# Optimizing the quality of TA6V and Inconel laser welding on airplane part manufacturing.

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**Abstract**

Aircraft manufacturing requires a very high quality of welded joints, that is a minimum to no porosity, no cracks, no surface oxidation on materials such as titanium alloys and stainless steels. CLFA tackled this problem to reach this goal for a 4 mm thick plates of TA6V and INCO718. In a first stage, we analyse the gas protection optimization in order to minimize the oxidation during cooling. Then, we present the experiments and results on welding parameters optimization. We use two types of laser sources : YAG and CO2 in order to compare the behaviour of the welded part against the wave lengths and energy distribution profile of the two sources. For each laser type, we apply two energy distributions: a conventional focusing system and a dual or lengthened spot disposal. Thus the welding conditions are dramatically modified.

## Introduction.

Achieving laser welding on stainless steels as INCONEL 718 or titanium alloy as TA6V offers valuable industrial prospects. Nevertheless, these types of welds are subject to severe welding criteria for the aeronautic applications (no porosity, no cracks, geometrical constraints…) and, thus, are difficult to respect. Nowadays, in the aeronautic industry, a number of CO2 laser welds of 2 or 3mm thickness assembles can be found. Using a YAG laser for those ranges of thickness requires a continuous source in adequate power range, which is quiet recent. It is now obvious to evidence the gain in robotics applications for fibered YAG laser against CO2 laser, especially for complex 3D mechanical parts. So, it seems interesting to compare the performances and quality of welds for both YAG and CO2 lasers. Moreover, seeking on optimizing the quality of welds, we investigate the twin spot system on YAG and CO2. Thus, we perform a double comparison : YAG and CO2 laser and single spot and twin spot aligned along the joint.

## Experimental Setup

### *The materials*

The proposed materials to investigate are both widely used in aeronautic applications, that is Inconel 718 and TA6V. Main components of turbines, fixed and rotating parts which require a high level of confidence in welds , are made of these two materials. The analysis of Inconel 718 and TA6V are given in the table hereafter:

| **TA6V** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **C** | **$H^2$** | **$O^2$** | **N2** | **Fe** | **Mg** | **Al** | **V** | **Ti** |
| 0.01 | 0.02 | 0.27 | 0.01 | 0.04 | <0.01 | 5.72 | 4.17 | solde |

| **INCONEL 718** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Cr** | **Fe** | **Ni** | **Nb** | **Mo** | **Ti** | **Al** | **Si** | **Mn** | **Co** |
| 0.21 | 0.21 | 0.46 | 0.05 | 0.03 | 0.01 | 0.007 | 0.0035 | 0.0035 | 0.01 |

All the trials were made on samples of 3 and 4 millimeters thickness.

## Yag & CO2 laser characterization

### *YAG laser characterization*

The YAG laser used for this part of trials is a Trumph HL4006D, delivering a continuous laser beam up to 4kW on the sample. The laser is fibered by a fiber of 600 microns diameter. The focusing head has a focal lenght of 200 millimeters, which allows to obtain either one 600 microns focal spot, or two 600 microns focal spots at an inter-distance of 600 microns. The total energy is equally split on the two spots. Figure 1 illustrates the two focal head configurations. Figure 2 shows the energy profiles at focus of the two configurations.

