THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47th St., New York, N.Y. 10017

97-GT-365

ADVANCES IN GAS TURBINE BLADE REPAIR BY LASER WELDING

BREAK

Ettore Gandini, Franco Agnesone
ATLA
Torino, Italy

Federica Taricco
FIAT AVIO S.p.A.
Torino, Italy

Leonardo Arrighi
ENEL / P–IN/STE/US–TO
Torino, Italy

ABSTRACT

Industrial gas turbine components are subject, in the course of their operating life, to various kinds of damages, requiring repair processes during periodical overhauling operations. Blades, in particular, suffer from creep, corrosion, wear phenomena.

The majority of blade damage is currently repaired by means of manual TIG welding, with a filler metal which is often different from the blade alloy. This leads to an inferior metallurgical and mechanical condition of the repaired area as compared to the base metal. Besides, the nickel superalloys of the blades are often subject to cracking during welding operations.

A process of laser welding for the repair of the airfoil tip has been introduced and optimized, to improve the characteristics of the repaired component. Powder of the same alloy of the part is used as filler metal, and the process is carried out using a Nd:YAG laser, equipped with a 6–axis CNC motion control. The original blade geometry is rebuilt by multi–layer cladding, then the blade is submitted to machining operations, NDT testing and heat treatment.

The optimizing activity has been performed with the aid of microstructural characterization, chemical composition checking (by EDX microanalysis), hardness and stress rupture testing of the welded specimens.

INTRODUCTION

The blades of industrial gas turbines are among the most damaged components during operation. The main failure types are due to:

- impact damage from foreign objects
- cracks and corrosion
- wear of the airfoil tip.

Turbine blades represent the driving force in terms of time between overhauling shop visits. As a consequence of the blade inspection, it is necessary to perform some repair processes (Gandini, 1991). Presently the majority of deterioration is repaired by manual welding.

Tip repair, in particular, can be accomplished by means of microplasma welding (Saltzman, 1992) or hand TIG welding (Vv.Aa., 1994), in which case welding skill is of enormous importance. The nickel or cobalt superalloys used are subject to hardening in the heat–affected zone (HAZ) and have a marked tendency to crack when TIG welding is carried out (Yeniscavich, 1987). Even if the operation is performed in the most correct way, if the filler metal is different from the blade alloy (this is often the case, to facilitate application) the final result is an inferior metallurgical and mechanical condition of the repaired area as compared to the base metal.

The activity described in this paper was undertaken with the aim of improving the repair cycle of industrial turbine blades, by means of a laser cladding process in which the same alloy of the component is used as filler powder.

The main intention was to exploit the beneficial effects of laser processes, especially its capability of transferring a high power density in a very limited region of material, with a very low total heat input.

Other advantages of laser welding are related to its great reproducibility and positioning capability, with the consequent saving in welding time, coating material and finishing processing time.

The proposed repair cycle is composed of the following operations:

- solution heat treatment
- removal of the damaged tip by electro–discharge machining

Presented at the International Gas Turbine & Aeroengine Congress & Exhibition
Orlando, Florida — June 2–June 5, 1997

- liquid penetrant inspection
- surface preparation by grit blasting
- laser cladding
- machining to required dimensions
- non–destructive testing, in agreement with the repair specification
- rejuvenation heat treatment (and coating if required).

As per the typical rejuvenation process, the procedure requires that a specimen is welded with the same parameters of the production cycle, undergoes the same heat treatments and is finally tested in order to check the repair process quality.

COMPONENT AND MATERIAL

The experimental activity has been performed on test pieces derived from a forged blade of alloy Udimet 520.
The preliminary trials were carried out using as a filler metal a powder of nickel alloy Inconel 625 (one of the most used in manual welding process). After reaching a sufficient level of skill in laser parameter controlling, the following phase was conducted with the same alloy of the blade (Udimet 520 powder). In Table 1 the chemical composition of the powders, supplied by Praxair Surface Technology, is shown and compared with the specifications requirements. The limits for Udimet 520 are the same required for the alloy of the blade.

