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TITLE : DEVELOPMENT OF REFURBISHMENT PROCEDURES OF INDUSTRIAL COMPONENTS BY NON CONTACT DAMAGE MAPPING AND CO_2 ROBOT-LASER WELDING AND CLADDING

PROJECT
COORDINATOR : CISE

PARTNERS : CHROMALLOY FRANCE
EGT
ENEL
JOBS

STARTING DATE: 1.8,92 DURATION: 48 MONTHS

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SUMMARY

A robotic welding Work Station equipped with a CO_2 laser was developed in the Project, integrating a damage monitoring sub-system able to perform a quantitative assessment of the extent, the size and the location of the darnage (using a 3D mapping) in high value industrial components. The data resulting by the comparison between the precise 3D contour of the” darnage with the original topography are used to drive the robotized laser welding device during the repair of the damaged article.

Among the most expensive and critical turbogas parts made of materials with weldability problems, four type of components/materials were chosen for the activity typically affected by different types of damages; both butt-welding of a new insert and cladding were considered, as refurbishment processes.

The $C0_2$ laser robotized system was used to develop repairing procedures to obtain defect-free welds and cladding on the materials of turbine components. Alternative component suitable weld-procedures were also studied for each type of material.

Discriminatory mechanical tests were performed on welded samples obtained with $C0_2$ laser and with the alternative processes. A comparison between these results demonstrates that laser processing gives the best performance in three of the four analyzed materials.

Finally the work station was used to perform automatized refurbishment of real components with the welding procedure developed in the project for the corresponding material class. For these components the cost-effectiveness of the $C0_2$ laser refurbishment system was assessed.

KEY WORDS

GAS TURBINE COMPONENTS, SUPERALLOYS, REPAIRING, ROBOTIZED LASER PROCESSING, AUTOMATIC DAMAGE MAPPING

1 OUTLINES of the PROJECT

Gas turbine components exposed to high temperature gases are liable to localized damage by several processes. The high costs and very long delivery times of new components make refurbishment ofdamaged articles very appealing. At the start of the project some limits of the state of art repairing procedures were:

traditional welding techniques gave unsatisfactory results on superalloys, due to their too high heat inputs

automation of welding processes was poor in gas turbine field: the long time required for path and parameter programmingg could not be amortized on big numbers of similar articles, due to unreproducibility of damages.

The overall objective of this Brite Euram project was to overcome these limitations using a combination of robotic and laser material processing techniques. In fact laser welding and cladding processes are characterized by high energy concentrations which allow low heat input and consequently produce small heat affected zones, limited distortions and good dimensional control of the welded seam. Moreover the integration of Darnage Management SubSystem (DMSS) and of a laser source in a robotized machining workstation allowed the automatization of the welding process.

The consortium was organized with the following partners:
CISE (I), Institute for advanced technological service and research (mainly for ENEL)
Chromalloy France (F), component coating and repairing.
ENEL (I), Italian Electricity Generating Company, end-user of gas turbines
European Gas Turbine (U.K.), gas turbine manufacturer.
JOBS (I), robotic workstation supplier.

The roles of the different partners are described in the following:

CISE worked in the project mainly in: program management; development of laser beam & cladding powder handling unit for welding and cladding integrated in the robot-laser workstation; establishing the process parameters for CO_2 laser treatments and producing samples for mechanical characterization; executing CO_2 laser repairing of components.

CHROMALLOY FRANCE worked in the project mainly in: establishing the process parameters for state of the art welding processes (TIG, diffusion brazing) and producing samples for mechanical characterization; performing mechanical characterization.

ENEL worked in the project mainly in: developing test procedures for thermomechanical fatigue, laser thermal shock and stress rupture and executing the tests.

EUROPEAN GAS TURBINES worked in the project mainly in: delivering the specification for DMSS; establishing the process parameters for state of the art welding processes (electron beam, MIG); performing extensive thermomechanical characterization.

JOBS worked in the project mainly in: development of the DMSS for 3D and linear damages in gas turbines hot section components able to teach an automatic repairing workstation; integration of DMSS into the robot-laser workstation.

The main technical achievements of the Project are:

the development of a CO_2 robo-laser workstation, with a Damage Management Subsystem (DMSS);

the optimization of repairing procedures for previously considered "unweldable" superalloy (γ' strengthened) both with traditional and laser technologies; qualification of such methods with extensive mechanical tests performed on welded test-pieces

refurbishment of real components with the automatized process in the workstation.

2 CO, ROBOLASER WORKSTATION WITH DMSS

To reach the goal of automatic refurbishment of turbogas components, the first line of activity in the Project was to develop a robotic workstation equipped with a CO_2 laser, integrating a damage management sub-system (DMSS) able to perform a quantitative assessment of the extent, the size and the location of the damage (using a 3D mapping) in high value industrial components. The data resulting by the comparison between the precise 3D contour of the damage with the original topography were used to drive the robot-laser during the repair of the damaged article. Both 3D damages like material loss due to erosion or impact with foreign objects, and linear damages like cracks are faced by DMSS.

Some applications of the system to turbogas components are described in section 4; in the following some technical details are given.

