LASER WELDING OF SIMILAR STAINLESS STEELS (304/304) AND DISSIMILAR STAINLESS STEEL (304)/CARBON STEEL (A36) ALLOYS

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ABSTRACT

The present study was undertaken to investigate the effect of welding speed on the micro/macro hardness and corrosion resistance of plain-carbon and stainless steels. An extensive study is carried out to investigate the effect of welding speed on the hardness and microstructure of the base metal, heat affect zone (HAZ) and weld metal. An understanding *of the effect of welding speed on the hardness and corrosion resistance would help in selecting conditions required to achieve the best welding quality. Sheets from stainless steels 304 of 1 mm thickness are laser welded. Also, sheets of 1 mm from stainless steel 304 and of and 1.3 mm thickness of plain carbon steel A36, are laser welded. Different welding speed i.e. 50, 80 and 100 mm/sec are applied for welding similar sheets and 65 and 100 mm/sec for welding dissimilar sheets. An extensive study are carried out to investigate the effect of welding speed on the hardness (HV) and corrosion resistance of similar and dissimilar sheets.it is found that, the weld metal has the highest hardness levels in both similar and dissimilar laser welding. Increasing welding speed (50-100 mm/sec) increase the hardness. This can be attributed to the low heat input and high cooling rate produced when using laser welding. Also, tt is found that welding speed can affect the corrosion resistance in the range of 50-100 mm/sec. Increasing speed increases the corrosion resistance in the range of (50-80 mm/sec) following a decrease in the (80-100 mm/sec) range when laser welding of stainless steel 304 alloys.*

Keywords: Laser Welding, Micro and Macro Hardness (HV), Microstructure, Corrosion Resistance, Stainless Steel 304 And Plain Carbon Steel A36

I. INTRODUCTION

Stainless steels are widely used in various industries because of their resistance to corrosion. There is often a need, when fabricating stainless steel structures and/or when incorporating them in other plant, to weld stainless steel to plain carbon or low-alloy steels. In addition, different types of stainless steels often have to be welded to each other. The welding of stainless steels, especially the austenitic grades, is important in energy related systems, for instance, power generation and petrochemical refining systems.

In order to obtain the best performance of such joints, particular attention must be paid to the metallurgy of the weld metal. [1] The ability to form chromium oxide in the weld region must be maintained to ensure stainless properties of the weld region after welding. [2] A major concern, when welding the austenitic stainless steels, is the susceptibility to solidification cracking. The effect of welding on various materials depends upon many of their metallurgical properties such as "hot strength." Materials that have a low tensile strength at temperatures near their melting point are said to exhibit "hot shortness," which often results in cracks appearing in the weld. [3] In cases where fully austenitic welds are required, such as when the weld must be nonmagnetic or when it is placed in corrosive environments that selectively attack the ferrite phase, the welds will solidify as austenite and the propensity for weld cracking will increase. [4]

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and inter-pass temperature, it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ [5]. The effect of heat input on cooling rate is similar to that of the preheat temperature. As either the heat input or the preheat temperature increases, the rate of cooling decreases for a given base metal thickness. Varying the heat input typically will affect the material properties in the weld. These two variables interact with others such as material thickness, specific heat, density, and thermal conductivity to influence the cooling rate.

Cooling rate is a primary factor that determines the final metallurgical structure of the weld and heat affected zone (HAZ), and is especially important with heat treated steels. Higher cooling rates for laser beam welding process (LBW) are often needed to suppress precipitation of harmful intermetallic compounds during the solidification of the weld pool. High cooling rates also help to avoid sensitization during welding of stainless steels. LBW is a modern welding process; it is a high energy beam process that continues to expand into modern industries and new applications because of its many advantages like deep weld penetration and minimizing heat inputs. LBW produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined. As the beam hits the surface of the work, kinetic energy is released and a weld pool is formed. LBW is characterized by its low distortion and low specific energy input. It is an accurate method capable of high welding speeds for most materials, including many difficult-to-join materials. Some manufacturers of cigarette lighters arc now using LBW as an alternative to resistance welding because of the lower porosity produced in laser welds. [6]

In laser welding of similar and dissimilar materials, there is often a need for understanding metallurgy of welding, when fabricating stainless steel structures and/or when incorporating them in other plant, to weld stainless steel to plain carbon or low-alloy steels. In addition, different types of stainless steels often have to be welded to each other. In order to obtain the best performance of such joints, particular attention must be paid to the metallurgy of the weld metal. For this purpose, an understanding of welding metallurgy and effect of different welding speed on hardness, corrosion resistance and microstructure of the base metal, heat affected zone (HAZ) and weld metal positions would help in selecting the conditions required to achieve the optimum mechanical properties and corrosion resistance after laser welding. There are many reports [7] that deal with the shape and solidification structure of the fusion zone of laser beam welds in relation to different laser parameters. However, the effect of all influencing factors of laser welding has up to now not been extensively researched.