TABLE 1 – CHEMICAL ANALYSIS (WEIGHT %) OF THE POWDERS

	INCONEL 625 POWDER			UDIMET 520 POWDER		
ELEMENT	Min.	Max.	LOT	Min.	Max.	LOT
Chromium	20.0	23.0	22.0	18.0	20.0	18.75
Molybdenum	8.0	10.0	8.0	5.50	7.00	6.21
Tantalum +Niobium	3.15	4.15	3.88			
Cobalt	/	1.00	<0.01	11.0	14.0	12.44
Titanium	/	0.40	<0.05	2.90	3.25	3.03
Aluminium	/	0.40	0.1	1.80	2.30	1.85
Tungsten				0.80	1.20	1.04
Carbon	/	0.10	<0.01	0.02	0.06	0.05
Boron				0.004	0.010	0.010
Iron	/	5.00	<0.01	/	2.00	<0.1
Silicon	/	0.50	<0.1	/	0.15	<0.05
Manganese	/	0.50	<0.1	/	0.15	<0.05
Copper				/	0.10	<0.05
Sulfur				/	0.01	<0.001
Silver				/	0.0025	<0.001
Nickel	Balance			Balance		

EXPERIMENTAL PROCEDURES

Welding tests were performed with a 1 kW continuous wave Nd:YAG laser system, equipped with a 6–axis CNC manipulator. This system is able to compare a damaged blade to a pre–programmed original. blade geometry and proceed automatically to the welding process. Powders were injected, by a spraying unit similar to those used in thermal spraying processes, inside the end portion of the laser nozzle, and then directed towards the molten pool. A sketch of the process configuration is shown in figure 1.
After welding the test pieces were submitted to rejuvenation heat treatments typical of Udimet 520 alloy, in order to restore mechanical characteristics of both the blade material and the repaired area:

- solution treatment at 1120°C for 2 hours;
- stabilization at 845°C for 24 hours;
- aging at 760°C for 16 hours.

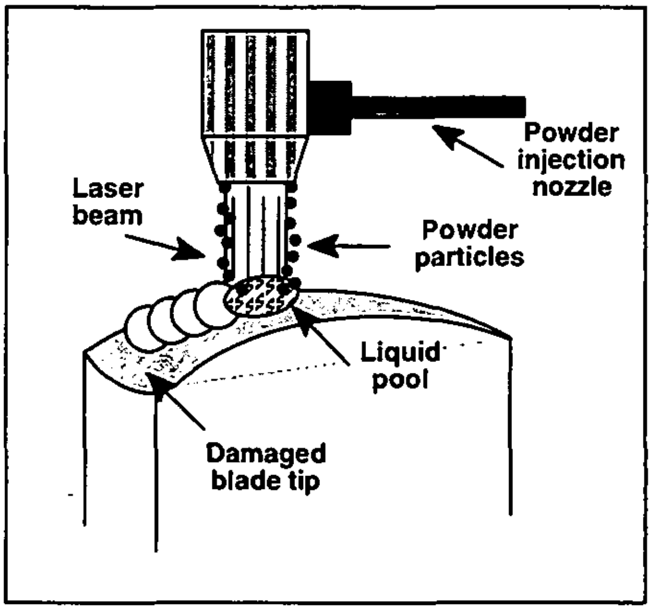


FIGURE 1 – SKETCH OF LASER CLADDING CONFIGURATION

Microstructural characterization of the laser processed specimens was performed by using optical microscopy; energy dispersive X–ray spectroscopy (EDX) was used to check chemical composition of the welded area. Vickers and Rockwell hardness and stress rupture tests were used for mechanical evaluation.

The test pieces used for microstructural and mechanical characterization had the geometry shown in figure 2; figure 3 shows the CNC laser welding program used to obtain them.

The stress rupture testing was conducted according to the requirements of specification ASTM E 139. The stress rupture specimens, which geometry is shown in figure 4, were machined from the welded zone, and test results were compared to those obtained from the base material having the same heat treatment.

