Using Laser Powder Cladding To Build Up Worn Compressor Blade Tips

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Abstract

For the weld repair of compressor blades, notably for restoring worn critical dimensions, various techniques are in use. A relative late arrival among these, laser cladding has gained wide acceptance. Providing fast, near net shape restoration of components to blueprint dimensions, it offers significant advantages over conventional weld cladding. This paper describes laser cladding techniques and presents experimental results achieved with them. Discussed also is a derivative method that uses a mold to contain the deposition process.

1 Introduction

These past several years, entirely new modes of cooperation have developed between engine operators and repair shops. Fly-by-hour and similar agreements have become common practice. They have made operators increasingly reluctant to pay for spares on top of the flat-rate overhaul contracts they have with shops. Accordingly, shops prefer to repair rather than replace worn parts, repair costs permitting. This has put added emphasis on the repair also of worn compressor blades.

Fig. 1 Integrally bladed disk (blisk)

Looking beyond current needs, compressor blade repair strategies must also anticipate realities that will be created by engines still to come. Next-generation powerplants, for instance, will increasingly incorporate blisks, a technology (see Fig. 1) that prohibits the current practice of replacing individual blades. Cladding techniques to build up worn compressor blade tips should be developed, therefore, with tomorrow’s needs in mind as well.

This report presents results obtained in the experimental laser powder cladding of worn compressor blades. To put this data in its proper perspective, the report also considers the pre- and post-weld operations involved. Since these investigations are largely empirical in nature, the report first presents the insights gained generally and then in a subsequent section proceeds to assess and compare results.

2 Approach

The repair of worn compressor blades normally involves the manual refurbishment of worn blade leading and trailing edges and the restoration of worn blade tips to their original dimensions. Depending on the type and service environment of the engines involved, wear on blade tips will run from one to five mm, give or take a little at either end of the range. Regardless of the severity of wear, compressor blade tips are usually repaired after a more or less identical pattern that includes the following operations:

- Clean the blade tip
- Deposit the buildup material
- Remove excess metal
- Inspect the repair

While for cleaning, mechanical or chemical processes are used, the standard practice for restoring the tip rub surfaces of blades through the deposition of filler material has been arc welding, with tungsten inert gas (TIG) and plasma arc welding (PAW) being the preferred techniques. The deposited metal subsequently needs machining to restore the blade to its proper contour. The techniques used for depositing the material and then post-machining it may be either manual or automated. Whatever they are, they must be able to cope with the individual geometry the blade exhibits when it emerges from engine service.

To cope with this specific individuality, solutions are sought that range from manual machining to sensor-aided automated adaptations of the repair process or a combination of both, depending on local labor costs. Still, the individuality of the blades limits the options available to make repair more efficient and affordable.

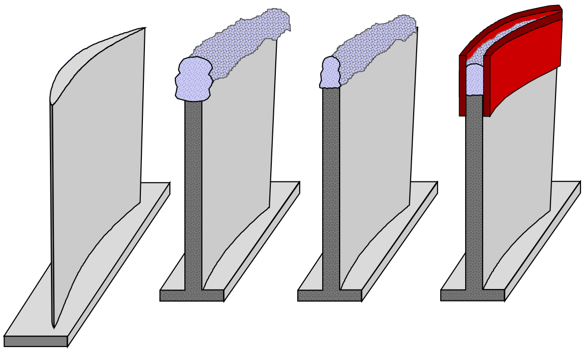

Fig. 2 Compressor blades before and after processing. From left to right – worn condition, after PAW, after LPC, after CLPC.

Within these limitations, laser powder cladding (LPC) is the one technology that still holds considerable promise. Its deposition rate exceeds that of arc welding by about a factor of 10 and makes individual blade geometries much less of a problem. But apart from speeding the metal deposition process and hence saving costly machine time, it also cuts down on post-weld machining. And when LPC is alternatively performed using a mold to contain the deposition process (mold-contained LPC or CLPC as opposed to free LPC), the tip buildup has little overhang (near net shape deposition) and therefore reduces if not eliminates the need for post-weld machining (see Fig. 2).

Despite the advantages afforded by LPC, its use in blade repair has been mostly experimental in Germany. The reasons why it failed to transition into industrial reality probably are several. One of them must have been that there were few if any industrially suitable machines available; another, that the notable complexity of the process discouraged its use.

3 Laser powder cladding technology

LPC is a complex technique defined by a plurality of process parameters. The major ones among these are

- laser power
- focal length
- deposition rate
- powder feeding rate
- powder gas flow rate
- power particle diameter
- material characteristics

What laser to use for best results is a matter of judgment, CO_2 and Nd:Yag lasers alike lending themselves to use in LPC work.