2.1 Workstation Morphology

The selected workstation is based on the structure of a commercial robotic system, produced by JOBS. Taking into account the dimensions of the components to be treated and the requested repair operations, the robot named JO'TECH 92 has been selected; it is 3D multi-function system for visualization, simulation and processing of complex components. Its most immediate practical utilizations are the following:

* tool route recording by scanning probe
* measuring by touch-trigger probe
* reduced and/or actual flying models
* 5 axis high precision laser material processing.

A special version for laser delivery and handling was chosen for this Project. Technical features are collected in Tab. 1 and the robot is shown in Fig. 1. All the required safety devices for systems employing high power laser beams were adopted.

Thanks to the last generation of CAD/CAM systems, JO'TECH is able to follow complicated geometrical single patterns in short times. The simple construction solutions adopted as well as component quality ensure high reliability and safety:

* monocoque body structure for rigidity/weight and operating area/external overall sizes ratio optimization
* protection against noise and dust pollution by monocoque structure complete with sound-proof transparent panels
* 220 V single-phase feeding

JO'TECH is designed for easy communication with the operator and with other computer systems:

* electronic handwheel which may be combined to TCP and RTCP functions
* integrated diagnostic
* 80 Mby mass memory and 720 Kb floppy disk 3" 1/4

- ETHERNET and DNC connection (optional)
- control by 32-bit multiprocessor JO’CAM system
- CPU 80486 (TM INTEL) 25 Mhz and/or 80386 (TM INTEL) 33 Mhz.

JO’TECH includes the “JO’CAM” CNC designed and constructed to improve very high speed in the machining of complex shapes. The characteristics of the system are:

- **5** axes controlled at the same time
- linear interpolation on 5 axes
- part-program block processing time: 9 ms
- 2 electronic handwheel
- Tool Centre Point programming
- measuring and recording by 5-axis mechanical deflexion scanning probe
- tool centre recording
- user programme memory
- look ahead (16-bloc circular buffers).

A commercially available motorized head can accommodate the 4* and 5th axis.

2.2 Damage Management SubSystem (DMSS)

Two different devices were integrated into the system: A) a linear repair device, allowing the operator to carry out quick repair for linear cracks; B) a 3D repair device, allowing surface reconstruction through data detected by digitizing of worn components and comparison with original geometries.

A vision system (based on CCD Camera: 5x or 30x) was developed and some specific procedures were defined, so that the programming time of an unknown path was reduced and at the same time, the precision of the joint-beam alignment was better than 0.1 mm, typically, as required to perform linear welding repair in a cost effective way. The linear path is stored in the NC as a number of representative points, later used to drive with thumbwheels the robot axis along the path reconstructed with linear or spline interpolation.

An analysis of 3D commercial sensors was performed by testing them on field, to get a classification according to TRACK (possibility of digitizing, scanning and memorizing a path line on a surface); PRECISION (scanning precision performance); ADAPTABILITY (adaptability to several and unknown types of lines and surfaces); USE IN HARSH ENVIRONMENT (in contained atmosphere and environment; on surface with different reflection degrees due to colour, roughness and oxidation). As the industrialized work-station should be competitive most of all in the European market, the system cost is one of the main elements to be considered even in the experimental step: the final results in fact aims to install as many stations as possible in order to prevent import of Japanese and American plants. On the basis of the obtained results and of this last consideration a touch probe was chosen.

2.3 Coaxial nozzle

The normal way to bring filler metal in laser cladding is to blow a stream of powder from a side nozzle or to use additional wire. Both methods have strong limitations when dealing with complex shaped paths, as those required in repair processes.

To overcome these problems an alternative solution was individuated; as filler metal a stream of powder coming from a special coaxial nozzle was used. Similar solutions were not available on the market so design and manufacturing were performed by CISE.

The isotropy of efficiency of powder deposition and its independence on movement direction was checked by programming interpolated circular paths on the CNC of the laser work station available at CISE; the cladding performed along this path using the coaxial nozzle had constant thickness. Nozzles for applications where the access is limited and for extended cladding with beam integrator (6x3 mm spot size) were developed and tested.

The laser processing capability of the developed system can be summarized as follows:

laser cladding thickness (per each pass): 0.2- 1mm; laser welding depth: typically 3mm, (if necessary up to 6mm); laser cladding width: up to 30mm; operating volume: 300 x 200 x 200 mm.

REPAIRING PROCEDURES

At the beginning of the Project an analysis was performed to find out which materials-components of turbine and compressor, even if weldable with some alternative techniques, could be refurbished in a cost effective way by automatic damage mapping and laser repairing with a robotized technique. This analysis of the most critical components of the gas turbine let to choose four materials (see Tab. 2) and to consider four components:

high Cr-Ni stainless steels used for discs and compressor blades (17-4-PH);

Co or Ni-based solution strengthened superalloy: Haynes 230 used for combustion chambers and IN718 for labyrinth seals;

Ni-based superalloys strengthened by a large volume fraction of γ' precipitates, used for turbine blades and vanes (IN73 8).

Different types of damage were analyzed; both butt-welding and cladding were considered, as refurbishment processes.

A range of welding methods and parameters suitable to repair typical service damages, on the basis of the existing international experience were used. New TIG and and laser processing procedures were developed; they were innovative mainly for γ' strengthened Ni-based superalloy. Both traditional and laser weld procedures were optimized by welding trials, NDT examination, metallography and simple mechanical tests. The best weld method/procedure for each type of weld repair in each component was selected for further thermo-mechanical characterization. A laser thermal-shock system was developed to test the repaired areas with a quick method.

