High impact laser metal deposition refurbishments for critical power equipment

Mark Newby of Eskom Research, Testing and Development, and Corney van Rooyen of the CSIR's National Laser Centre talk about the longstanding bilateral collaboration between ESKOM and the CSIR on high impact refurbishment projects, including the repair of PTR-tanks in the nuclear industry, a laser metal deposition tenon re-build on turbine blades, and other turbine rotor, blade and understrap repairs.

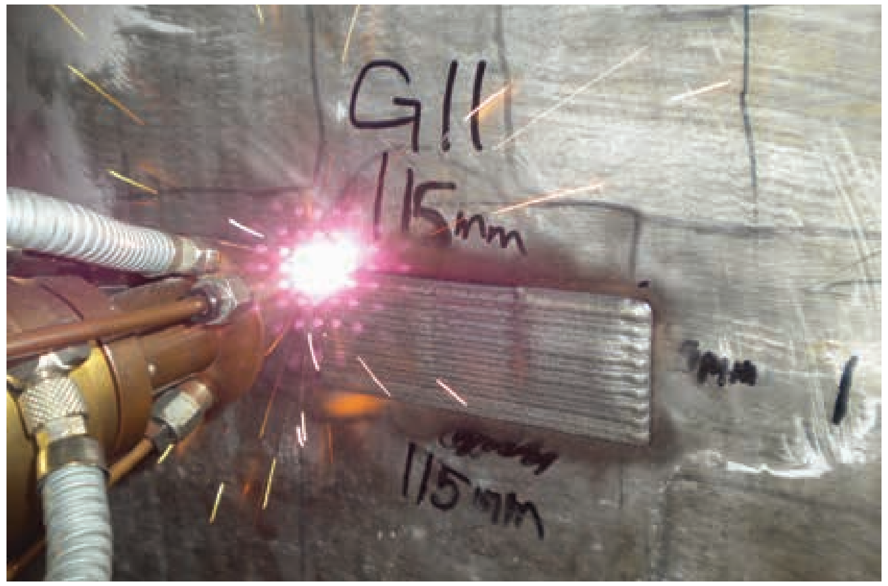
Mark Newby is part of Eskom's multidisciplinary research, testing and development group, one of the hundreds of technical people involved in physical metallurgy and material related research and development at Eskom's Rosherville site in Johannesburg. "I am a mechanical engineer who specialises in experimental stress and vibration analysis," he begins.

Newby began his career as an Eskom trainee and completed a Masters diploma of Technology at Port Elizabeth Technikon. "I joined Eskom as a bursar directly after completing national service and, apart from a three and half year 'break' as a lecturer at the Port Elizabeth Technikon, I have been with them ever since," he adds.

"Our team at Eskom Research, Testing and Development includes chemical, material and electrical specialists so we can offer a whole range of disciplines – and in my experience, the most successful research comes from multidisciplinary projects." Newby tells *African Fusion*.

The Eskom-CSIR Tenon laser weld repair project team, clockwise from 12:00 o'clock: Paul Stangroom, Maritha Theron, Mark Newby, Hardus Greyling, Dheshan Naran, Dewan Schoeman, Phathutshedzo Nemakhavhani, Danie Louw, Johan Visagie, Herman Rossouw, Devilliers Moll, Ronnie Scheepers, Corney van Rooyen, Andre King, and Eliza Dlamini.

His involvement with laser welding began in 2008 on a project with his late colleague, Philip Doubell, and a team from the CSIR National Laser Centre (NLC) headed up by Corney van Rooyen. "Our first project involved the repair of atmospheric stress corrosion cracks (ASCC) along the welds of the PTR cooling water tanks at Koeberg nuclear power station. We explored the use of friction stir welding with the guys at Nelson Mandela University (NMU) and laser weld repair with CSIR's NLC.



On the two Koeberg PTR tanks, a laser-based welding technique was used to seal leaking ASCC cracks before using a powder filler to build up and reinforce the surface area.

"With NMU, we developed a non-consumable friction stir welding technique using a lanthanum tool that did not need to penetrate the wall. Similar techniques are widely used for joining aluminium, but the PTR tanks are made from 304L stainless steel, and we successful qualified a procedure to repair these cracks on a full-sized mock up while they were in service.

"At the same time, we were working with Corney on a powder-fill laser welding technique to do the same job. With the laser, we were able to seal leaking ASCC cracks before using a powder filler to build up and reinforce the surface area," says Newby, adding that the laser technique was preferred and the two Koeberg PTR tanks were repaired in 2011 and 2012, respectively, and put back into service for an additional six years.

