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LASER BEAM WELDING EFFECT ON THE MICROHARDNESS OF WELDING AREA OF 304 STAINLESS STEEL & LOW CARBON STEEL

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Abstract

During laser beam welding focused high-capacity laser beam moved over the seam of the parts to be welded. The high intensity of the laser beam causes both parts to highly melt. In the melting bath a so-called keyhole formed, which enables the deep penetration of the laser beam. The melting bath solidifies quickly after the laser beam has passed, where strong connection with good metallurgical characteristics is the result.

For this research, the laser sources applied for laser welding are mainly the CO2 laser. This research aimed to an attempt to investigate the microhardness changes of the welding area to unsimilar metals and which occur during the welding processes between unsimilar metals (304 stainless steel & low carbon steel), where the surface of laser beam welding offers deepness up to (3mm), The variables studied, which may have an effect on the welding processes, discussing the relationship between the welding parameter and Microhardness of welded joint and explaining the major effected of these variables (power) on the welding area.

Keywords: Laser Beam Welding; Unsimilar Metals; Microhardness; Welding Area; And Power.

Introduction

The history of joining metals goes back several millennia, with the earliest examples of welding from the Bronze Age and the Iron Age in Europe and the Middle East. The Middle Ages brought advances in forge welding, in which blacksmiths pounded heated metal repeatedly until bonding occurred. In 1540, Vannoccio Biringuccio published De la pirotechnia, which includes descriptions of the forging operation. Renaissance craftsmen were skilled in the process, and the industry continued to grow during the following centuries [1].

Welding is a fabrication process that joins materials, usually metals, by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material (the weld puddle) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work pieces to form a bond between them, without melting the work pieces.

Until the end of the 19th century, the only welding process was forged welding, which blacksmiths had used for centuries to join metals by heating and pounding them. Arc welding and oxyfuel welding were among the first processes to develop late in the century, and resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electro slag welding. Developments continued with the invention of laser beam welding and electron beam welding in the latter half of the century. Today, the science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties [1, 2].

Arc welding many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in outer space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, eye damage, poisonous fumes, and overexposure to ultraviolet light.

During the middle of the century, many new welding methods were invented. 1930 saw the release of stud welding, which soon became popular in shipbuilding and construction. Submerged arc welding was invented the same year, and continues to be popular today. Gas tungsten arc welding, after decades of development, was finally perfected in 1941, and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases.

Other recent developments in welding include the 1958 breakthrough of electron beam welding, making deep and narrow welding possible through the concentrated heat source. Following the invention of the laser in 1960, laser beam welding debuted several decades later, and has proved to be especially useful in high-speed, automated welding. Both of these processes, however, continue to be quite expensive due the high cost of the necessary equipment, and this has limited their applications.

But in fusion welding subjects the metal to quite a severe thermal treatment and one in the objects of the welding procedure is to ensure no significant damage occur , a strain cycle accompanies the thermal cycle , and it's a combination of embitterment with tensile strain that represent the most serious hazard .metallurgical changes take place in the weld pool and in the high , intermediate and low temperature regions of heat effected zone and it will be convenient to discuss these for regions separately [3].

This research is an attempt to investigate the microstructural changes of the welding area and which occur during the welding processes between two metals (stainless steel & low carbon steel), where the surface of laser beam welding offers deepness up to (3mm), We will study the variables, which may have an effect on the welding processes, discussing the relationship between the selected technique of welding and the microstructure of welded joint and explaining the major effect of these variables on the welding area and finding the effect of microstructure for the welded part on the welding efficiency.

Most stainless steels are considered to have good weldability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean. The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful in welding. Less welding heat is required to make a weld because the heat is not conducted away from a joint as rapidly as in carbon steel. In resistance welding, lower current can be used because resistivity is higher. Stainless steels which require special welding procedures are discussed in later sections [3-6].

Welding processes such as Gas Metal Arc Welding and Gas Tungsten Arc Welding are commonly used for welding carbon steel, since high localized heat input is important when welding materials with high thermal conductivity. Manual Metal Arc Welding of low carbon steel may be used although the quality is not as good as that obtained with the gas shielded welding processes.

In this study in the experimental part welding unsimilar metals, the variables of the work parameters of laser beam welding such as (speed, flow rate, gas...) are kept constant with changing of (power parameter).