17-4-PH for compressor blades and disks

The following welding procedures were examined:

TIG (Chromalloy), Electron Beam Welding (EGT), CO_2 laser (CISE)

The electron beam Process was abandoned by EGT due to cost evaluation. The laser-processing technique gave good results (see an example in Fig. 2). Different post-weld heat treatments (PWHT) were considered to eliminate hardness peaks. LCF test were performed: only laser welded testpieces were compared with parent material as no TIG welded samples on forged 17-4-PH could be prepared. LCF tests were performed on laser clad forged 17-4-PH material without any Post Weld Heat Treatment (PWHT). There was a large reduction in fatigue strength when compared with parent material. These results were then compared with samples which had undergone some form of PWHT (both the full standard heat treatment, solution and ageing, and only ageing treatment) were considered. The results suggested that an improvement in fatigue strength could be gained simply by carrying out an ageing heat treatment, as shown in Fig. 3. The fatigue strength was still, however, below that of the parent material. HCF results showed a big scatter, probably due to the porosity of the weld bed.

HAYNES 230 for combustion chambers

Combustion chambers can be subjected to cracking and damage due to flame impingement. Electron Beam Welding (EGT), TIG welding and Diffusion Brazing (Chromalloy), CO_2 Laser Welding (CISE) were performed on a 3 mm thick sheet of Haynes 230.
The discriminatory bend tests indicated that only TIG and CO_2 laser welding are suitable techniques for repairing this material. In Fig. 4 a comparison between the macrographs of TIG and of laser welding is shown. The tensile tests performed on the test-pieces obtained with the different repairing techniques are shown in Fig, 5. Electron Beam welding gave rather good results but was considered unsuitable due to failing in the weld in bend tests. TIG welding performed by Chromalloy was found to give slightly better results than that performed by CUK but was still lower in UTS and elongation than CO_2 laser welding. So the laser welding is the best repairing technique as tensile results are comparable to that of the parent material.
High cycle fatigue tests showed a rather high scatter of results, due to the several small porosities present in the weld bed, but laser thermal shock cycling of the laser processed sheet did not induce any crack into the repaired material (till 1500 cycles between 600 ‘C and 1000 ‘C; in the cycle time on = 4-5 s and time off = 2-3 s).

IN 738 for turbine blades

This was the most difficult and most important point of the Project. The low weldability of Inconel 738 Low Carbon superalloy limits the number of cladding techniques useful for the repair cycle of turbine components. Three repair processes were selected for the turbine blade and nozzle components made in γ’ strengthened IN738. These along with the partners responsible for developing these processes were TIG (Chromalloy), Diffusion Brazing (Chromalloy) and CO_2 Laser (CISE).
The brazing technique gave good results, but poor tensile resistance (see Fig. 6). The TIG procedure developed in the project is rather innovative and very promising, but it showed some limits on big volumes and is difficult to automatize.
The laser processing technique was successfully applied with IN625 filler powder, even to the components (as described later), but the mechanical characterization of IN738-IN625 joints demonstrated that this solution has too poor properties to be applicable to real components of the hot section of the turbine (see for example creep rupture results in Fig.7).
In the last part of the project a laser processing procedure with self-similar powder was optimized for IN738; as shown in Fig. 8 very good weld beds cam be obtained even with a multipass process; good hardness results are obtained after the standard heat treatment.

At the end of the Project some technological improvements are going to be applied to the robolaser workstation to obtain the industrial applicability of the laser processing methodology to real components.

IN 718 ***for labyrinth seals***

Three repair processes were selected for the labyrinth seal component. These along with the partners responsible for developing these processes were MIG (EGT), TIG (Chromalloy) and CO_2 laser (CISE). As this component is usually damaged by abrasion between rotating and static parts in the turbine, this type of test was chosen for qualification. The first process was excluded as with the MIG technique no test-pieces for abrasion tests could be obtained. The bending tests show good results for TIG welding except in the root position samples which show a too large HAZ. The laser welded samples do not show problems at the root position (a smaller HAZ than in the TIG case), but the angle obtained for deformation in face bend tests was lower than that of the TIG samples; moreover some cracks (possibly due to an insufficient gas protection) were found in the weld zone of the laser processed samples. Abrasion tests performed on CO_2 laser and TIG cladded samples at different temperatures and using different test conditions let to conclude that the TIG repaired specimen and the reference one have the same behaviour, but for laser repaired specimen a partial or complete destruction occurred at the beginning of translation after penetration. TIG weld resulted to be the most appropriate technique for this type of repair.

3 AUTOMATIZED REFURBISHMENT OF COMPONENTS

As the laser procedure resulted in welded joints with the best mechanical performances both in Haynes 230 and 17-4-PH and IN738, the robolaser workstation was used to refurbish the corresponding true components.

For 17-4-PH a CO_2 laser repair cycle of a real forged 17-4-PH compressor blade without any coating or oxidation film on the surface. Both the tip and the root of the blade were repaired with the optimized procedure of laser cladding. The contact damage monitoring technique was adopted for contouring and storing of damaged surface profiles (see Fig. 9 and results in Fig.10). Also the repairing of a forged 17-4-PH compressor blade by $C0_2$ laser welding of an insert was carried out, with the previously defined procedure.