"Based in this success, we started looking at turbine components in two key areas, turbine blades and turbine shafts. We have now successful applied laser welding techniques in both these areas, although the approaches required are very different," he notes.

Newby says that on a large turbine shaft, a localised rub from a seal often causes local wear damage. "Any slight touch on a rotating shaft spinning at speed will tend to cause a localised groove on the shaft. Performing a small repair without having to heat treat the whole shaft can be tricky. We have developed a technique that involves machining away material to a 3.0 mm depth before applying a laser metal deposition technique in layers of less than 1.0 mm each. The technique involves exceptionally low heat input, which avoids the post-repair need to heat treat the rotor, which can put the seal at risk," Newby explains.

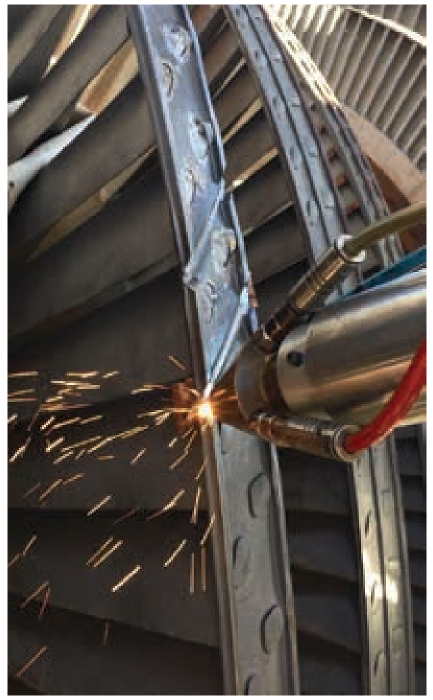
The repair also retains the shaft's original dimensions, which avoids machining down and then having to accommodate oversized bearings or replace them with resized ones.

Turbine blade refurbishment

Steam turbine blades for power stations, according to Newby, are susceptible to erosion on the low pressure turbines from the relatively wet steam passing through them. "Typically, the aerofoils get pitted and worn, which led us to explore re-surfacing in the worst affected areas: machining away worn sections of turbine blades, building them up using laser metal deposition before machining the area back to the precise dimensions.

"Soon after we started to develop these techniques, however, we encountered this tenon problem," he says, describing how turbine blades are mounted between the rotating shaft and the outer shroud: Around the outside of the turbine blades, there is an outer shroud, supporting a 'packet' of turbine blades, typically 10 blades. These shroud segments are connected to each other by short titanium understraps, which are connected to the shroud via tenons on the two blades at the end of each 'packet'.

"The full ring of shroud segments interconnected by the understaps turns the whole row of turbine blades into a disc, which helps to control vibration while the turbine is running," Newby explains.



Above: A laser based repair being done on a turbine blade shroud of a low pressure turbine.

Right: An Initial test in progress on turbine blade shroud.

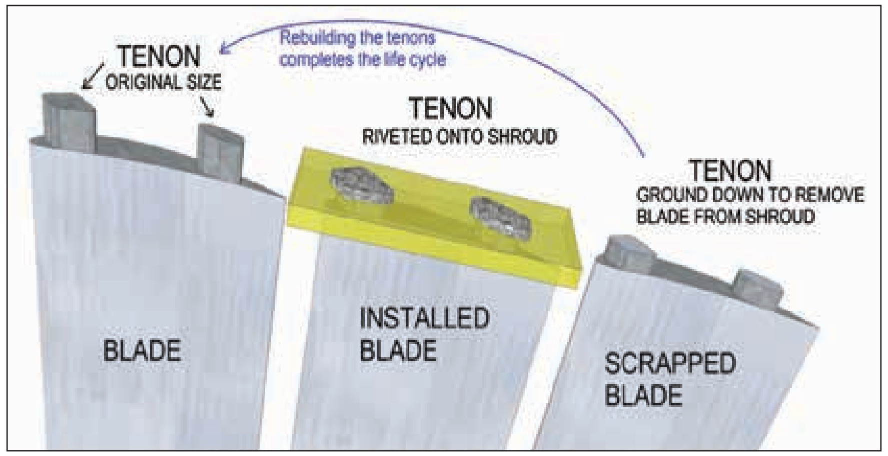
On assembly, he says that the turbine blades with tenons on their outer ends are first attached to the shaft in a straddle root configuration. Two understraps are fitted at the appropriate distance apart with the turbine blade tenons passing through aligned slots in the understrap. Then a shroud segment, which has similarly aligned slots, is fitted over each blade's tenons, with the two end blades of each 'packet' overlapping the understraps.