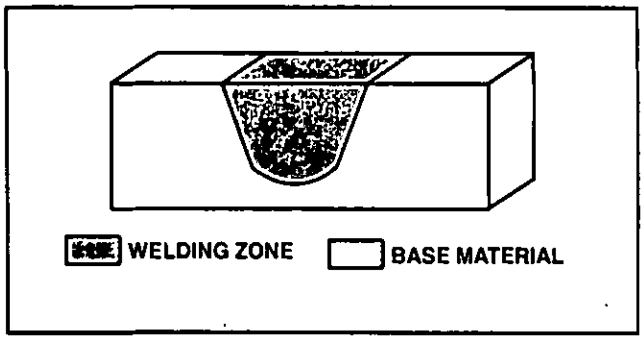


FIGURE 2 – WELDING SPECIMEN

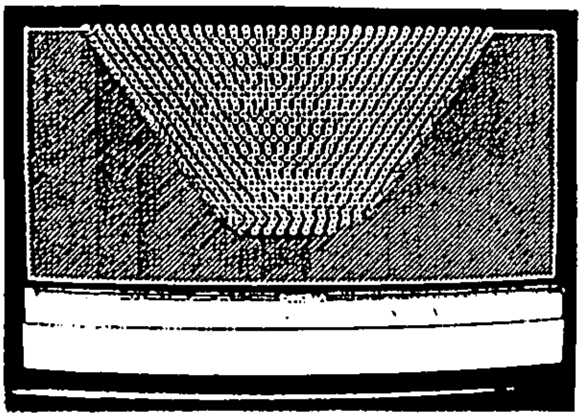


FIGURE 3 – LASER WELDING PROGRAM FOR THE SPECIMEN

RESULTS AND DISCUSSION

The metallographic specimens (figure 5) show a very narrow heat–affected zone in which, after heat treatment, it is almost impossible to distinguish the transition to base material. The weld area is sound and has a good bonding to the base material. No cracks or porosities were detected. By means of EDS microanalysis the chemical composition of base material, heat–affected zone and weld zone was checked, with the results contained in figure 6: the composition is practically the same. A microhardness testing was performed along a welded and heat treated specimen, with the results shown in figure 7.

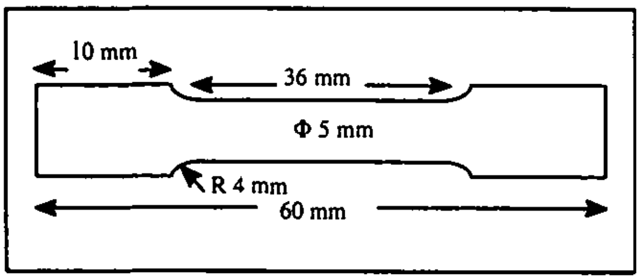


FIGURE 4 – STRESS RUPTURE SPECIMEN

These results have been made possible by the positive features associated with laser, that is the possibility of transferring a high power density in a very limited region of material, with a very low total heat input. In this process powder particles melt rapidly and the weld deposit solidifies rapidly after forming a sound metallurgical bond. The size of the heat–affected zone is consequently greatly reduced; thermal gradients and solidification induced stress are minimized.

Table 2 shows the results of Rockwell hardness and stress rupture tests, performed on Udimet 520 base material, and welded specimens.

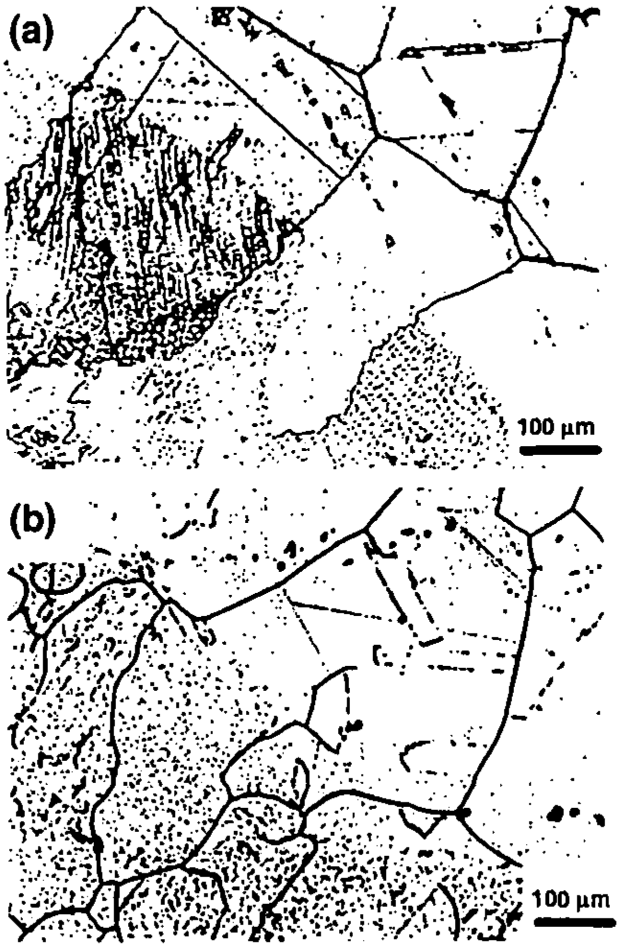


FIGURE 5 – METALLOGRAPHIC EXAMINATIONS
a) BEFORE HEAT TREATMENT
b) AFTER HEAT TREATMENT

CONCLUSIONS

The feasibility of laser cladding with powder of the same composition of the base alloy has been demonstrated for Udimet 520. The trials conducted up to now have produced sound welds, with mechanical properties meeting the requirements.