During our field trips as part of an inspection job in generating power stations such as Zawia oil refinery and Mellitah oil gas company many problem had been realized some of them was a kind of corrosion effects in welding joints for heat exchangers, during generating power in these companies they used steam turban or gas turban or together (combine cycle) such as Al-harsha electric station, noted in this stations had heat exchangers to generate power like boiler in steam station, it’s made from small pipes from stainless steel and main body from low carbon steel and joints between them by locally welding processes, the corrosion happen in the welding areas between metals specially in heat effected zone areas, this kind of corrosion usually happened between stainless steel and low carbon steel in welding area specially (Heat Effected Zone) [6-9].

As resulted of the heat applied on welding area in the locally welding processes appears side reaction which is reduction reaction, where the carbon in low carbon steel reduces the chromium in stainless steel to aggregations of carbides. However, the cost is main target for any industry processes, so this study was done to reduce maintenance cost as much as possible by controlled the power parameter in laser beam welding processes to minimizing the carbide formation in the microstructure of welding area [9-11].

Methodology

The laser output power or rate of energy delivery is universally described with the SI unit of power, the watt, which is one joule per second, Laser power is normally monitored from a position near the laser cavity. Otherwise, monitoring and displaying the beam power during welding is an advantage from a quality assurance standpoint [12-16].

Where the laser power is measured close to the laser cavity and the beam is transmitted to the work by a series of mirrors, as can often be the case with CO2 lasers, a small loss in beam power will occur (approximately 3% per mirror) and this loss can gradually increase with the service life of the mirror train [17]. On the other hand. the power Density or Irradiance (I) is important where the unique processing capabilities of the LBW process are due to the extremely high-power densities that it can deliver to the workpiece surface. The laser beam power per unit area at the surface is commonly known as the beam power density or irradiance. The shape of the fusion zone is controlled by the power density. Power density, in W/cm2, is given by the following equation:

$$I=P/A \qquad (1)$$

Where: -

- **A** the area of the focused laser beam at the work.
- piece surface = $(\pi D2) / 4$.

Material selection

304 stainless steel

Austenitic stainless steels find important and manifold applications as construction materials in chemical and petrochemical industries, in oil and gas exploitation, shipbuilding, food and drug processing, and in water purification and distribution systems.

Grade 304 it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. For severely corrosive environments, Type 304L is preferred because of its greater immunity to intergranular corrosion. [7]

Type 304 can be used in the “as-welded” condition, while Type 302 must be annealed in order to retain adequate corrosion resistance. Type 304L is an extra low-carbon variation of type 304 with a 0.03% maximum carbon content that eliminates carbide precipitation due to welding. As a result, this alloy can be used in the “as welded” condition, even in severe corrosive conditions. In many cases it eliminates the necessity of annealing weldments except for applications specifying stress relief. Type 304L has slightly lower mechanical properties than Type 304. Type 304L is an extra-low carbon version of Type

304 that eliminates harmful carbide precipitation due to welding, we note that in table (1) as show:

Table (1). Chemical compositions of 304 stainless steel

Contant	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	Ti	Sn	Fe
%	0.0651	0.5486	0.0033	0.0275	1.6695	8.2114	18.4347	0.1282	0.0480	0.4100	0	0	0.0100	70.4408

Low Carbon Steel

Steel is essentially an alloy of iron and carbon or of iron, carbon and other alloying elements. The carbon content of steel is between 0.16–0.29%. that carbon steel with carbon content between 0.05–0.15% is termed low carbon steel, while those with higher are respectively classified as medium and high carbon steel.

Low steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. therefore, it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large amounts of steel are needed, for example as structural steel. The density of mild steel is 7,861.093 kg/m³ (0.284 lb/in³).

Low carbon steels suffer from yield-point runout where the materials have two yield points. The first yield point (or upper yield point) is higher than the second and the yield drop dramatically after the upper yield point. If a low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop luder bands.

Table (2) Chemical compositions of low carbon steel

Contant	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	Ti	Sn	Fe
%	0.1611	0.2071	0.0059	0.0127	0.8498	0.0260	0.0296	0.0046	0.0012	0.0460	0.0015	0	0	0

The metals are received in form of plate of 10 cm length, 4cm width and 3mm thickness by used low speed with cooling solution to avoid generated temperature and stress concentration during process, the samples section as showing in figure (1):

