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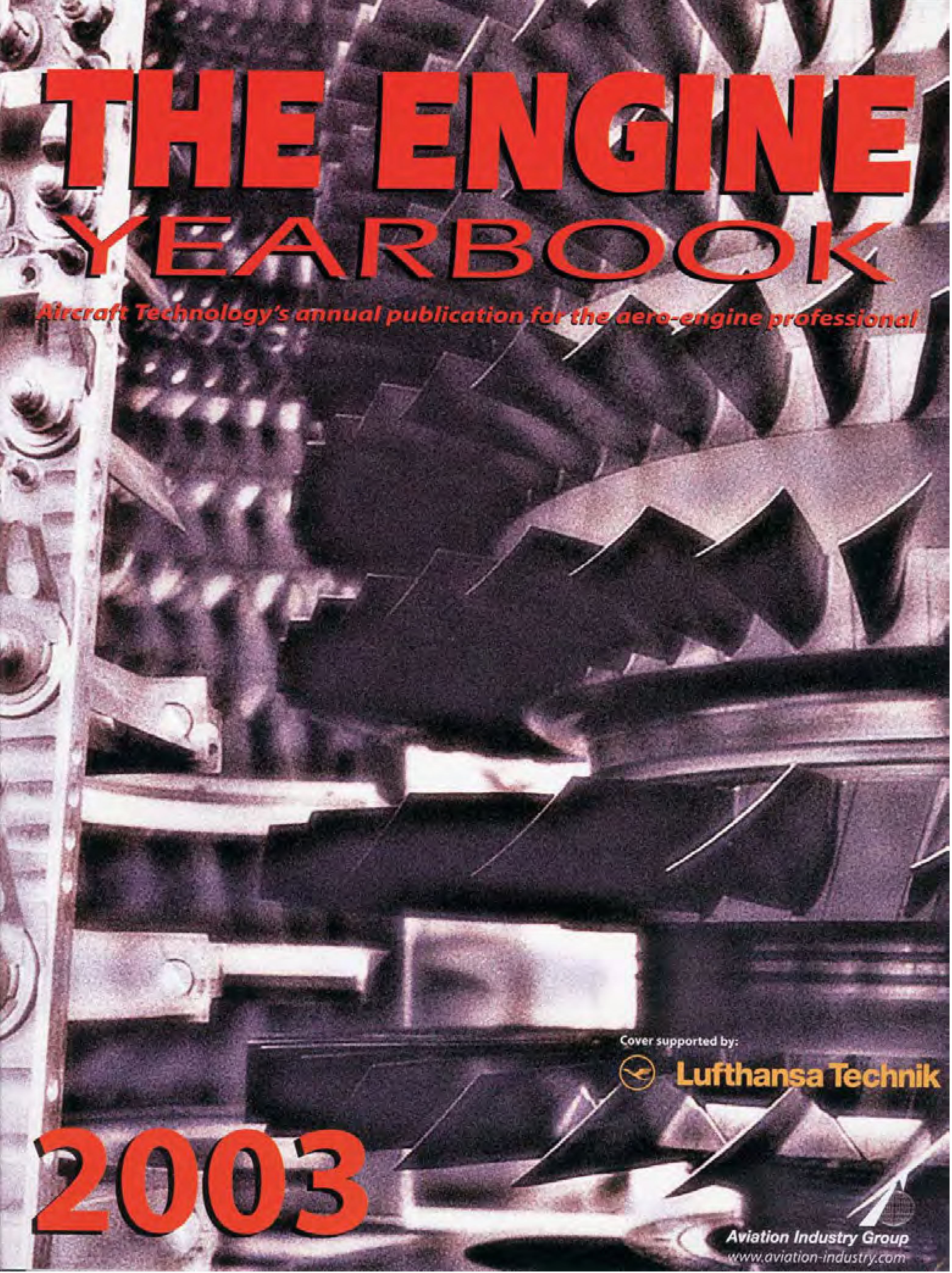

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Welding with laser powder fusion and plasma wire feed systems

Bob Tollett of Liburdi Engineering reviews the quality of laser powder fusion and plasma wire feed systems in relation to more conventional welding systems.

Automated arc welding of a case assembly at Pratt & Whitney Montreal

The laser has been limited in its acceptance and, on occasions, its capabilities, because of the relative infancy of its associated technology.