To perform the repair cycle on actual components it was necessary to set a CNC program able to rebuilt the original blade geometry by multi–layer cladding (figure 8). This permits to exploit the advantages of laser welding: great reproducibility and positioning capability, with the consequent saving in welding time, coating material and finishing processing time. Figure 9 shows a blade during the laser welding operation.

The use of the welding repair process by laser with a filler material having mechanical properties similar to the base alloy, can allow not only to increase the repairability area on the tip of the airfoil, but also to be able to repair critical areas of the blades. Figure 10 shows the present limits of repairability by means of TIG welding using Inconel 625 alloy as filler metal: the darker area shows the zone where the welding repair is allowed. It is possible to fill material not exceeding 25 % of the entire darker area volume, while with laser welding, the target is to fill up to 100 % of the volume. It will of course be necessary to evaluate, case by case, the economical benefit of extended repair as compared to component scrapping.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to ENEL (Italian National Energy Board) and to Sulzer Innotec Ltd. (Switzerland) for the support and collaboration that permitted the development of the process.

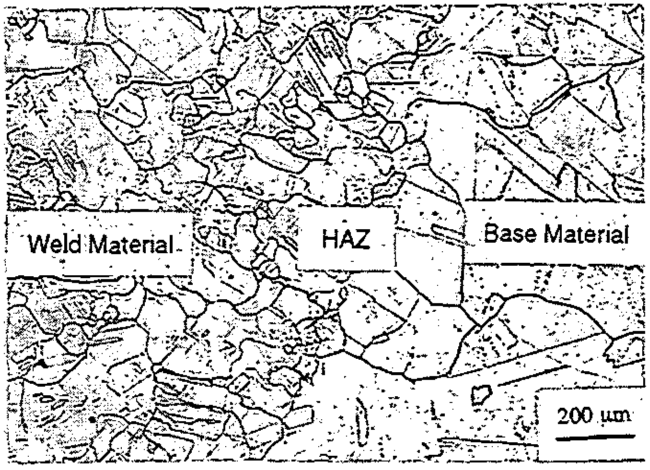
REFERENCES

Gandini, E., 1991, "Riparazioni e Rivestimenti di Componenti per Parti Calde", Proc. Workshop Materiali per Parti Calde di Turbine a Gas in Applicazioni Terrestri, AIM, Milano (in Italian)

Saltzman, G.A. and Sahoo, P., 1992, "Applications of Plasma Arc Weld Surfacing in Turbine Engines", Proc. of the Fourth National Thermal Spray Conf., Pittsburgh, USA, 4–10 May 1991

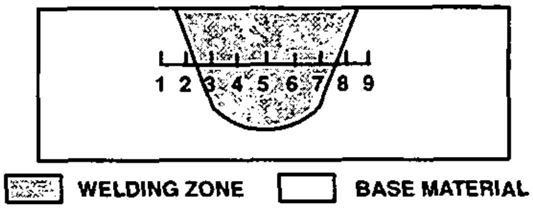
Vv.Aa., 1994, "Turbine Blade Repairs", Aircraft Technology Engineering & Maintenance, February–March 1994, p. 32.

Yeniscavich, W., 1987, "Joining", Superalloys II, C.T. Sims et al., ed., John Wiley & Sons, New York, pp. 495–516



CHEMICAL COMPOSITION (WEIGHT %)							
	Ni	Co	Cr	Al	Ti	Mo	Si
BASE	57.1	12.8	19.1	1.83	3.18	6.71	0.18
HAZ	56.6	12.7	18.9	1.77	3.04	6.54	0.35
WELD	57.7	13.0	18.9	2.15	2.9	6.09	0.14