In the case of Haynes 230 the laser procedure optimized in the Project for this material was applied on a hemi-cylinder similar in size to a real combustion chamber (see Fig. 1 I); the hemicylinder contained a curved linear crack which was measured by the DMSS; the automatic robo-laser workstation could perform a good weld along the path of the crack, repairing it.

These results demonstrate that the robolaser technology developed in the project is suited to manufacture and repair both Co-based superalloy combustion chamber and high Cr-Ni compressor blades.

Finally the robolaser workstation was successfully used for monitoring damage and repairing IN738 turbine blades with the filler metal IN625 (Fig. 12). Actually the mechanical performances of this type of cladding are unacceptable; for the application of the automatized technology to these hot section parts it is necessary to use the procedures with the filler powder self-similar to the parent material, as studied in the Project. The brazing and the TIG procedures studied by Cromalloy France showed some geometrical limits and the laser results to be the most flexible technology. As this procedure for laser processing with the self-similar powder could be optimized only at the end of the project its application to real components requires some technological improvements now under way in CISE. The industrial applicability of the robolaser technology to refurbish real components of γ’ strengthened superalloysis going to be furtherly developed as the industrialization of the laser processing technique on IN738 is the most innovative aspect of the Project and the most interesting from an economical point of view.

The laser technology seems very promising, due to its limited heat input, its flexibility and the ease of automation. The increased costs of running a robotic weld repair station, are more than offset by the reduction in the time and manpower required to produce welds of a consistently high quality over those produced manually (e.g. tip build up of a turbine rotor blade = 5 minutes by TIG or -5 seconds by automated $C0_2$ laser). The precision delivered by the laser process linked to a robot also leads to a reduction in the overall processing time due to the repeatability linked with the increased confidence brought about by an increasing amount of experience gained with increased usage. As the popular practice of both TIG and MIG welding are mainly manual operations; the hazards of gas inhalation, bums, flash, etc. are eliminated by the use of a robotic station, thus guaranteeing the safety of both the operator and any observers to the process data.

4 CONCLUSIONS

A robotic workstation equipped with a CO_2 laser was developed, integrating a damage management sub-system able to perform a quantitative assessment of the damage in high value industrial components. The data resulting by the comparison between the precise 3D contour of the damage with the original topography were used to drive the robot-laser during the repair of the damaged article. The procedure for welding Ni-based alloys strengthened by big volumes of 7’ phase was developed. The mechanical tests performed on different types of welds showed that the laser processing procedures produce defect-free welds and cladding with favorable properties in three of the four material-components analyzed in the Project. Finally the workstation was used to perform automatized refurbishment of real components with the welding procedure developed in the Project for the corresponding material class.

The feasibility and industrial applicability of the refurbishment procedures, with the CO_2 robotized system resulted confirmed. The refurbishment of real components with laser processing in an automated workstation was evaluated to be cost-effective in at least two materials and three components among those analyzed. These results are expected to give a good economical impact on the market of turbogas high cost components; the possibility of a cost-effective repairing will avoid scrapping and let to use exercised and refurbished ones, instead of their substitution.

Table 1

- Characteristics of the machining center used in the project

number of axis	4
x axis length	1000 mm
y axis length	500 mm
z axis length	500 mm
c axis	continuous
precision	0,05 mm
repetibility	0.02 n-ml
maximum speed	10000 mm/min

Table 2

	C	Fe	Ni	Cr	Co	Mn	W	Ti	Al	Nb	Mu	Si	Altri
17-4-PH	0.07	bal	3-5	15÷17.5	-	-	-	-	-	0.15	-	-	Cu 3-5 0.45 Ta
Haynes 230	0.1	-	bal	22	-	1.2	14	-	-	-	-	-	0.02 La
IN 738 LC	0.11	<0.s	bal	16	8.5	1.7.5	2.6	3.4	3.4	0.9	<0,2	<0.3	1.75 Ta 0.1 Zr
IN 718	0.04	18.5	bal	19	-	3.1	-	0.9	0.4	5	0.18	0.1s	-
IN 625	0.05	2.5	bal	21.5	-	9.0	-	0.2	0.2	3.6	-	-	-