For many years inert gas arc welding processes have been preferred when welding critical aero-engine components. Consequently, welding techniques such as gas tungsten arc welding (GTAW) and tungsten inert gas (TIG) welding have dominated the aviation manufacturing and aftermarket sectors. Such processes are commonly specified in aircraft maintenance and engine overhaul manuals by airframe and engine OEMs, in both manual and automatic applications.

Plasma arc welding (PAW) is a sister process to GTAW, although it features an additional gas flow lens and a recessed electrode. The process provides a constricted arc by means of a metering orifice through which the arc plume is transferred to the work piece. The constriction of the arc reduces the width and increases the axial pressure of the arc, resulting in a narrower weld bead and increased weld penetration.

The laser has been limited in its acceptance and, on occasions, its capabilities, because of the relative infancy of its associated technology. Nevertheless, the laser is a power source that can produce a very narrow bead profile and, depending on the heat input, it can have significant weld penetration capability. Indeed, some OEMs have recently made changes to their repair manuals to permit selected repairs with laser processes.

One of the factors that fundamentally changed considerations with respect to welding processes was the requirement to add filler alloy, which introduces additional variability to the welding process. Such variability changes the quality and yield of output of the welding processes.

Meantime, the OEMs have continually sought to improve their operating business margins and have been implementing planned improvement philosophies through programmes such as Six Sigma and ACE. Ultimately, they have sought the highest efficiencies for all manufacturing and repair processes, with the intention of achieving yields in excess of 99 per cent.

Achieving these high yields is paramount for any automated process and is the focus of the progression from manual to automatic welding. Whilst manual welding can be better than automated processes for certain tasks, it does not necessarily produce the required consistency and yields in all circumstances. Where there is additional variability or input, this complicates matters further for manual welding and directly affects weld bead quality and strength.

Trends

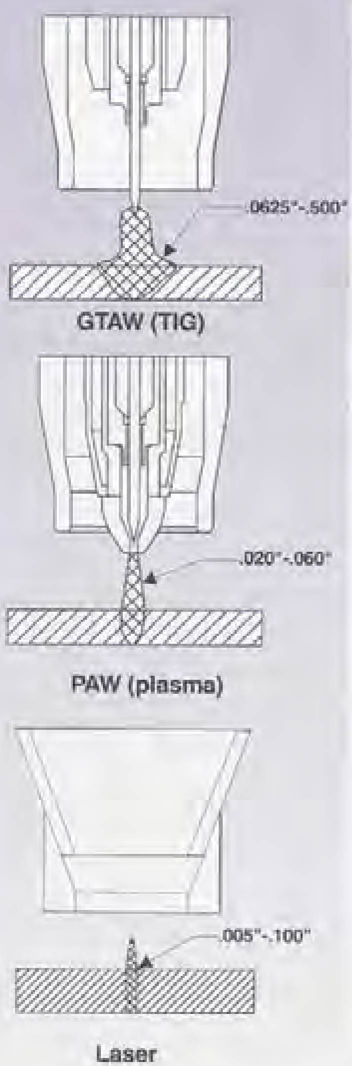
While many OEMs have had over 30 years experience with TIG welding and perhaps as much as 15 years with plasma welding, laser welding has only been developed over the last 15 years and is still in its infancy in comparison. Many OEMs purchased lasers a dozen years ago, only to see them gather dust on the shop floor, and subsequently became more conservative about the application of new technologies. Other OEMs employed large departments of scientists and engineers to investigate the possibilities of lasers. Some companies have been successful in using lasers for drilling and autogeneous welding of certain alloys. And over time the ability to drill with lasers has become fairly commonplace, finding its way into new applications which had not previously been considered suitable for production lines. Laser welding without filler wire has also become more successful with many applications being developed for thin sheet metal.

If a poll of the major aerospace OEMs and MROs was to be undertaken, a range of different welding processes would be seen to be employed. Typically, their application would vary depending upon demographics, the size of company and individual preference. But, generally speaking, the following welding technologies would be most commonly employed as follows:

- The circumferential welding of combustors, cases, seals, rings and almost anything circular in shape is generally accomplished with a rotary positioner type, semi-automated welding system with GTAW or, in some cases, PAW. Very little is currently accomplished with laser technology.
- Stationary parts (non rotating hardware) are usually welded by hand using the GTAW process or variations of the process using preheat on crack sensitive alloys (sometimes referred to as SWET or WRAP welding). These tend to be hot section parts that have irregular geometrical shapes.