FIGURE 6 – MICROGRAPHIC EXAMINATION AND EDX MICROANALYSIS OF THE WELDED AREA



Indentation spacing: 3 mm

POSITION	HV 0.3
1	391
2	384
3	331
4	346
5	308
6	315
7	334
8	379
9	387

FIGURE 7 – VICKERS HARDNESS VALUES ALONG THE WELDED SPECIMEN

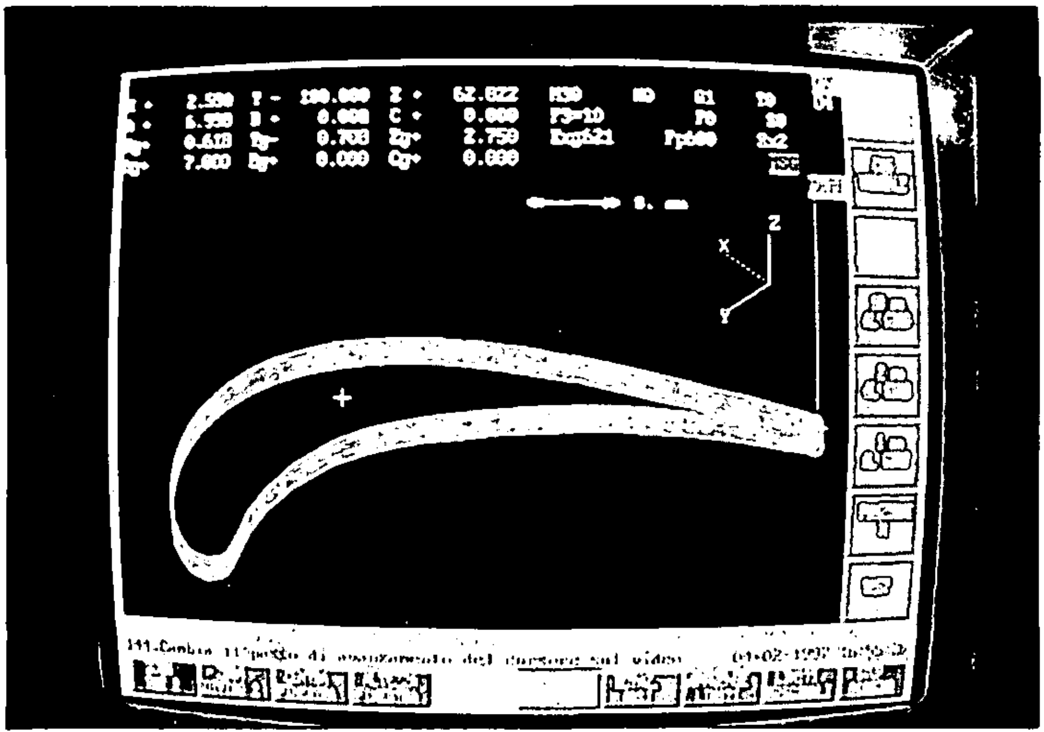


FIGURE 8 – LASER WELDING PROGRAM FOR THE BLADE TIP

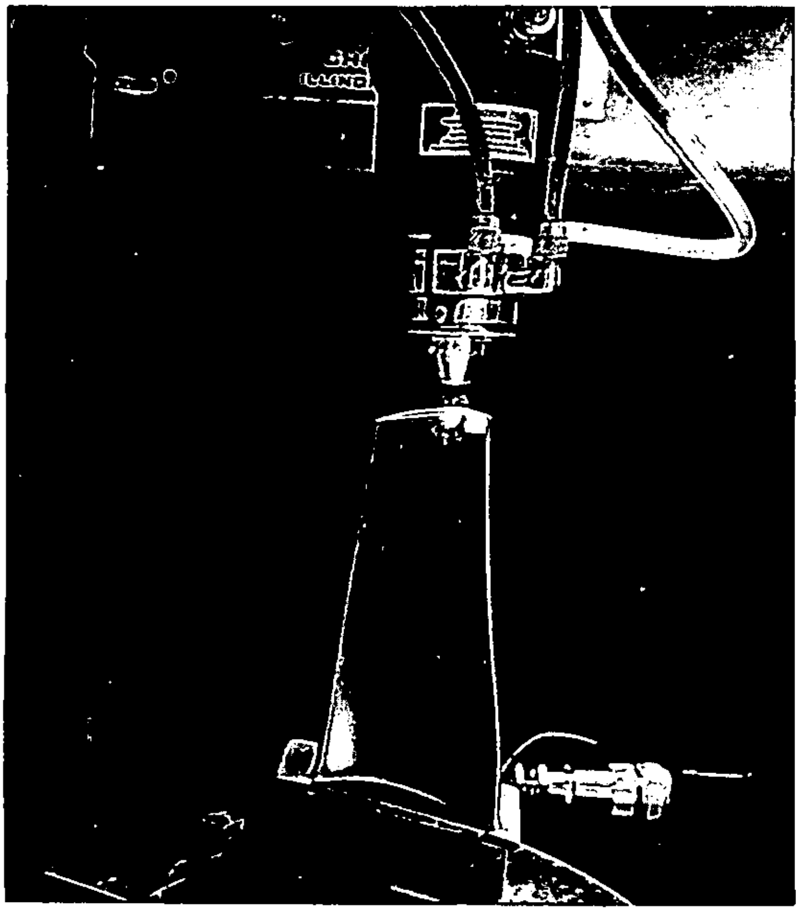


FIGURE 9 – LASER WELDING OPERATION ON A BLADE TIP

TABLE 2 – AVERAGE OF THE MECHANICAL TEST RESULTS