As in related industrial applications and experience, the use of solid state lasers has proved advantageous also for LPC. One advantage derives from the solid state laser’s relatively short 1.06 µm wavelength, which makes for ready absorption of the laser beam by the materials being fused, i.e. the substrate and the filler material. Another of the solid state laser’s merits is that it permits the laser energy to be transported from the resonator to the laser head through a fiber optic cable.

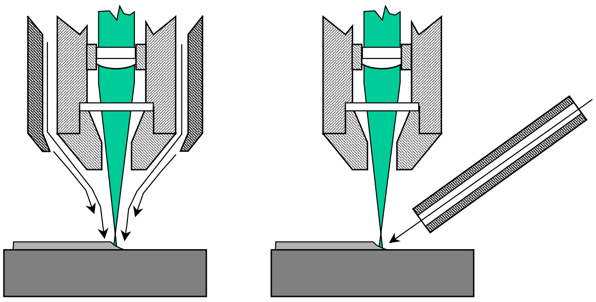

Fig. 3 Laser powder cladding using coaxial (left) and lateral (right) powder feed.

The laser beam traveling through the optic fiber is transmitted to the target substrate using bipolar optics. For LPC, and depending on the form of beam required, optics of focal lengths ranging from 80 to 300 mm have proved adequate. The filler material needed for the tip buildup can be fed to the beam in several different ways, the lateral or coaxial powder feed being standard choices (see Fig. 3). In combination with various optics, then, laser heads can be combined in modular system fashion to suit the LPC job in hand.

3.1 Free laser powder cladding

While for free LPC work, lateral powder feed and a focal length of about 150 mm is common practice, coaxial powder nozzles have proved more suitable for the deposition of metal on free-standing compressor blade tips. The coaxial type of powder feed has a number of advantages, but it should also be remembered that its powder efficiency falls behind that of a sharply focused lateral feed by a factor of 5. If coaxial powder nozzles are in use regardless, it is because they more readily accommodate the irregular wear normally encountered on compressor blades.

Usually, when the blades come in for cladding, they differ in length about 0.1 to 2 mm. When an external (lateral) powder nozzle is used, the entire laser head must continually be repositioned to allow for the length variation from one blade to the next. Considering that the impact points of laser beam and powder stream must be made to coincide on the substrate within ±0.2 mm, elaborate fixtures or sensor systems are needed to satisfy this coincidence requirement in industrial applications.

When coaxial powder feed is used, the need for such elaborate provisions is largely obviated because owing to the coaxial alignment of laser beam and powder stream, the two remain coincident over a relatively wide range. A coaxial powder head, therefore, is much better suited to compensate for blade length differences than would a laterally arranged powder nozzle. Also, coaxial powder feed facilitates programming, considering that laser beam and powder stream will remain in alignment regardless of the direction in which they are pointed. Accordingly, the degree of process stability offered by coaxial powder feed substantially surpasses that of lateral feed.

Apart from these process constraints, another criterion in the selection of a suitable repair process is the impact it has on the component under repair. The blade repair process should be optimized to keep the heat input to the airfoil low. The less heat is induced, the less the strength of the workpiece is degraded by the structural transformation associated with cladding processes. And as previously suggested, the lower the energy input, the greater the process stability.

Accordingly, the laser energy applied should be just strong enough to locally fuse the substrate and melt the powdered filler material in the respective application. Depending on the type of blade and the cladding position, therefore, the laser power is set at a mere 500 to 800 W or so. A deposition rate of 300 to 500 mm/minute also helps minimize the energy input to the substrate. Process characteristics such as these also benefit the integrity of the weld, since the low heat input and absence of turbulent gas flows keep the porous fraction in the tip buildup low. Additionally, the energy input is too moderate to overheat the melt pool and cause spillover, a condition that will not normally benefit the desired geometry of the buildup.

Individual layers, deposited with just the right amount of energy, have a height of normally 0.3 to 0.5 mm, usually requiring several overlaid passes to achieve the desired aggregate height of the blade tip buildup.

To cope with the complexity of the task and achieve the necessary degree of repeatability, the process will have to be automated when used on blades. One caveat for automated cladding with lateral powder feed is, however, that if the actually produced height of layer does not match that programmed, laser beam and powder stream may no longer impact the substrate in the same spot, causing the buildup to be defective or nil. Here, too, the use of coaxial powder feed provides advantages, its wide working range automatically offsetting the noted deficiencies.