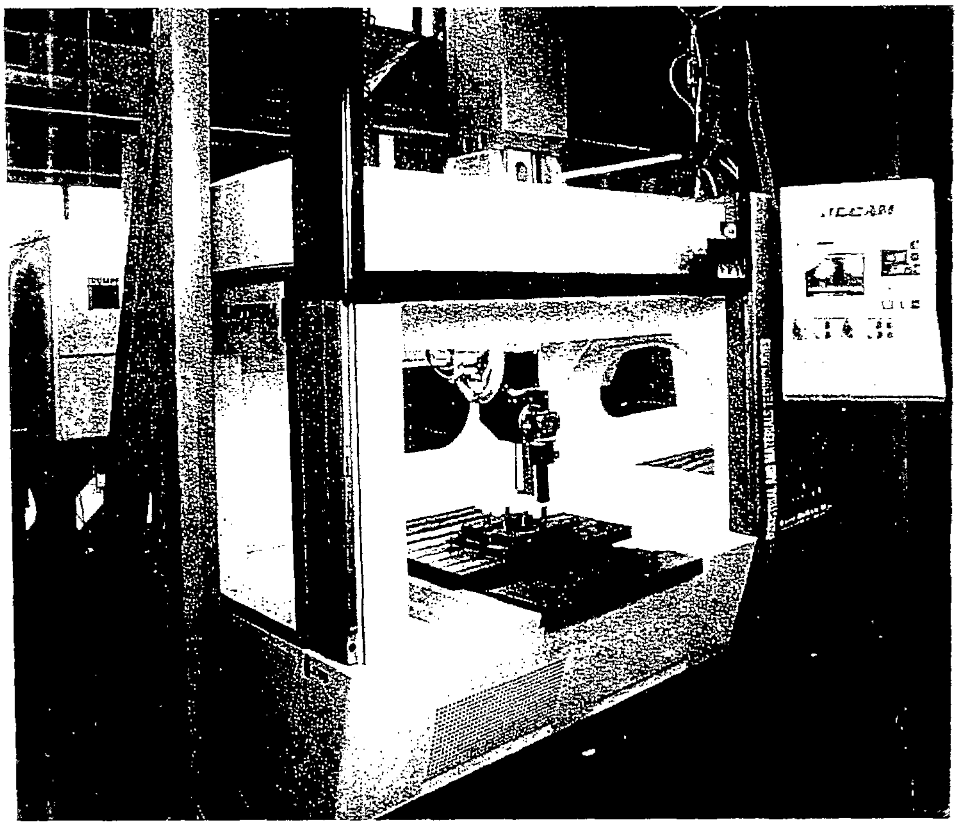

Fig. 1- The CO_2 robot-laser workstation

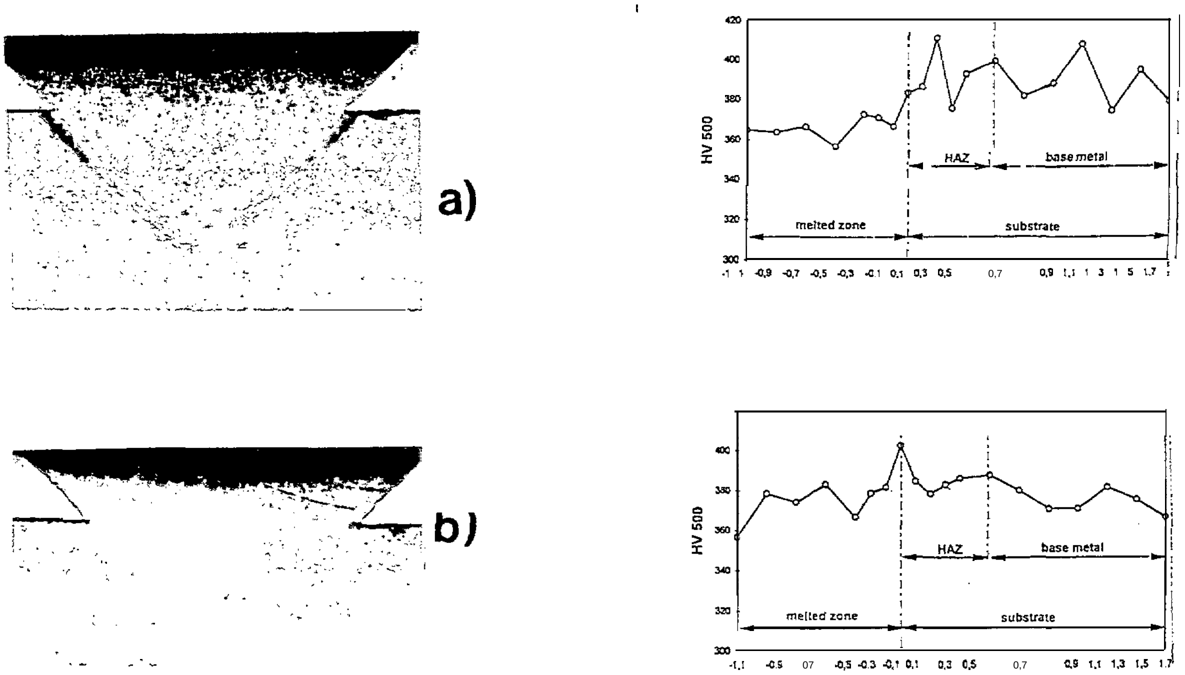

Fig. 2- Comparison between laser-cladded 17-4-PH tests-pieces for tensile tests: a) as welded; b) PWHT.