Normally, a manual welder would repair a variety of these parts during a single work shift. Segment seals, shroud blocks, and a host of other small hot and cold section parts are typically welded manually. When OEMs have sufficient volumes of similar parts, automation of the process become financially viable, if it warrants the associated capital expenses.

Welding processes



source: Liburdi Engineering

- A significant amount of laser welded repairs have been developed in recent years and most of these have been for hot section parts. Indeed, laser welding of hot section parts seems to be gaining acceptance as a viable alternative to GTAW. The laser welding of precipitation-hardened alloys can be advantageous depending upon the nature of the parent material, the filler material being used and the ability to control the total heat input.
- GTAW and PAW welding have been advanced to the point were they can be applied with less than one amp of electrical current when microscopic welding is required. Tool and die shops commonly repair small extrusion dies using such processes. The effective use of cold wire to regulate the pool temperature makes manual welding possible in such circumstances.
- The "Dabber" process, developed by Hobart Brothers in conjunction with GE in the 1960s, was an extension of the art of quenching the molten weld pool with cold wire. The system uses a cam and motor drive system to wiggle the wire in and out of the molten pool allowing it to quench (cool & solidify) and fuse in a rapid pulsing manner. The lowering of the total heat enabled GE and others to weld many aerospace parts. Today this process is controlled digitally by synchronising the power source pulsing and the injection of the cold wire into the molten pool. Heat management is the name of the game when it comes to superalloy welding.

Cultural constraints

For a variety of reasons, manual TIG welding is still the most commonly used process when repairing hot section rotating components. Most OEMs will not admit that they have cultural difficulties when it comes to the installation and ultimate acceptance of automated welding equipment for such repairs. Objections to automating a process are usually based on the variability of the process flow, the nature of defects, the types of parts and regardless of how you approach the subject; variability in process flows does not economically lend itself to automation.

Automation and new technologies are difficult to assimilate into larger organisations because of the human factor. Unless management absolutely insists on driving new technologies into a business, involving their workforce in the switch over, it will not be successful. Shop personnel will either make or break the incorporation of advanced technology, and they can bring much to the party if their opinions are considered and they are treated as an integral part of the equation.

Quality and yield

After investing significant capital in a new process, few companies will want to admit that their systems have yield problems. However, in a lot of cases, powder feed systems are only obtaining 70 to 80 per cent yields with 20 to 30 per cent of the parts welded being rejected for non-conformance reasons.

Every process that is introduced into a manufacturing operation has a learning curve associated with it. It may be called a performance curve or an integration curve, but they all go through it. When introducing GTAW with wire or PAW with wire, similar learning curves will be experienced. But the focus of interest for discerning companies is the tail end of the learning curve.

Once the process has been operated for a year or so, what yields should be anticipated? Certain companies will not accept systems that operate at less than 99 per cent yield rates. Micro plasma and GTAW wire feed systems can certainly obtain such yields on a consistent basis. But powder feed systems, with the inconsistent nature of powder feeders and powders themselves, are more problematic. The laser or plasma power source is not usually the problem.

While most systems are likely to start with a series of good welds that translate into an initial yield of 60 to 70 per cent in production, only a few will immediately achieve 99 per cent yields on a consistent basis. Over the last 10 years site visits to OEMs and MROs around the world have not uncovered a powder feed system with a yield of more than 93 per cent. In some instances, OEMs have relaxed welding strength and porosity values to cater for powder feed systems but usually, in view of their conservative nature, they have only done so on less critical parts where mechanical failure due to welding is of less significance.

It is interesting to note that the majority of engine cold section rotating part repairs are performed with wire feed systems. High-pressure compressor (HPC) parts have very exacting specifications on their porosity and strength. Such parts are commonly manufactured from stainless steels, inconel type nickel alloys and titanium alloys which are relatively thin in section and susceptible to mechanical vibration under aerodynamic loading. Repair specifications can be two pores per blade tip, no larger than 0.006 in and no closer than 0.040 in the repair rebuild area. With this kind of limitation, powder fusion welding becomes difficult, particularly if there is variability in the welding process.