Figure 1: mono and twin spot Yag focusing head

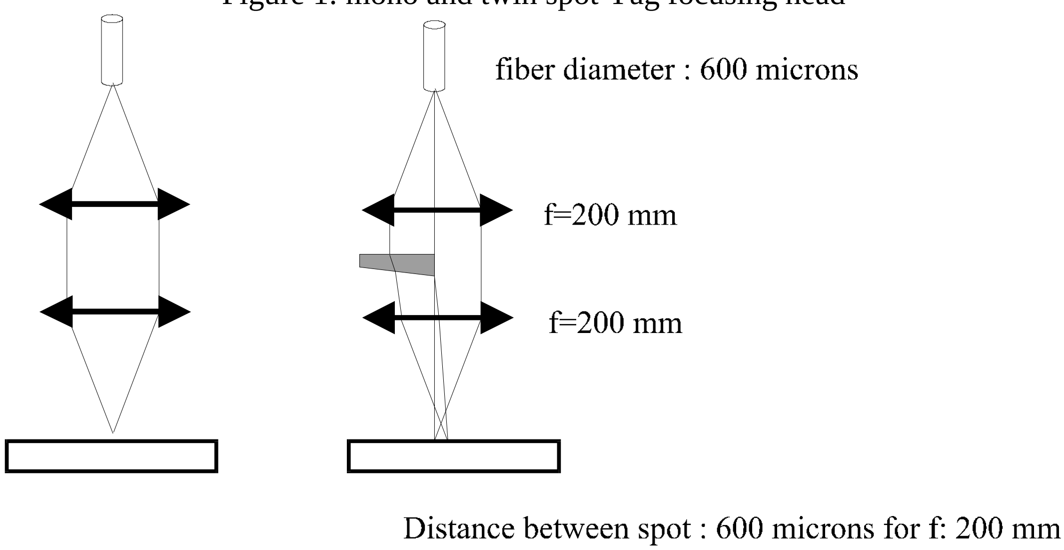



Figure 1: mono and twin spot Yag focusing head

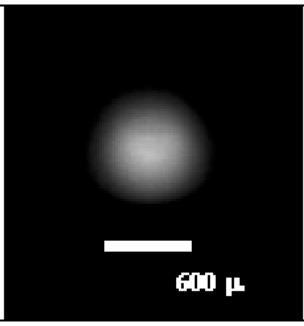
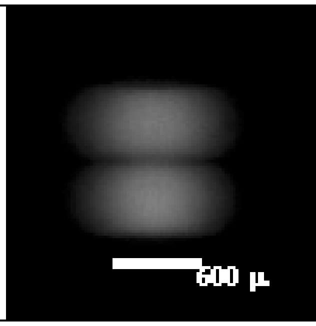
| <br> | <br> |
|---|---|
| Mono-spot configuration | Bi-spot configuration |

Figure 2: mono and twin spot Yag beam analysis.

### *CO2 laser characterization*

The CO2 laser used is a UTIL, providing a continuous beam up to 20 kW. For the considered thickness, the maximum power has been fixed to 8 kW. The focusing head consists in a parabola of 300 mm working distance, allowing a focal spot of less than 200 microns diameter. A twin-like spot is obtained by the use of a prismatic mirror. The resulting spot is 200 by 800 microns. So, the chnage from single to bi-spot is obtained by using a planar mirror or a prismatic mirror.

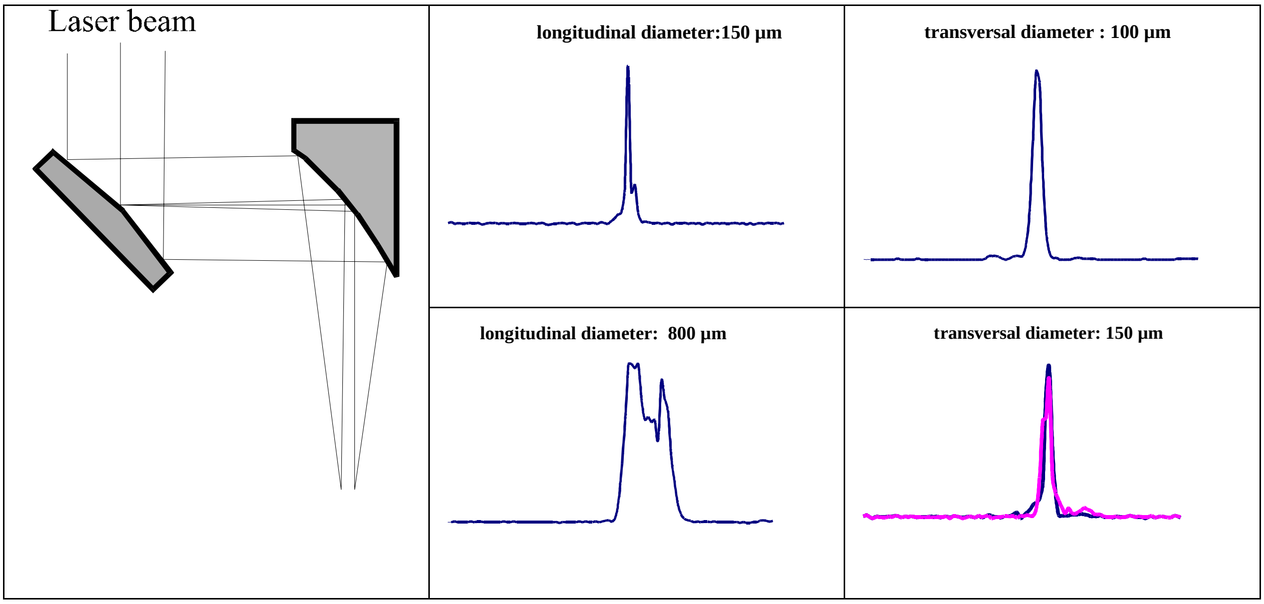



Figure 3: CO2 focusing head and mono and twin spot profiles

### *Gas shield characterization.*

A critical aspect on welding Titanium alloy or stainless steel is the gas protection against oxidation. The use of Helium as gas shield allows both to confine the plasma and to avoid superficial oxidation. A simple gas shield nozzle, from those widely used for regular stains welding, doesn't allow to protect perfectly the melting pool from oxidation.