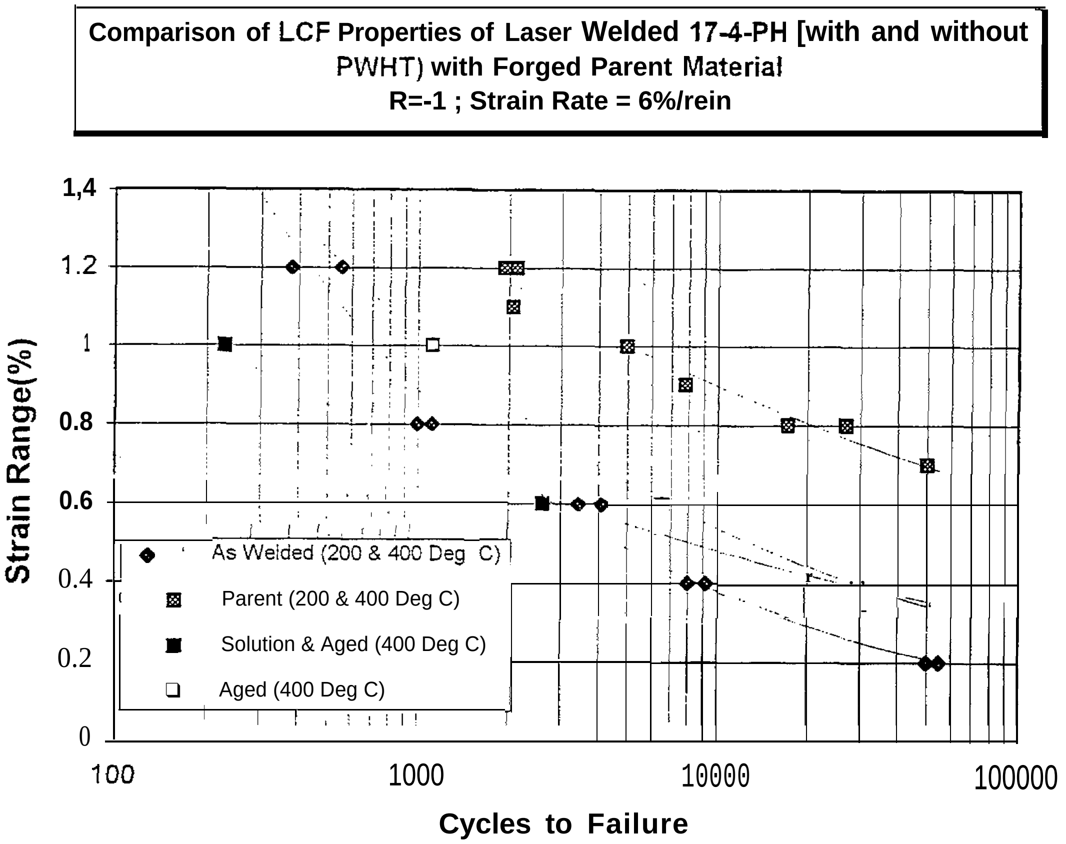

Fig. 3- Comparison of LCF properties of laser-welded 17-4-PH (with and without PWHT) with forged parent material.

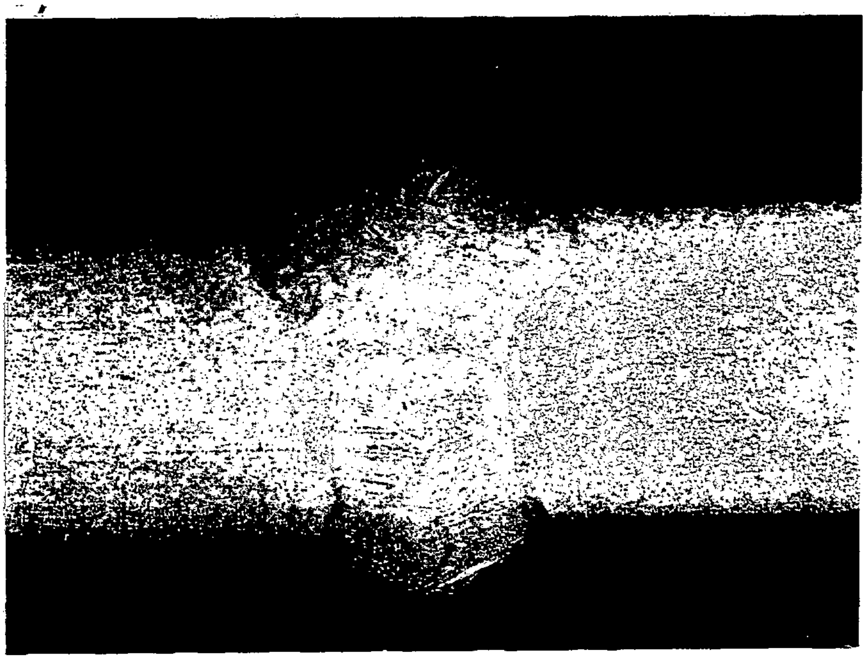

Fig. **4**- TIG laser welded Haynes 230.