As in most fusion welding processes, the integrity of the LPC weld significantly depends on atmospheric conditions. The process will therefore be stabilized if additional use is made of an inert gas nozzle to shield the weld area. This holds true for most types of blade, as well as the materials investigated, such as nickel-base and titanium alloys. Argon will here adequately serve shielding and powder feed purposes alike. The effects other buffering gases or gas mixtures may have on the process have not been studied at this date.

3.2 Mold-contained laser powder cladding

Copyrighted under its German acronym LPAiK ©, mold-contained LPC (CLPC) uses a copper mold in which the worn blade tip is built up, with the mold replicating the contour of the airfoil. CLPC restores the airfoil to its specified height using powdered filler material and leaving little material overhang that needs removing. The underlying idea—to reduce if not eliminate post-weld machining—is not new.

Thought had been given earlier to using rollers to shape LPC layers while still in their pasty presolidification state /1/. Also the use of fixed copper dies to form a mold to assist in the laser powder cladding of honing tools has been reported /2/.

CLPC is an adaptive process based on resource excess. It is only when the process threatens to go awry that resources like laser power and beam speed are adjusted to suit. This model concept permits the identification of process parameters to achieve continuous buildup at varying width-to-height ratios from 2/1 to 1/10.

In this process, it is the extreme 1/10 width-to-height ratio in the blade edge region that makes control of the buildup process more difficult than elsewhere. Owing to the individual geometry of the blades, contact between the blade and a standard mold is not always ensured in this region, so that locally interrupted heat transfer between blade and mold makes the cladding process unstable. Using iterative modification, however, the shape of the mold can be adapted to match the blade contour in this area sufficiently close to permit laser powder cladding to be achieved with about 95% of the compressor blades of a type, using optimized molds.

Copper molds exercise considerable influence on the LPC process, owing to their thermal conductivity and capacity. When defining process parameters, then, these must be considered accordingly, meaning that in addition to the energy intended to go into the laser track, excess energy must be provided to make sure the heat transferring into the molds will not unbalance the LPC process. As in free LPC, it again has proved advisable to use just the amount of energy that is needed to do the cladding job. Also, minimal heat input will keep fusion from occurring between the buildup material and the mold. To ensure that, given these constraints, the amount of energy supplied to the laser track is still sufficient, recommendations are to consistently use a ±0mm stand-off distance in this area.

In CLPC, the type of powder feed is a considerable factor. Lateral powder feed has proved the most suitable in CLPC. Its flexibility regarding nozzle diameter and incidence permits optimizing settings for each different blade type. Arranging the powder nozzle ahead of the trailing laser beam will in all phases supply sufficient amounts of powder ahead of it. This is an important consideration especially in the blade edge area, where the greatest portion by far of the available energy is used to fuse the filler material. When in these places, powder is absent as the beam advances, the compressor blade will suffer irreparable damage and the repair job must be abandoned.

3.3 Comparing processes

Any comparison of laser weld cladding techniques used in compressor blade repair would remain academic if not also comparing the results achieved with them.

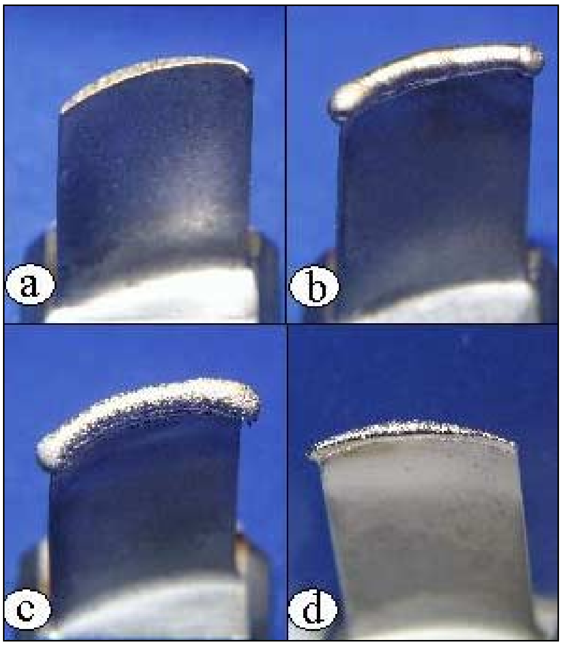

Fig. 4. Compressor blades in Nimonic 90, shown in various conditions
a) worn b) after PAW c) after LPC d) after CLPC

LPC constituting a technology leap, the results achieved with it are here viewed against those from tungsten plasma arc welding, heretofore the dominant cladding technique.