ROCKWELL HARDNESS TEST	
UDIMET 520 BASE MATERIAL	35 HRC
INCONEL 625 WELDED MATERIAL	30 HRC
UDIMET 520 WELDED MATERIAL	34 HRC

STRESS RUPTURE TEST TEMPERATURE: 802 °C STRESS: 345 MPa			
	TIME (hours)	ELONGATION (%)	REDUCTION OF AREA (%)
UDIMET 520 BASE MATERIAL	125	7.0	8.0
INCONEL 625 WELDED MATERIAL	73	6.5	7.0
UDIMET 520 WELDED MATERIAL	118	6.5	6.0

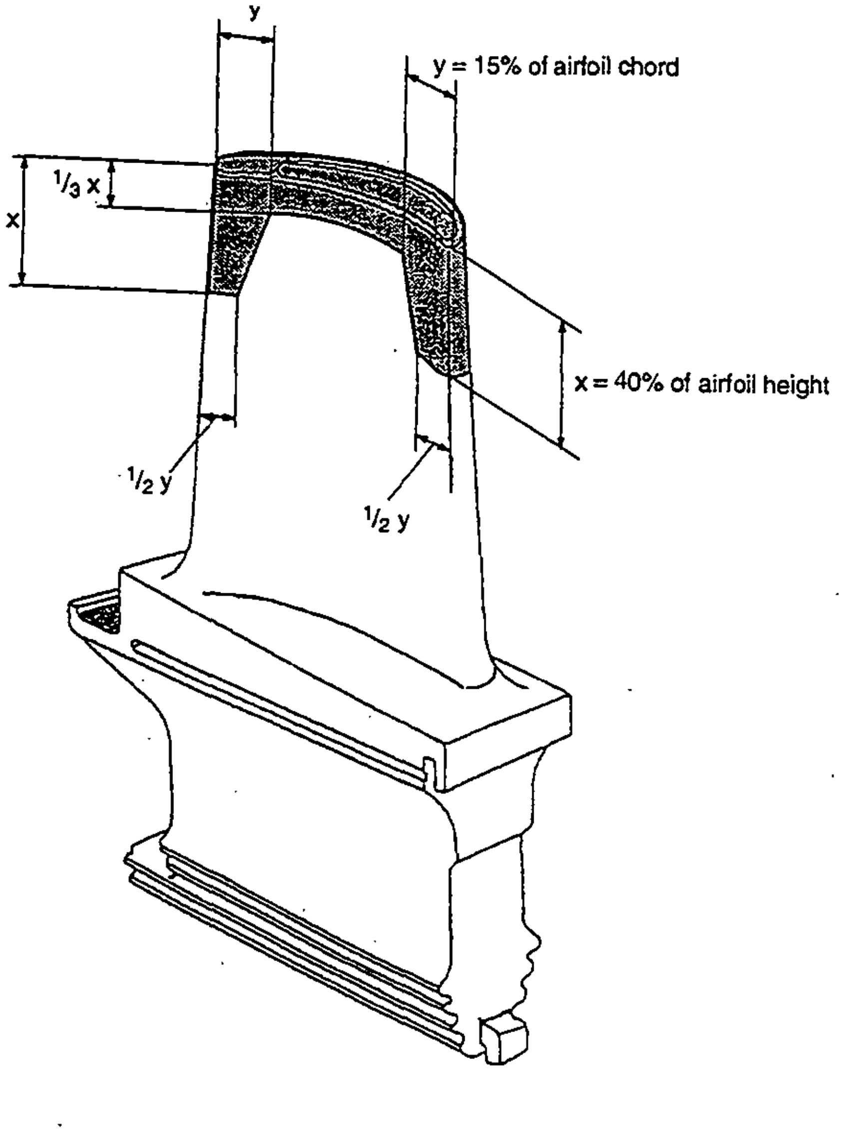


FIGURE 10 – SKETCH OF WELDING REPAIR LIMITS