"The tenons are then mechanically peened to form rivets that securely hold the shroud segment and understrap onto the turbine blades. By repeating this process for each shroud segment, the complete shroud is formed around the shaft, securing the row of blades attached to the turbine rotor," Newby explains.

"Once fitted, any pit, crack or flaw in any of these interconnected components creates a problem, because you can't easily dismantle individual turbine blades. The peened tenon 'rivets' for a whole section of blades – sometimes more than one packet, depending on the access point and the component of interest – first have to be ground off so the shroud section and/or the understrap can be removed. This destroys the turbine blades, because without a tenon, they can no longer be refitted," Newby tells *African Fusion*.

To dismantle and replace an entire row of turbine blades, understraps and shroud packets on a steam turbine rotor, he points out, could take 12 to 18 months to complete, and the affected turbine rotor would be out of service in a workshop for the entire period.

Eskom Research, Testing and Development and CSIR's National Laser Centre therefore embarked on an extensive investigation to develop a repair technique for the turbine blade tenons after having removed them. "These are 12CrMoV steel and we started by building up suitably sized tenon shapes on test plates by fusing thin layers of powder using a laser. After machin-



A schematic illustration of the tenon problem on steam turbine blades that led to the development of a laser metal deposition rebuild procedure.

CSIR unveils world-class Photonics Prototyping Facility to support South African Industry

South Africa's photonics industry is set to benefit from the state-of-the-art Photonics Prototyping Facility (PPF) that was unveiled at the Council for Scientific and Industrial Research (CSIR) on Friday, 5 March 2021.

The PPF facility aims to enhance the development of photonics-based products, specifically for the prototype development phase, and to test the market for acceptance of planned products in the country. It offers Class 1 000 clean rooms with technical and optical equipment, including electronic, mechanical and diagnostic equipment for a variety of wavelengths.

The facility, which is funded by the Department of Science and Innovation (DSI), will fast-track photonics technology in line with market needs and stimulate the growth and competitiveness of the South African photonics industry. It further aims to address the current lack of commercialised photonics products in South Africa by providing world-class photonics facilities, technical support and scarce skills development in optics and photonics, as well as the networks needed to facilitate the development of prototypes.

Photonics applications are pervasive in all branches of 21st century science and engineering, and everyday life. These include fibre optic information and communication networks and systems; cameras; sensors and imaging systems; illumination systems and displays; applications in the energy sector, such as photovoltaic materials and systems; and applications in manufacturing where photonics plays an increasingly important role as a tool for supporting advanced manufacturing technology, such as 3D printing.

One of the projects focuses on optical coherence tomography for the 3D extraction of fingerprints. The novelty of this fingerprint acquisition device is that it is capable of extracting both the internal (sub-dermal) and external (surface) fingerprint, thus removing the possibility of fooling the detection system. It also offers a non-contact approach, which has applications that can be used in banks, mortuaries and forensic service facilities. The prototype has been developed and the team has received positive feedback from the trials.

Speaking at the launch event, the Director-General of the DSI, Dr Phil Mjwara, said the establishment of the Photonics Prototyping Facility is without doubt a significant milestone for the CSIR, industry and the national system of innovation as a whole.

Dr Mjwara added that the setting up of the facility is part of broader efforts by the DSI to support industrial and economic development that is driven by research, development and innovation.

"These initiatives are also key components of our contribution to national development imperatives as set out in the White Paper on Science, Technology and Innovation and the South African Economic Reconstruction and Recovery Plan. Most importantly, they are a fulfilment of our obligation as government to develop interventions in support of the creation and utilisation of knowledge and innovation for industrial and economic development."

South Africa's photonics industry is set to benefit from the state-of-the-art Photonics Prototyping Facility (PPF). From Left: T Dlamini, CSIR; P Mjwara, the Department of Science and Innovation; Cobus Jacobs, CSIR National Laser Centre.

At the unveiling of CSIR's Photonics Prototyping Facility are, from left: Dr. P Mjwara, Director General of the Department of Science and Innovation; and Dr. T Dlamini, CSIR Chief Executive Officer.

The Chief Executive Officer of the CSIR, Dr Thulani Dlamini, said the facility has a huge role to play in developing and supporting new and existing enterprises in the field of photonics, in order to improve their competiveness.

"This initiative is an important platform for the accelerated development of innovative products and technologies in photonics. This PPF will help to develop South Africa's expertise in the area of photonics product innovation and development, thus stimulating the growth of the country's photonics industry by supporting small, medium and micro-sized enterprises (SMMEs) and creating opportunities for new high tech jobs."

Dr Dlamini further called on South African scientists, researchers, engineers, industries, SMMEs, as well as entrepreneurs and investors to make use of this facility to develop photonic-related products.