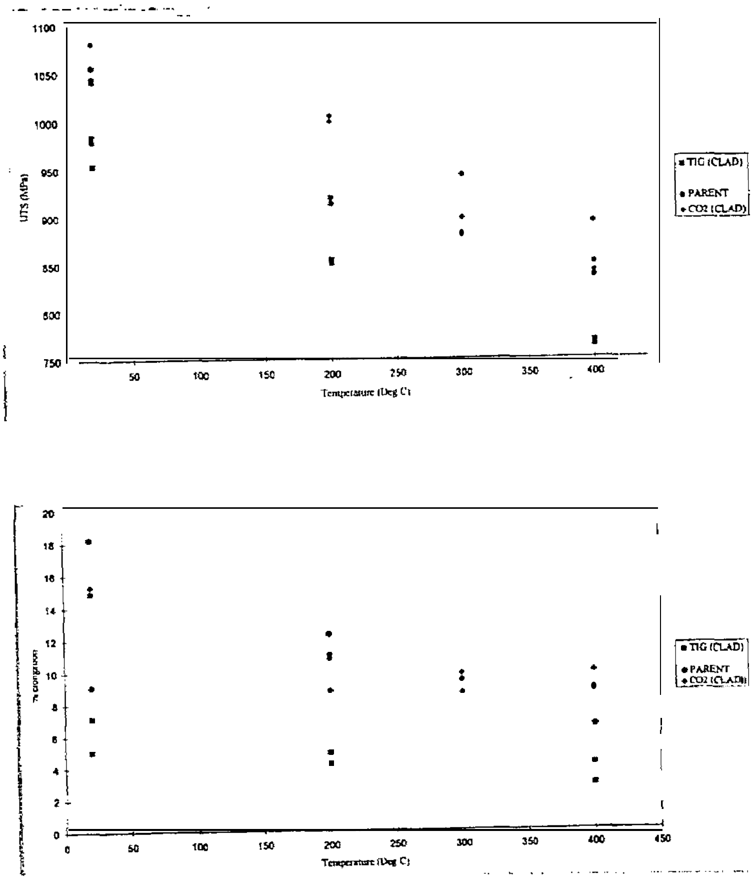

Fig. 5- Tensile tests results on Haynes 230 welded test-pieces.

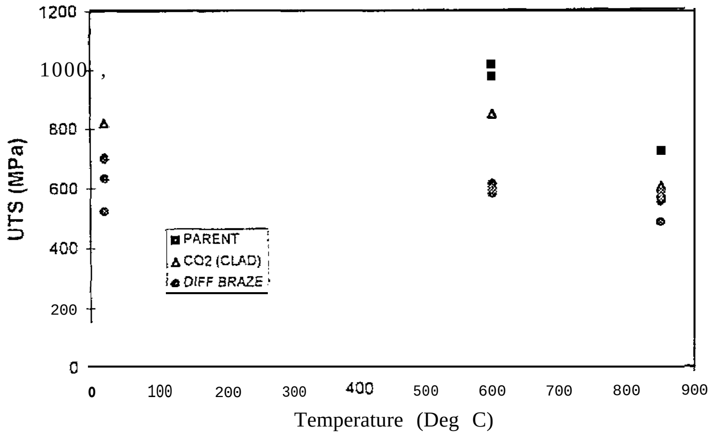

Fig.6 - Results of tensile tests on IN738 test-pieces.

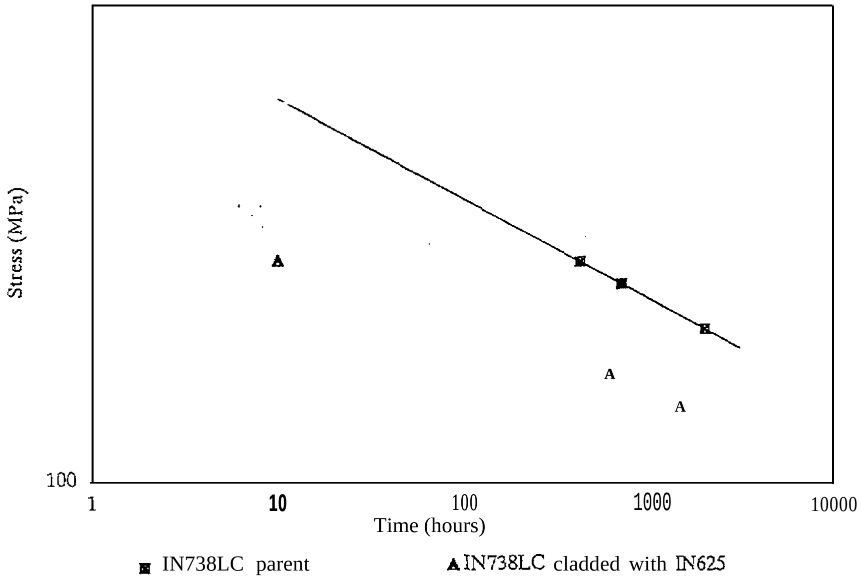

Fig. 7- Creep-rupture results on IN738 laser-cladded with IN625.

Fig, 8- IN738 laser cladded with IN738.

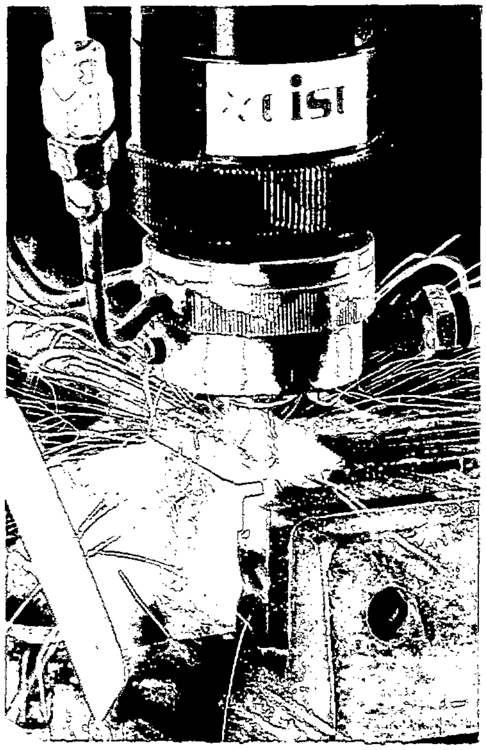

Fig. 9- CO_2 robolaser repairing of a 17-4-PH compressor blade: build-up phase of the root.