The various blade tip buildups shown prove PAW, LPC and CLPC to be viable compressor blade repair options (see Fig. 4). The results here presented come from an area which, owing to the untoward blade geometry, is counted among the most difficult places to repair. In its various shapes, the tip buildup is about what you would expect from the particular weld cladding techniques used. The widths of the PAW and LPC tip buildups are about the same, whereas the CLPC buildup is appreciably narrower and more near net shape of the finished blade.

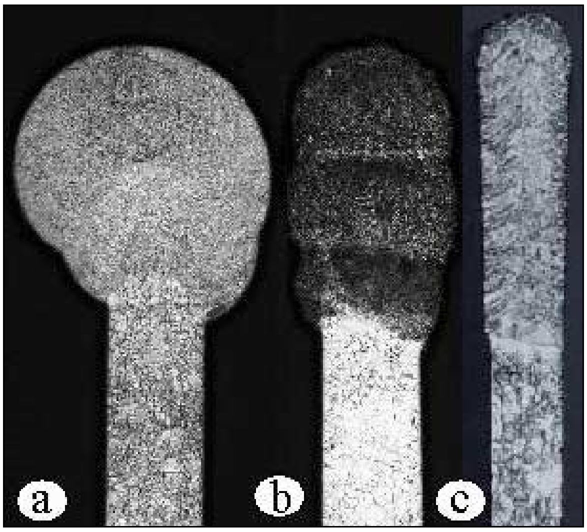

Fig. 5. Microsections of the blade tip buildups shown in Fig. 4. a) PAW b) LPC c) CLPC

These characteristics also reflect in the microsections of Fig. 5. The sections are representative, taken from a mid-chord position of the built-up blades. The outline of the buildups, as do the transitions in the microstructure, indicates the number of layers deposited on the respective blades. To achieve the necessary height of buildup, the PAW cladded blade required two passes, the LPC blade three, and the CLPC blade one. Otherwise, the properties of the deposited material are comparable among the three techniques used. All buildups are characterized by a notch-free bond with the parent metal. The internal weld defect fraction is small. The fast deposition rate and the associated fast solidification rate produced a few, isolated pores. Running far below upper size limits, however, these are uncritical.

Microhardness test results, too, vary with the weld cladding technique used (see Fig. 6). The relatively high hardness levels of the blades, work hardened by forging, appreciably drop across the heat affected zone and toward the cladding area with all three of the techniques used. This is attributed to coarse grain produced by recrystallization and is especially pronounced on PAW cladded blades. Not unexpectedly, the area of transition between the substrate and the buildup is smaller on laser cladded blades, owing to the briefness of laser beam action on the material. Any influence the molds might have had on the transitional zone in the microstructure would be difficult to prove.

WPL = PAW
LPA = LPC
LPAiK = CLPC

Weg in (mm) = mm distance

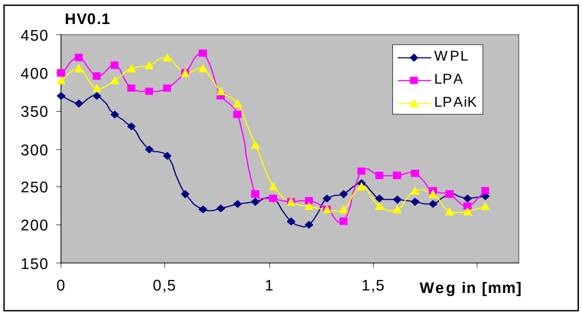

Fig. 7. Hardness profile across the compressor blades shown in Fig. 1.

Strength loss is noted in all instances of the weld cladding techniques used. It is nevertheless assumed that the blades were properly repaired. This argument bases on previous investigations into the reversed bending strength of repair-welded blades. The blade tip buildup, therefore, does not constitute a critical stress area. This claim, as is the preceding argument, is corroborated by several reverse bending tests on built-up blades and several years in engine service.

4 Summary

Experimental results are presented that highlight the opportunities laser powder cladding opens up for compressor blade repair and that witness the appeal laser powder cladding in its generally practiced form has for compressor blade repair. The report also discusses a laser powder cladding technique that uses a mold to contain the deposition process and is a logical elaboration of conventional laser cladding. The comparison made at the close of the report between powder weld cladding and traditional arc welding methods testifies to the desirability of the mold-contained laser powder cladding technique. The report also makes it apparent that the technological complexity characterizing the LPC process makes controlling it a difficult task requiring solid knowledge of the process.

5 Literature

The German acronym LPAiK © for mold-contained laser powder cladding is a registered brand name of MTU Aero Engines.