Photonics Prototyping Facility
Hardus Greyling
Manager: Research and Implementation
+27 12 841 2713
hgreyling@csir.co.za

ing the shape, we found that the integrity of the steel with respect to the residual stress was good. This was validated at the *Institut Laue Langevin* neutron diffraction facility in Grenoble, France," says Newby.

Corney van Rooyen adds that, after some investigation, Inconel 625 powder was chosen for the tenon repair. "A matching low carbon 12% martensitic stainless steel requires too much energy to deform via peening. Inconel is widely accepted in the industry and is well suited because it is much more ductile and with adequate mechanical strength to secure the shroud," he notes.

Successful initial research enabled the process to be taken further with the CSIR's National Laser Centre and Van Rooyen being contracted to develop a viable welding procedure to perform an *in-situ* repair of the tenons: that is, to repair the tenons while still attached to the turbine rotor. "The process started with field trials on a scrap rotor. We attached a laser-based welding system to a robotic arm on a portable platform. We then developed a highly controlled additive laser-based welding sequence to rebuild the tenons on the ends of each turbine blade," says Van Rooyen.

With a typical near net shape profile of 10 by 10 with a 6.0 mm height for the shroud-only tenon connection and 9.0 mm for the tenons passing though both the shroud and understrap, Van Rooyen and his team chose to use a 2.0 kW IPG Photonics Fibre laser for the *in-situ* rebuild. "IPG fibre lasers offer good beam quality and high power, but they are compact and very robust," he tells *African Fusion*.

A small Kuka robot was chosen to manipulate the laser via a fibre optic and the powder through a nozzle to rebuild the tenons. "The robot was programmed to build a near net shape profile from a predefined tool path. All we had to do onsite was reference the starting point for each tenon. We could also easily reprogram the tool path for other tenon sizes, which were different depending on the location and stage of the turbine blade on the turbine," Van Rooyen adds.

Argon was used as the carrying gas for the powder, which was metered using a disc and groove type powder feeder. "Changing the rotating speed of the feed disc adjusts the powder feed rate very accurately, to within ±2.5% on a 0.5 kg/hour powder-feed rate," he explains.

Highlighting the onsite suitability of the process, the laser power source was installed in a truck to enable the repair to be applied outside. "Once the tenons were

ground off and a reference starting point for each one was established, the repair proceeded automatically at a rate of about 0.5 mm per layer. We could, in theory, have rebuilt all 10 tenons on a packet of turbine blades in a single two shift day, but with the necessary inspection required to ensure the integrity of the repair, it did take several days longer," he notes.

Following build up, intermediate ultrasonic inspection, and post weld heat treatment of the welded tenons, each tenon was hand dressed by skilled blade fitters to the exact size and finish required.

Once a packet of blades was assembled to its understrap segment, the shrouds were joined to reconnect the removed shroud segments to the remaining segments either side. Following intermediate non-destructive testing on the shroud welds, the tenons were mechanically peened so that they were firmly and permanently attached to the shroud.

"The shroud welds, which also have to be subjected to stress-relieving heat treatment, are more easily done using the TIG process, but we initially used the laser as we had the procedures in place to perform the repair," Van Rooyen continues.

Newby adds: "The tenon repair procedure involved very high levels of detail at every stage, ending up with ultrasonic

Above: A completed in-situ turbine blade understrap replacement after the rebuilt tenons have been peened.

Left: As welded turbine blade tenons.

and penetrant NDT testing on every part of the repair."

After a full field trial, the qualified tenon refurbishment process was applied to an *in-situ* understrap replacement on a 657 MW Majuba low pressure steam turbine in January 2020 at ESKOM-owned Rotek Engineering. Tenons on ten blades, five blades either side of the understrap, were removed. The two half shroud sections either side were cut after blade five, enabling them to be removed. The tenons were refurbished using laser metal deposition to near net shape before being hand-dressed. Following inspection and heat treatment, the understrap was replaced, followed by fitment, weld-joining and heat treatment of the removed shroud sections on either side. The repair was then completed by peening the tenons to firmly hold the turbine blades in place.

"We started the repair in December 2019, and we completed the work in January 2020. The actual implementation took place in a single month over the festive period. This is what we call an *in-situ* repair, and it costs a fraction of that associated with the replacement of a full row of 128 blades. Once optimised, this repair can be completed within a 15-day window, which will have a huge impact for power stations," says Van Rooyen.

"We also believe we can do this onsite with the rotor removed and mounted in the laydown space adjacent to the turbine floor, which will further simplify the logistics and reduce downtime at the power station," Newby concludes.