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TESI DI DOTTORATO

DISK LASER WELDING OF METAL ALLOYS FOR AEROSPACE

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Laser welding is the logical processing solution to accomplish different needs. Improvements at the design stage are actually aimed to remove any mechanical fastening, thus moving towards a technology which would not increase the joint thickness; moreover, a number of benefits in comparison with conventional welding methods are provided when considering laser beams, since deep penetration is achieved and the energy is effectively used where needed, thus melting the interface to be joined rather than excessively heating up the base metal, which would suffer from thermal distortion and degradation of metallurgical properties otherwise.

Further advantages are achieved in laser welding with thin disk sources, since high output power, high efficiency and good beam quality are simultaneously delivered, unlike traditional laser systems; costs are significantly reduced in comparison with lamp-pumped laser systems. As a consequence, specific interest is shown in aerospace where strict specifications apply.

Nevertheless, a number of issues must be addressed, depending on the material to be welded, as many variables and sub processes concerning fusion and vaporization are involved in laser welding and a delicate balance between heating and cooling is in place within a spatially localized volume. Therefore, extensive studies are required to manage both the stability and the reproducibility of the overall process, before introducing any change in industrial environments. Methods, experimental results and discussions concerning laser welding of common metal alloys for aerospace are provided in this Ph.D. thesis.

A general view of applications and basic advantages of laser welding is first given, with mention to diagnostics and safety. Hence, the principles of laser emission are examined, with respect to the architecture of the sources, beam geometry, quality and efficiency, in order to better portray the benefits of a thin disk laser concept.

Processing dynamics of laser welding are explained afterward, referring to conduction and key-hole mode, instability, gas supply and leading governing parameters such as laser power, welding speed, defocusing and beam angle to be considered in the experimental work. Procedures are provided for proper bead characterization, from preliminary examinations including non destructive tests such as fluorescent penetrant inspections and radiographic tests, to sample preparation and eventual mechanical assessment in terms of tensile strength and Vickers micro hardness in the fused zone.

A straightforward description of the design of experiment approach and the response surface methodology is given, so to introduce the testing method to be taken, as well as the steps for data elaboration via statistical tools.

Hence, four case studies about metal aerospace alloys are presented and discussed in their common seam configuration: autogenous butt and overlapping welding of aluminum alloy 2024; autogenous butt welding of titanium alloy Ti-6Al-4V; dissimilar butt welding of Haynes 188 and Inconel 718; dissimilar overlapping welding of Hastelloy X and René 80. All of the welding tests were conducted at the Department of Industrial Engineering at the University of Salerno; a Trumpf Tru-Disk 2002 Yb:YAG disk-laser source with a BEO D70 focusing optics, moved by an ABB IRB 2004/16 robot was employed. When needed, additional tests for the purpose of specific bead characterization were conducted by Avio and Europea Microfusioni Aerospaziali.

As general procedure for each topic, the operating ranges to be examined are found via preliminary trials in combination with the existing literature on the subject. Then, special consideration is given to the processing set-up, the resulting bead profile, possible imperfections, defects and overall features; consistent constraint criteria for optimization of the responses are chosen on a case-by-case basis depending on materials and seam geometry and referring to international standards as well as customer specifications for quality compliance. Optimal combinations of the input welding parameters for actual industrial applications are eventually suggested, based on statistical tools of analysis. Convincing reasons are provided to give grounds to improvements in real applications. Moreover, based on the results, a proper device for bead shielding, to be conveniently adjusted depending on both geometry and materials to be welded has been designed, produced and patented (SA2012A000016).

As concerning aluminum welding, a comprehensive description is given for laser-related issues: reflectivity and thermal conductivity influence on the material response is illustrated; the porosity evolution is discussed with respect to thermal input and defocusing; a theory for softening in the fused zone is provided through energy dispersive spectrometry and estimations of magnesium content in the cross-section. Optimization is performed for butt configuration of 1.25 mm thick sheets;

the discussion about the interactions among the governing factors is deepen with reference to overlapping welding.

With respect to titanium welding, optimization is performed for 3 mm thick butt welding; the resulting micro structure in the weld is discussed since it is thought to be closely related to the mechanical properties. In particular, special care is taken of the grain size as a function of the governing factors.

Dissimilar welding of super alloys is considered for gas turbine components; for this specific purpose, laser welding is expected to offer a valid alternative to arc and electron beam welding, whose weaknesses are pointed out. Given their actual application in the engine, Haynes 188 and Inconel 718 are examined in butt welding configuration, whilst an overlapping geometry is preferred for Hastelloy X and René 80. Considerable tolerances are matched, thus promoting the suggested range of the operating variables.