AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Design and Production Engineering

Assessment of Stainless Steel 316 Joints Welded by Laser

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Mechanical Engineering

(Design and Production Engineering)

by

Ayman Magdy Mahmoud Morsy

Bachelor of Science in Mechanical Engineering
(Design and Production Engineering)
Faculty of Engineering, Ain Shams University, 2012

Supervised by

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Prof. Khalid Mahmoud Abd El-Ghany

Cairo - (2019)

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(14/4/2019)

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Statement

This thesis is submitted as a partial fulfillment of Master of Science in Mechanical Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Summary

Continuous wave diode pumped Nd:YAG laser was applied for welding of AISI 316L Stainless steel. Butt joint Sheets of 1.5mm thickness and 30mm width were joined together in a single pass without using filler material. Design of experiment is applied to investigate the effects of laser power, welding speed, and focal point position on fusion zone profile and the type of shield gas on the microstructure of the weld. Metallography, EDX analysis and mechanical properties including tensile strength and microhardness were investigated. The expected solidification mode according to WRC curve was Ferrite-Austenite (FA). The microstructure showed that most of the solidification was FA and the rest is Austenite- Ferrite (AF) mode of solidification. The depth of penetration is directly proportional with the laser power and inversely proportional to the welding speed. Maximum penetration depth was 753 µm at zero focal point and 602 µm at subsurface focal point. The tensile strength is directly proportional with the laser power. Maximum tensile strength is 632 MPa. Ductile fracture is revealed by SEM analysis. The average value of Microhardness of the weld when using nitrogen gas is 259 HV and by using argon gas is 275 HV while the average of the base metal reached 225 HV, this is because of the presence of different phases in weld metal from base metal.

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Abbreviations

Abbreviation	**Description**
LBW	Laser Beam welding.
Nd:YAG	Neodymium-doped yttrium aluminum garnet.
PW	Pulsed wave
CW	Continuous wave
HAZ	Heat Affected Zone
ANOVA	Analysis of variance
WRC	Welding research council
FN	Ferrite number
Yb	Ytterbium
SEM	Scanning Electron Microscope
EDX	Energy Dispersive X-ray Spectroscopy
AISI	American Iron and Steel Institute

Introduction

Welding and other joining techniques are deeply embedded in every engineering field to such an extent that it will be impossible to realize any of the great modern achievements, such as cars, buildings, and transport infrastructure without it. Joining by rivets was not applicable in all applications, so it was substituted by welding, and this was the first leap in joining technology. Because of welding, the increase of productivity of high quality, reduced weight and artistic goods was granted. New advanced materials are now welded efficiently by ultrasonic, laser and electron beam methods, and this open the minds to explore more new ideas and fields of industry.

The availability of lasers has opened new opportunities in industrial applications replacing many conventional welding technologies in the recent 50 years. Laser processes provide higher beam power and quality, which consequently provide higher production rate, great focus ability (because of delivering precise directed energy at the desired beam shape), lower heat input and distortion, improved welding surface finish, and lower residual stress in welding. The key strength of laser beam welding is its ability to produce a weld without defects and with a narrow heat affected zone. Welding by laser also has the potential to produce high weld quality with control of the thermal cycle and flow of fluid in the fusion zone. These benefits are particularly useful when combined with an arc-based welding source into hybrid welding. However, the full benefit of high productivity can be used only if high quality is also achieved. Various researches of welding in different fields have demonstrated the high complexity of laser and hybrid laser welding.

To develop a reliable welding process a comprehensive understanding of fundamental laser material interaction phenomena is required. Despite many potential benefits of laser technology, heavy industry is still reluctant in using it, seeing lasers as complicated, energy consuming and unreliable. This is particularly due to the high percentage of sensitivity of the process to the variation of gap between joined faces, the difficulties with achieving consistent mechanical properties and the required high complex standards. Laser welding is often attributed with the complicated phenomena that occur when the beam of laser interacts with the material, control of which can be cumbersome.

Flexibility is a featured character of laser where transmitting energy can be achieved effectively to the workpiece. For example, it can be focused to a large beam diameter, providing a moderate power density and a large processing area for surface treatment or brazing. Alternatively, it can be focused to a very small beam diameter of tens of microns, providing a high-power density and causing an intense evaporation of material. Laser keyhole welding or cutting are applied by small beam diameter. The same laser beam has the ability to affect the materials in various ways, which depends on many parameters, such as absorption conditions and energy density. This, on one hand, demonstrates the versatility of lasers and can be easily share in many processes, such as micro-joining, marking, hardening, brazing, deep penetration welding and cutting. However, the number of variables, which can affect the resultant welds, makes the process difficult to control.

Welding by laser can achieve joints with relatively deep penetrations, as compared to the traditional arc-based processes. Penetration height is the main parameter that users wish to control, to accommodate a thickness. Typically, the depth in laser welding varies between a fraction of millimeter and tens of millimeters, depending on the applied conditions. Since many parameters can affect the achieved depth of penetration, a lot of effort is required to select the optimum values of different parameters for a process to maintain a stable process. If we consider resonation power and travel speed, equal ranges of penetration depth will be available with many combinations of these parameters.

However, each combination of the travel speed and the resonation power will result in different weld profiles, despite the same depths of penetration. Thus, it can be deducted that the applied laser parameters are directly reflected on the mechanical characteristics of the resultant welds, which should be considered when selecting parameters for an application.

Austenitic stainless steels are one of the materials that have a countless uses and applications in different fields of the industry, especially in power generation, transportation, and the petrochemical industries because they have high welding characteristics and high service performance. Stainless steel is chosen in manufacturing of the components that work under high temperature conditions because of they have high resistance to oxides formation and sufficient strength against creep. Austenitic steels mainly contain 16 to 26% percent chromium and up to 35% nickel, and this make them have the highest corrosion resistance. 316L grade is one of the main types that has high immunity from sensitization, and it is resistant to pitting and crevice corrosions in environments that consist mainly of warm chloride and to stress corrosion cracking above 60 ^{o}C. It has a good oxidation resistance up to about 900 ^{o}C in continuous work. 316L stainless