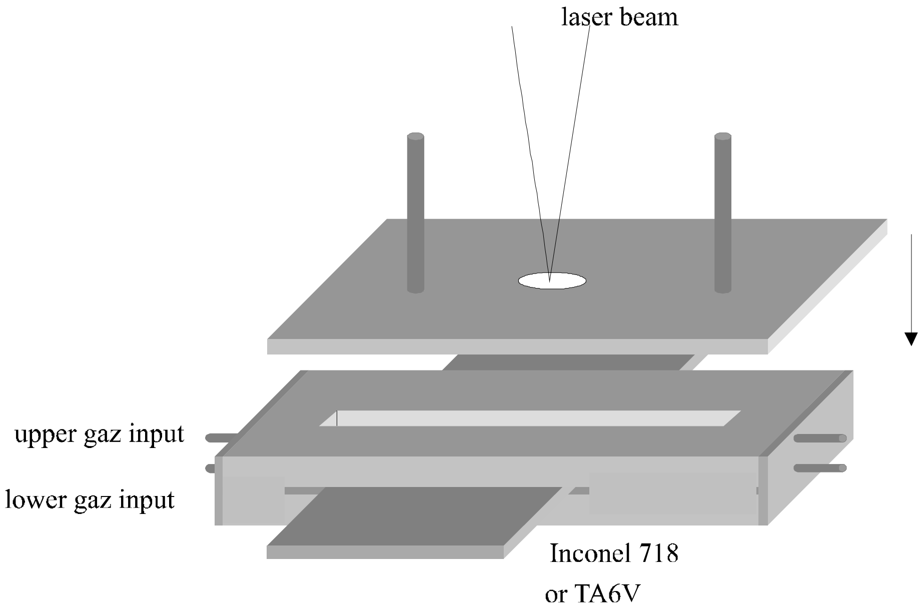


Figure 4: gaz shield configuration

The gas protection must be applied during the welding process and the cooling of the part. Thus, a closed box around the part insures a good protection on both sides of the planar parts to weld. Of course, this solution must be adapted to the geometry of the parts in case of industrial application. The figure 4 presents the existing system. The gas is delivered at the top and at the bottom of the box. Gas flows are accurately tuned to minimize porosity and insure a good protection.

## CO2 Results.

Trials have been achieved for a 4mm thickness for TA6V and Inconel 718. The acceptability criteria of the weld are :

- Geometry of the welds (width of the upper side, minimal width of the bottom side)
- Absence of superficial and visible oxidation
- Absence of porosity and crack.

### *Inconel 718*

From the cracks and porosity point of view, after radiography, all the trials with the CO2 laser or single or twin spot show good results. The main difference is the modification of the geometry of the welds. Actually, for the single spot configuration, only the trials corresponding to a low speed tuning (1 m/mn) show an acceptable minimal width. On the other side, using a twin spot configuration allows to obtain an acceptable geometry of the welds for nearly all the welding conditions. At maximum power, the trials of up to 3m/mn guarantee a minimum width from 1mm and more.

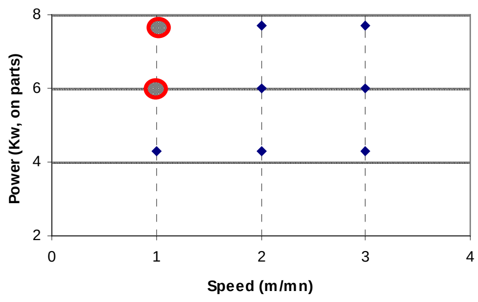



Figure 5a: Mono spot configuration results.
(circled : good results)

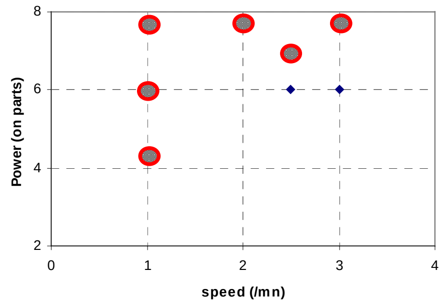



Figure 5b: Twin spot configuration results.
(circled : good results)