Basics

The differences are subtle but once filler alloy is added to the welding of aerospace parts, a new regime is required. Many organisations have struggled with this problem and eventually systems have been put into production with a wide variety of results. In most cases, the laser power source is not the cause of problems and instead the means employed to deliver the filler to the molten weld pool is where problems are usually found. With wire feed systems such as TIG and PAW, the wire is purchased from a vendor that supplies specific metallurgical information with regard to the heat to be applied. In some cases wire alloys can be purchased in a form called "extra low interstitial" (ELI) which is very clean with no rogue elements. When such materials are used as a wire and filler to the molten weld pool, the cleanliness of the material being melted in the puddle is fairly high, all other things such as gas shielding, being equal. Laser welding, with its very fine beam size and high intensity beam energy can be used to form a small molten pool on the material surface. This translates into reduced heat transfer and thinner weld beads that can be used to create the required "nearly net" material shapes. Alternatively, the laser with its increased energy density and narrow beam can be used for cutting or drilling. Also, because of the columnar penetrating force of its energy beam, a laser can be used to penetrate through thin sheet metal to produce lap joints.

While the laser is a good power source, it still needs to be improved to have the full range of controllability that certain arc power sources currently possess. Generally, lasers have simply been turned on to a certain power setting and then turned off again after the weld process is complete. This is similar to selecting a source of electrical current at 100 amps with no ramp up during the start process

HPC blade welded by PAW with cold wire feed (Titanium).


HPT blade with Rene 142 on Rene 142, no preheat, cold wire feed.

and no ramp down when completing a weld segment. It is the modulation of a laser's power that provides better quality of weld deposit and controllability at the weld pool.

When going from GTAW to plasma and from plasma to laser, the ability to modify the heat input improves until such time that filler material is added, when the whole heat transfer equation changes.

Powder and wire feed media have a quenching ability that is related to the thermal mass of the material being injected into the molten weld pool. This quenching capability depends largely on process controls such as feed rate, material type and the material form (its size and whether it is wire or powder). The quench rate is then balanced against the heat input from the heat source of the arc or laser, and the average heat input at the weld pool is a combination of these inputs.

Low heat input can be achieved by the use of highly controllable energy sources; tighter arc or beam diameters; lowering of surface temperatures by the use of filler materials; and better integration and control of the welding process.

To obtain good metallurgical properties, it is necessary to fuse metals together at the melting point of the alloys involved in the joint or weld build up. For this to happen, the heat source, be it arc, laser or electron beam, will have to be applied at the correct power setting. Power settings will define the surface temperature and provide the latent heat to interact with the materials to be joined. Inherent stresses that cause cracking and distortion problems can be minimised when the total heat input is reduced.

Lasers have extremely low heat input but they still need to use pre-heat on highly alloyed oxidation resistant base alloys and fillers such as Rene 125 or 142. Liburdi Engineering has proven its capability to automatically weld these alloys utilising PAW in an open atmosphere with only local shielding. This is possible when arc stability and weld pool control pool is optimised and managed by the synchronisation of the current source and cold wire injection. The wire's solid mass is used as a quenching medium for the molten pool.

In the case of powder feed systems, things become a little more variable and it is this that causes difficulty at the weld pool. Powders do not have the same quenching ability as solid wire feed systems. The power source PTA, laser and so on become the predominant means of controlling heat at the pool.

Powder can be manufactured by a number of different means, such as water or gas atomisation. Alternatively, ground materials can be obtained with different mesh sizes, but this can lead to the poorest quality of powders. Oxidation, humidity and mesh size are some of the key problems to be overcome when powder is used as a filler material.

In welding and brazing, "cleanliness is next to godliness", and attention to detail is crucial. Depending upon the manufacturer, powders obtained from a mechanical grinding process can have many impurities, depending upon the cleanliness of their equipment. Residual powder in grinding equipment can be transmitted to the next batch and this imports foreign alloys into the mix.