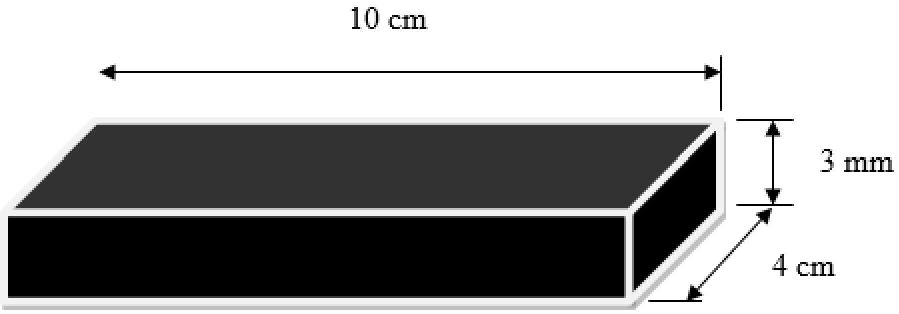


Figure (1). Row material specimen

Experimental and discussions

After used lathe machine to prepare samples, welded it by laser beam welding machine with constant parameters except power, it's changed to found out the best weldability and minimum effect of temperature on welding areas between metals, next table (3) showing the parameters of welding process for best samples were welded. While, the samples were welded, and the internal values is selected depends on the experience.

Table (3). set of samples welded with changed power.

Samples No.	**Power *KW***	**Speed *Mm/min***	**Flow rate *L/Hr***	**Focal Position *(Δz) in mm***	**Gas shielding**
1	2400	*100*	*1500*	-2	N_2
2	2500	*100*	*1500*	-2	N_2
3	2700	*100*	*1500*	-2	N_2
4	2800	*100*	*1500*	-2	N_2
5	2900	*100*	*1500*	-2	N_2
6	3100	*100*	*1500*	-2	N_2

Nondestructive testing (NDT) has been used which is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. It is a highly-valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Nondestructive Examination (NDE) is a general term used in this text to identify methods that permit evaluation of welds and related materials without destroying their usefulness. The majority of prospective weld inspectors already know that visual examination certainly meets this criterion.

In manufacturing, welds are commonly used to join two or more metal surfaces. Because these connections may encounter loads and fatigue during product lifetime, there is a chance that they may fail if not created to proper specification. For example, the base metal must reach a certain temperature during the welding process, must cool at a specific rate, and must be welded with compatible materials or the join may not be strong enough to hold the surfaces together, or cracks may form in the weld causing it to fail. The typical welding defects, lack of fusion of the weld to the base metal, cracks or porosity inside the weld, and variations in weld density, could cause a structure to break or a pipeline to rupture. Welds may be tested using NDT techniques such as industrial radiography using X-rays or gamma rays, ultrasonic testing, liquid penetrant testing or via eddy current and flux leakage. In a proper weld, these tests would indicate a lack of cracks in the radiograph, show clear passage of sound through the weld and back, or indicate a clear surface without penetrate captured in cracks.

- **Visual Examinations**

The most extensively used of any method of nondestructive examination, visual examination is easy to apply, quick, relatively inexpensive, requires good eyesight, and gives important information regarding the general conformity of the weldment to specifications. Visual inspection was performed for all samples and showed some defects as the laser parameters varied, the results and the defect causes are listed in the table (4):

Table (4) The Results of Visual Examination

SAMPLE NO.	**DEFECTS**	**H.E.Z**	**DEFECT'S CUASE**
1	Lack of penetration	Low	Very Low power
2	Acceptable penetration	Acceptable	Low power
3	Good penetration	Acceptable	Good power
4	Full penetration	Big	High power

All laser beam welding sample was found have good penetration specially samples 3, as shown in Figure (2):

Figure (2). Visual Examination of sample 3.

- **Radiographic Test (X-ray)**

The process test was inducted for all samples after welding by using x-ray machine, the radiographic equivalent factors were selected according to metal and the thickness of the samples. The results show some welding defects in some samples and the rest of the samples were acceptable. by used X-ray machine (Andrex smart 300HP) and processes parameters were 100KV power, 3 mA, 70 cm distance between machine head and samples and fillem type was (Agve D5).

Table (5) The Results of X-Ray.

Sample no.	Specification	Defect
1	2500 KW	Undercut
2	2700 KW	Good
3	2800 KW	Good
4	2900 KW	Good

- **Mechanical Tests (destructive testing)**

For any welded product, the determination of the quality of welds depends to a large extent on competent inspection and adequate testing. In general, specifications and codes call out the mechanical tests for weld strength and other weld and HAZ properties to determine the quality of welds and adjacent areas.

The Microhardness Test

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Where these properties depended on microstructure in these metals in carbon content, space between atoms and heat input in welding process. The Micro hardness test procedure ASTM E-384 specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. typically loads are very light, ranging from a few grams to one or several kilograms.