Figure 6a: Mono-spot : V 3 m/mn
P 7.7 kW
Thickness : 4 mm

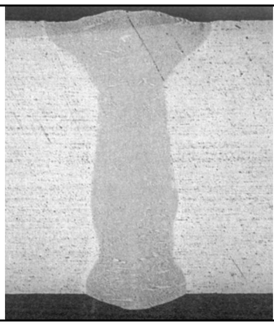


Figure 6b: Bi-spot : V 3m/mn
P 7.7 kW
Thickness : 4 mm

***TA6V.***

For the TA6V, all the trials, either single or twin spot, are correct from the porosity point of view after the metallographic analysis. And again, only the geometry of the weld shows significant differences between the samples. Using a twin spot leads to enlarge the minimal width of the weld. All the welds made with a twin spots, on the TA6V, show acceptable geometrical characteristics.

***Conclusion on CO2 results.***

Using a twin spot system strengthens the quality of the welds, more particularly from the geometrical point of view. The twin spot system allows to obtain similar results at higher speed from those obtained with a lengthened spot [2][3][4]. This effect may result of the reduction of velocity of the induced melt flow when elongated focal spot are used [1]

## YAG results

The YAG trials have been made with a continuous source of 4 kW maximum. This power doesn't allow to obtain significant results on 4mm samples. A 6kW source is needed to weld properly such a thickness.

This power limitation doesn't allow to obtain full penetration welds for every welding condition. The figure 7 sums up the used parameters for the trials we made, identically for a single or twin spot configuration.

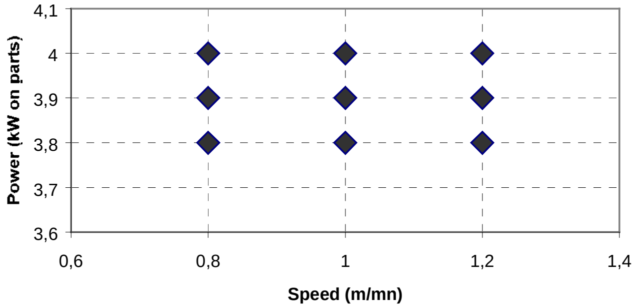



Figure 7: Experimental conditions for mono and twin spot Yag welding.

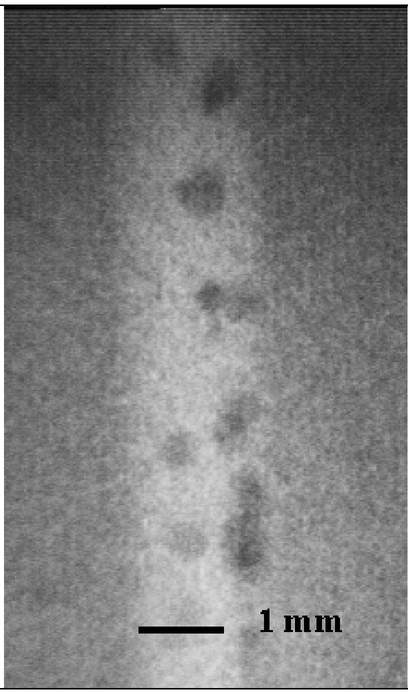
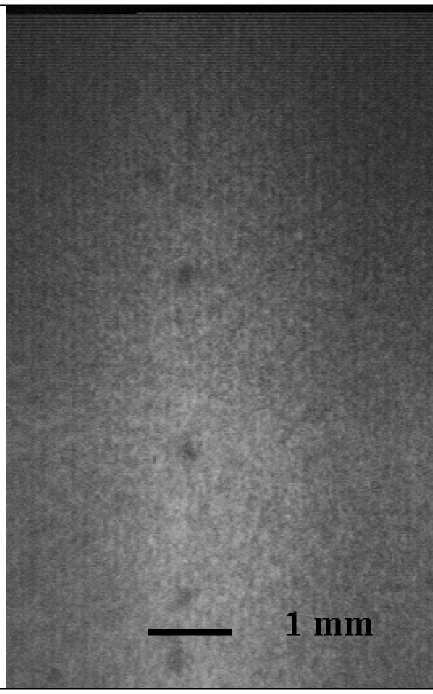
***Inconel 718.***

After radiographic analysis, the results on single spot exhibit a string of porosities up to 0.5mm diameter for every welding conditions. The upper width of the weld are between 3mm (at a welding speed V:1.2m/mn) and 4 mm (V: 0.8 m/mn). The minimal width are between 0.9 mm (V: 1.2 m/mn) and 2 mm (V: 0.8 m/mn).