In contrast, gas atomisation is probably the most controlled method of powder production, and it is almost always used in the manufacture of superalloy powders. In this process, molten alloys are poured through a long tube which has inert gas jets located around its peripheral walls. During the pouring process, the high pressure gas (argon) breaks up the molten alloy into small droplets that are allowed to solidify as they fall to the bottom of the tube. But this process can also suffer oxidation and foreign alloy migration. If oxygen is available in the tube and the particulate is not completely cooled, oxidation can occur. This oxidation is present on each tiny sphere and, once used in a welding system in sufficient quantity, it can entrain the oxides into the weld pool and cause defects leading to weld rejection.

Humidity is another potential source of contamination for powders. Humidity causes problems of oxidation and porosity within the weld and can be a cause for rejection, depending on the nature of a component and the acceptance criteria of the OEM. Also, humidity can cause powders to bind or stick, thereby upsetting the powder flow through the system and making the flow inconsistent at the torch. It is therefore a variable that needs to be controlled if defects in welds are to be avoided. Consequently, many powder distributors have now incorporated "heating blankets" around their powder hoppers to reduce humidity and aid the flow of powders.

Mesh size is another parameter that needs to be examined at the purchasing level. Powders can be produced in a wide range of mesh sizes ranging from 20 microns to 350 microns. If a mixed range of mesh sizes is purchased, prices will be relatively low, but the powder may not be appropriate for welding production requirements. It could be that the best mesh size for a particular application ranges from 95 microns to 120 microns. But a particular manufacturer may routinely produce mesh sizes from 50 microns to 160 microns. If the tighter range of 95 to 120 microns mesh powder is specified, the manufacturer will charge significantly more since only a fraction of any particular batch will be used.

Vibration tends to segregate powders by size and this can impart significant variability to the laser welding process. This occurs naturally and starts at the powder manufacturer's facility when the material is purchased and the mesh range is shipped in containers. The shipping process involves a continuous vibration sequence from truck to plane and to truck again. During transportation the range of mesh sizes naturally sort themselves with larger particles migrating to the top of the container and smaller particles being forced between the larger ones to the bottom. The process is comparable to a box of cereals, where the large flakes are to be found at the top of a carton and all the fine flakes end up in the final serving.

This process can influence powder type welding systems and many users mix their powders after delivery from the powder vendor for this reason. Once powder is poured into powder hoppers, the process starts again and, as the powder is consumed in the welding process, segregation can start to add variability into the process as a result of changes in the particle size. Inevitably, the operator is forced to tweak welding parameters as work progresses, to adjust for the variability in powder sizes flowing to the weld pool.

Vibration can also be associated with the powder feed delivery systems themselves. Some powder feed systems use vibrating trays to transport the powder to the delivery orifice. These systems can add to the segregation problems but usually operators discover a "work around" for such problems by only using the minimum quantities of powder in the hoppers. Unfortunately, this is difficult to control.

Conclusions

Torch, powder feed head design and attention to detail are always important factors when dealing with process variabilities. But it is equally important to look at the "bigger picture" by considering human aspects, system ergonomics and the process details from all possible angles to remove process variations that impact on the quality and consistency of deliverables. Acceptance criteria, alloy type and the complete process from start to finish need to be evaluated from a metallurgical and practical standpoint before selecting a process for automation.

Arc processes that utilise wire feed systems require vigilance in their daily set up and over the course of the production day. Tungstens and plasma orifices are used, and arc gaps change. Nevertheless, arc processes are more robust in automated welding applications and have proven track records of 99 per cent plus yields on critical applications in rotating hardware in the compressor section.

Laser powder systems can also achieve high levels of productivity on specific alloys. However, in cases where defect tolerance is very restricting, it may not yet be possible to achieve high yields in a consistent manner. Yields often fall below 80 per cent, and they can vary from day to day. This, together with an inability to process certain alloys, is one of the major reasons that laser powder systems are not widely used on HPC hardware by OEMs and MROs.

Lasers are in their infancy, but they have great potential for automated welding, if porosity and consistency issues can be resolved. Certainly, within the next decade, with the introduction of more sophisticated controls and greater emphasis on the control of filler materials being introduced into the weld pool, yields will improve, and the laser powder process will become more generally accepted on critical rotating hardware.

Micro Plasma Arc welding of an IPT Shroud Interlock with cold wire feed (PWA-694).

Powder and heat control are critical when welding with filler materials. Porosity in the above shot is a problem for critical rotating hardware.