The term Microhardness test usually refers to static indentations made with loads not exceeding 1 kg. The indenter is either the Vickers diamond pyramid or the Knoop elongated diamond pyramid. The procedure for testing is very similar to that of the standard Vickers hardness test, except that it is done on a microscopic scale with higher precision instruments. The surface being tested generally requires a metallographic finish; the smaller the load used, the higher the surface finish required. Precision microscopes are used to measure the indentations; these usually have a magnification of around X500 and measure to an accuracy of +0.5 µms. Also, with the same observer differences of +0.2 µms can usually be resolved.

Microhardness test for low carbon steel side

For low carbon steel side in these samples welded at different power, where sample 1 at 2500 KW, sample 2 at 2700 KW, sample 3 at 2800 KW and 2900 KW for sample 4 and tested in 15 sec by load 200g and started from welding area to base metal(µm), in table (6) see result of sample (1,2,3 and 4):

Table (6) The result of micro hardness test to laser beam welding sample

Distance µm	***Samples 1***	***Samples 2***	***Samples 3***	***Samples 4***
0	190.3	107.3	197.8	198.3
100	192.0	100.7	184.8	204.8
200	179.5	101.0	184.4	195.1
300	177.2	112.4	176.4	195.3
400	162.7	109.9	168.6	188.1
500	157.7	110.8	171.9	184.0
600	154.1	109.9	171.5	183.5
700	152.6	111.0	172.6	187.7
800	146.0	119.0	164.7	187.3
900	151.7	114.7	162.3	186.7
1000	167.2	121.9	159.3	178.4
1100	166.1	----	148.6	182.7
1200	158.3	111.8	148.3	185.2
1300	154.1	119.5	151.7	181.1
1400	158.3	134.3	156.0	178.0

1500	152.6	----	137.7	173.0
1600	158.0	----	159.6	172.3
1700	160.0	142.6	154.8	167.5
1800	155.7	----	----	169.7
1900	----	123.5	----	173.3
2000	----	126.2	159.6	172.3
2100	----	126.0	150.1	----
2200	----	147.2	147.8	----

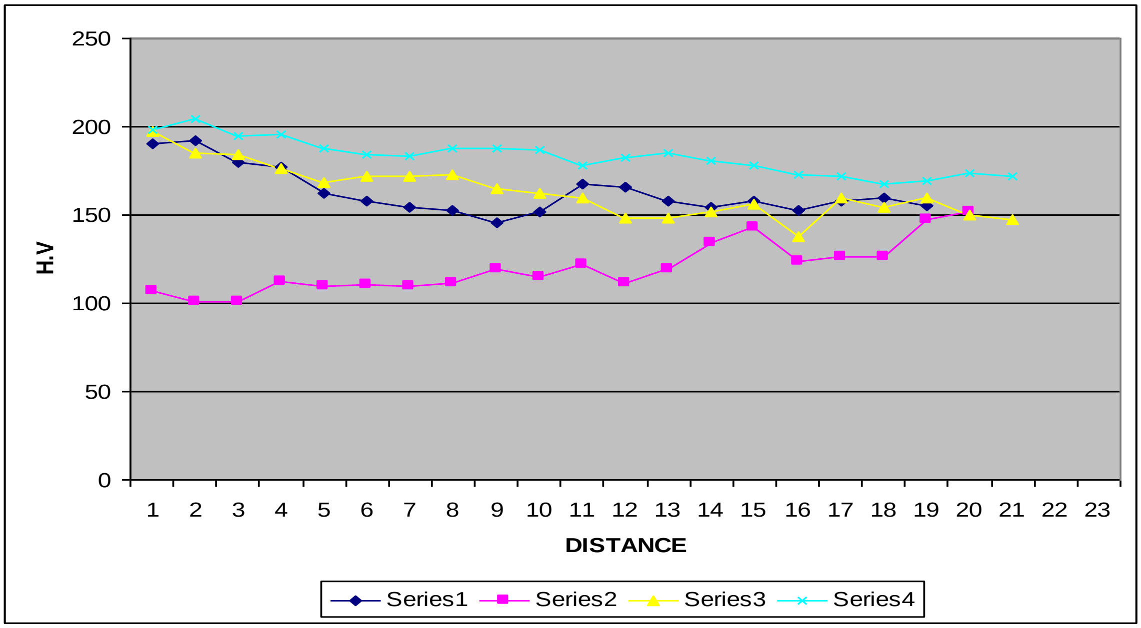


Figure (3) Relationship between distance and HV, sample (1, 2, 3 and 4) for low carbon steel side.