The table 1 presents some measurement made on the radiographs.

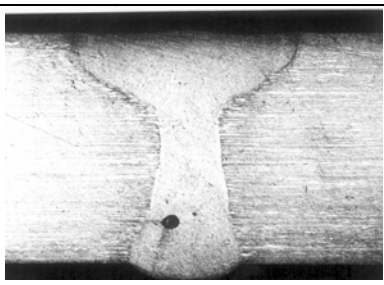
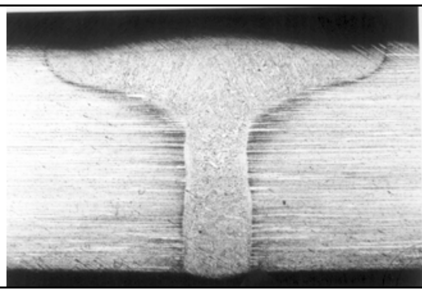
| | | Mono Spot Configuration | | Twin Spot Configuration | |
|---|---|---|---|---|---|
| | Welding conditions | Number of porosity<br>D: diameter of porosity | Equivalent surface of all the porosities | Number of porosity<br>D: diameter of porosity | Equivalent surface of all the porosities |
| 1 | 1m/mn<br>3.8 kW | 53,<br>.2 mm<D<0.5 mm | 5 $mm^2$ | 23<br>D < 0.1 mm | 1.1 $mm^2$ |
| 2 | 1.2m/mn<br>3.8kW | 43,<br>.2 mm<D<0.5 mm | 4.1 $mm^2$ | 10<br>D < 0.1 mm | 0.5 $mm^2$ |
| 3 | .2 m/mn<br>3.9 kW | 30,<br>some porosity D 0.5 mm<br>Mainly<br>0.2mm <D<.3mm | About<br>1.5 $mm^2$ | 12<br>D < 01 mm | 0.5 $mm^2$ |

Table 1: Comparisons of number of porisities between mono and twin spot configurations

| | |
|---|---|
|   |   |
| Figure 8a: Porosities on radiograph, Mono spot 1m/mn, 3.8 kW | Figure 8b: Porosities on radiograph, Bi- spot 1m/mn, 3.8 kW |

In the twin spot configuration, the decrease of the power density doesn't allow to obtain full penetration welds from a 0.8 m/mn speed. Unfortunately, the current power limitation doesn't allow to explore the complete range of solutions for porosity suppression.

The geometry of the welds is very different between the single and twin spot configuration. Using twin spot, the upper side of the weld is very large (up to 9-10 mm), and 1 mm for the back side. We don't have yet an interpretation to this observation, but it seems to be related to the low power density of the laser beam on the sample.

| | |
|---|---|
|  |  |
| Mono spot V : 0.8 m/mn P 3.8 kW Thickness: 4 mm. | Bi spot V : 0.8 m/mn P 3.8 kW Thickness: 4 mm. |

### *TA6V.*

The trials on TA6V have been made at low speed in order to obtain a complete penetration. With this condition, the TA6V welds tend to exhibit deep undercuts. Solving this problem requires more power from the laser source in order to reach higher speeds.

## Conclusion.

This study demonstrates the interest of using a lengthened spot for the optimization of the welding conditions. The results are particularly significant for the CO2 laser welding, where a twin spot configuration allows to reach higher welding speeds with a valuable quality. Concerning the YAG laser trials of 4mm thickness, the 4kW power source doesn't lead to evidence acceptable results. However, it is clear that the lengthened spot improves the quality of the welds. Thus, the next step is to propose a YAG source coupling (by the juxtaposition of two fibers from two laser sources) which will allow to use a twin spot configuration with higher power density.

## References


1: Dynamical Interpretation of Deep Penetration of CW Laser Welding.
R Fabbro & Al. Proceedings of ICALEO 98.
See Key-hole behavior for deep penetration laser welding.
R Fabbro and K Chouf, . Proceedings of ICALEO 99.
2: Advanced Process for high speed High power Laser Welding
J C Monbo-Caristan. Proceedings of ICALEO 96
3: Parabolic Mirror Adapted Alignmenet for High Speed High Power Laser Welding with an Oblong Focused Beam Spot.
J C Monbo-Caristan. . Proceedings of ICALEO 97.
4: Multi Beam Technique to Increas Power, Flexibility and quality.
F Dausinger, R Hack. . Proceedings of Eclat'96