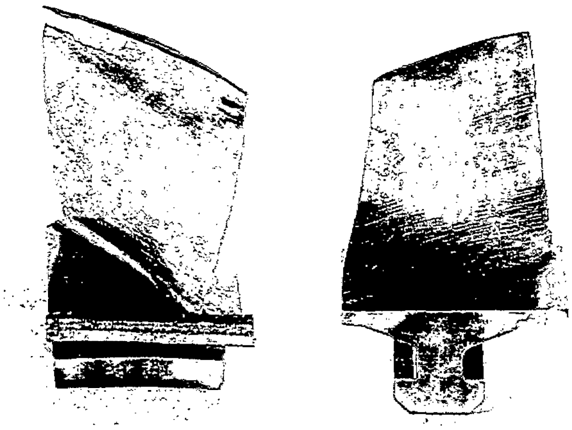

Fig. 10- Compressor blade after laser repairing and subsequent machining.

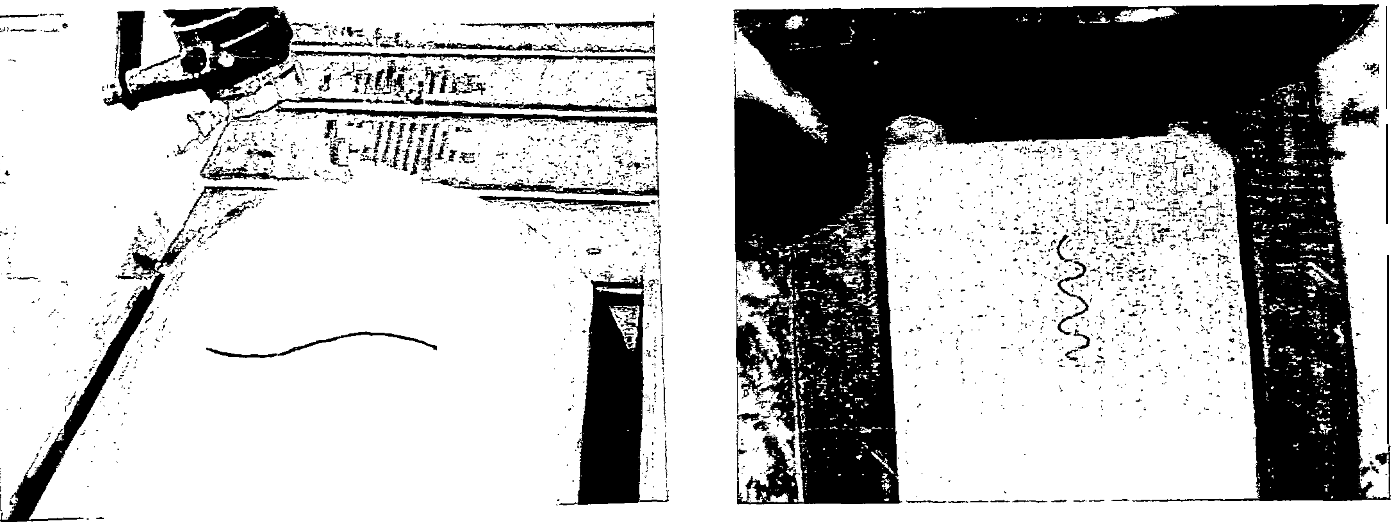

Fig. 11- Example of the crack paths repaired by robolaser processing on a hemicylinder of Haynes 230.

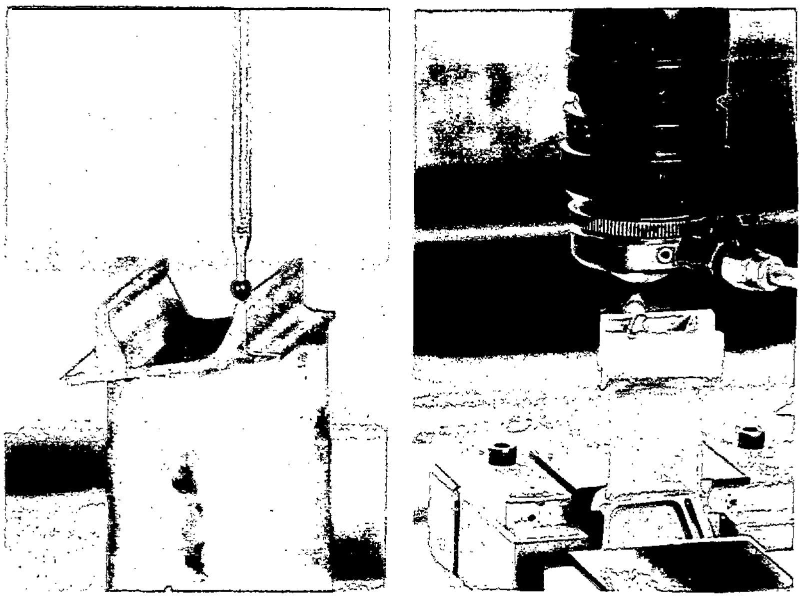

Fig. 12- Two phases of the laser processing repair of a turbine blade: a) damage monitoring; b) laser cladding.