's, it was not until the past few years that this has become the mainstay for the production of shafts and discs on modern variants of the Trent engine. This transition from arc based processes towards friction type processes has been rapid because there is an increasing difficulty in welding nickel based alloys that have increasing chrome equivalents which are required to improve the temperature capability. As friction welding does not involve any melting, inertia welding can be used to join difficult to weld nickel based alloys provided optimum welding parameters are chosen. Furthermore, it is more suitable for production than electron beam welding since it does not require a vacuum environment. Rolls-Royce plc is employing inertia friction welding to join high pressure compressor drums on the recently installed 2000 ton force inertia welder near Nottingham, UK.

Diffusion Bonding / Super Plastic Forming

Rolls-Royce has for the past 15 years used a diffusion bonded superplastically formed sequence for the manufacture of large hollow fan blades on civil aircraft. This process allows the simultaneous joining and forming of the blade profile with an intricate internal stiffening structure. Trent 700 and subsequent generations of the Trent use second generation hollow wide chord fan blades. The manufacturing process includes diffusion bonding and super-plastic forming. Sheets of titanium separated by a titanium membrane are diffusion bonded at around 1000oC at high pressure. The blade is then twisted to its near final shape. The aerofoil shape and rigid internal structure is then inflated using an inert gas at temperature, superplastically forming the inner membrane which now becomes the hollow structural core of the blade. By developing this process, the weight of the blades (compared to first generation wide cord fan blades) is reduced some 15%, which represents a saving of around 50 kg per engine set, and gives rise to further weight benefits for both the disc and the containment structure. Construction costs are reduced by removing a number of the processing steps taken to make the blade.

Linear Friction Welding

Although rotary friction welding had been in place for a considerable number of years within Rolls-Royce, it was the reduction in weight that can be achieved on military jets that saw the development of a linear friction weld (LFW) technology to put a hollow fan blade produced in the manner already described in the previous section onto a blisk using linear friction welding technology. This is the only technology that allows a hollow blade to be attached to a disk, which is a requirement for low weight. Rolls-Royce use a Curvi-Linear friction welding process to attach hollow and solid blades to discs to form the blisk. Rolls-Royce have

proven LFW machines and technology which are enabling LFW manufacture of production blisks on EJ200 and development blisks on Joint Strike Fighter.

The Rolls-Royce LFW process is a self-cleaning process, whereby surface contaminants are removed from the pre-welded components and are expelled into the weld flash, which is later machined away. Care has to be taken with the re-entrant features and porosity that can occur, however once the parameter set has been optimised, the process is inherently stable.

It has proved to be an ideal process for joining blades to discs where the high value-added cost of the components justifies the cost of a LFW machine. In using this process, a much reduced overall weight is achieved. This approach is more cost-effective than machining blade/disc (blisks) assemblies from solid billets for blade sizes >100 mm.

Laser Welding

Modern equipment can now direct laser beams of 2 to 10 kW into a very small area. This means that power levels in excess of 100 W/mm² are produced on the surface of the parts to be welded. The laser beam makes a 'keyhole' and the liquid metal solidifies behind the traversing beam, leaving a very narrow weld and heat affected zone. The weld is typically 1 mm wide and because the heat input is relatively small, distortion of the surrounding material can be much less than other welding technologies. Additionally, as the weld bead is small, there is usually no need for finishing or re-working which reduces costs.

Within Rolls-Royce plc, welding of Ni & Ti alloys has been demonstrated from 1 to 4 mm thick butt joints with much quicker cycle times than using electron beam processes. Lasers can also be used in components where a high heat input would damage an applied thermal barrier coating integrity.

Shaped Metal Deposition

Rolls-Royce plc has developed an innovative manufacturing process without the need of expensive fabrication tooling which significantly reduces cost and time-to-market. This innovative process primarily integrates TIG and Gas Metal Arc Welding technology with simulated software systems to produce fully dense structures directly from a Computer Aided Design definition. The successful development in titanium alloys, 400 series stainless steels and complex precipitation hardening nickel-based alloys such as Inco 718 has delivered substantial cost and manufacturing benefits to Rolls-Royce plc. For example, it is possible to fabricate complete components such as the Trent 800 intercase, which dramatically reduces the lead time over conventional manufacturing routes and to manufacture components with hybrid structures to maximise materials performance. The technology is also available through external licensing.

Future Developments

There has been a growing trend for the manufacture of gas turbines to move away from arc type processes that have been the mainstay since the last world war through electron beam welding technologies which were pioneered during the 1960's to friction welding in linear and rotary forms. These developments typically take 10 to 15 years to go from an experimental concept through to production. This trend is likely to continue with friction processes replacing arc and electron beam processes on an increasing basis. Furthermore, joining processes that allow net-shape technologies to be introduced will become more widely used as will increased use of additive manufacturing. Finally, the cost demands on the business will see increased automation being brought in to allow more repeatable, stable processes to be developed and established.