It can be note that the test results of (1. 2. 3 and 4) are in same range started from welding area to base metal between 204.8 in sample 4at power (2900 KW) to 100.7 in sample 2 at (2700 KW), where noted increase hardness in sample with increase in power in welding process.

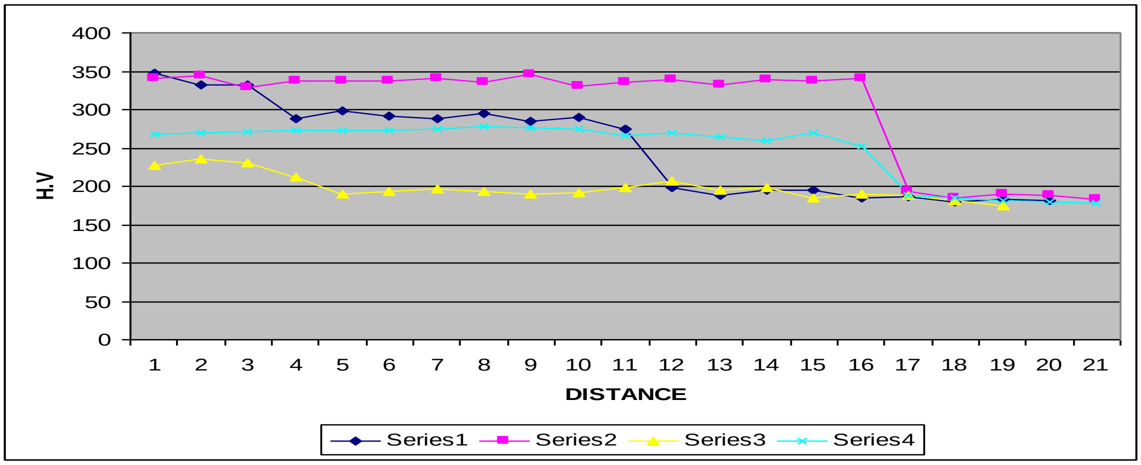
Microhardness test for stain less steel side

From stain less steel side in these samples was welded at power 2500 KW for 1, 2700KW for sample 2, 2800KW for sample 3 and sample 4 at 2900 KW. And testing in 15 sec by 200g, in table (7) we see result of sample (1):

Table (7): The result of micro hardness test to sample 1.

distance(μm)	***Samples 1***	***Samples 2***	***Samples 3***	***Samples 4***
0	346.8	340.6	227.2	267.3
100	331.8	344.7	235.0	270.2
200	332.4	328.9	230.1	271.6
300	288.6	337.5	211.7	273.2
400	297.6	337.5	189.8	273.4
500	291.0	336.5	192.4	272.6
600	287.8	340.6	196.9	275.3
700	295.1	335.4	193.8	277.6
800	285.4	345.8	190.0	276.3
900	290.2	330.5	192.3	275.3
1000	273.9	335.4	198.0	266.6
1100	198.7	338.5	206.0	269.4
1200	188.0	332.4	195.0	265.1
1300	194.6	339.5	197.8	259.6
1400	194.2	336.5	185.1	270.0
1500	184.8	340.6	190.3	252.2
1600	186.4	193.3	187.3	187.3
1700	180.3	184.4	180.7	184.0
1800	183.5	189.4	175.3	181.9

Figure (4). Relationship between distance and HV, laser beam welding samples (1,2,3 and 4) for stain less steel side.



After see the test results of (1. 2. 3 and 4) are started from welding area to base metal between 346.8 in sample 1at power (2500 KW) to 175.3 in sample 3 at (2800 KW), where noted decrease hardness in sample with decrease in power in welding process.

Conclusions

This study is an attempt to investigate the microhardness changes of the welding area for unsimilar metals and which occur during the welding processes between (304 stainless steel & low carbon steel), where the samples thickness was (3mm), length and width were (10cm and 4 cm), the results shown that the Laser beam welding given good joint between unsimilar metals, and with using it in industry applications the joint problems decreasing. Laser beam welding produced a small welding pool and heat effected zone. The excellent appearance of specimen was noted with minimum heat effected zone at power 2800KW. Power parameter has strong effect on welding area specially for unsimilar metals. the response was changed dramatically with changing the power value, so the Power value should be carefully selected. Low carbon steel has hardness less than 304 stain less steel.

For Future research, it can be studying the economic side for the laser beam welding process. in addition, testing and identify the effect of other experimental variables in laser beam welding process such as shielding gas, welding speed, and focus position.

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