The scope of the present work is therefore to investigate the effect of welding speed during laser welding processes of similar and dissimilar materials on the hardness and corrosion resistance as well as the microstructure of base metal, heat affected zone (HAZ) and weld metal positions, and particularly the alloy commercially known Stainless steel 304 and A36. The results of this study will provide a large input to existing data, in particular, by determining the effect of welding speed in both similar and dissimilar laser welding processes on the hardness, corrosion resistance and microstructure of base metal, HAZ and weld metal positions.

II. EXPERIMENTAL PROCEDURES AND METHODOLOGY

In the present study, sheets from stainless steels 304 of 1 mm thickness are laser welded. Also, sheets from stainless steels 304 and plain carbon steel A36 of 1 mm and 1.3 mm thickness, respectively are laser welded. Welding is carried out at different speed i.e. 50, 80 and 100 mm/sec for similar sheets and 65 and 100 mm/sec for dissimilar sheets. Micro- and macro-hardness measurements (HV) are performed on the base, HAZ and weld zones in all specimens with different conditions. Several reading will be taken in the base metal, heat affected zone (HAZ) and weld metal positions. Electrochemical measurements are carried out using Autolab PGSTAT 30. Linear polarization and Tafel plot tests are performed on welded specimens for similar and dissimilar sheets. All potentials will be measured with respect to silver/silver chloride reference electrode (Ag/AgCl).

Samples for metallographic examination are sectioned from the broken impact samples after hot rolling and hot forging (corresponding to each condition), mounted, polished and etched using Nital solution. The microstructure is analyzed using an optical and SEM microscope.

Table 1 Chemical compositions for similar and dissimilar welding alloy sheets used in the present work.

Alloy	C	Si	Mn	P	S	Ni	Cr	N
St. St. 304	0.08	0.75	2.0	0.045	0.03	8.0-10.5	18.0-20.0	0.1
St. 37 (A36)	≤0.2	≤ 0.35	0.6-1.0	0.02	0.008	-----	-----	-----

III. RESULTS AND DISCUSSIONS

3.1. Micro and Macro Hardness (HV) Results

Hardness measurements (micro and macro Hardness HV) were performed on all specimens after laser welding with different conditions. Several reading was taken in the base metal, heat affected zone (HAZ) and weld metal positions. The results are provided in Table 2 and Table 3. All results for micro hardness and corresponding standard deviation are listed in Table 2 and graphically presented in Fig 1 (a). It is observed that the hardness increase in both heat affected zone and weld metal zone as the welding speed increase from 50 to 100 mm/sec. this can be attributed to the low heat input and high cooling rate produced as a result of increasing speed and hence increasing hardness in both HAZ and weld metal. Some readings has fluctuation this return to the microstructure variations effect as the measured done on the micro-hardness scale and measured values may influenced by different phases present in the microstructure of both HAZ and Weld metals.

Similar results for macro-hardness (HV) and their corresponding standard deviation when two sheets of stainless steel and carbon steels are laser welded with different travelling speed 65 and 100 mm/sec are listed in Table 3 and graphically presented in Fig. 1 (b). It is observed that hardness slightly increase in both heat affected zone and weld metal zone as the welding speed increase from 65 to 100 mm/sec, as shown in Fig. 1(b). Again, this can be attributed to the low heat input and high cooling rate produced as a result of increasing travelling speed. Figure 1 show the micro hardness results for different method i.e. similar and dissimilar welding for steels as a function of travelling speed. It is observed from Fig. 1 that the hardness increases when welding speed increases. Also, the smaller HAZ produced and the high level of hardness in the weld metal at 100 mm/sec may be explained on the basis of the low heat input and high cooling rate produced with increasing travelling speed.
Macro hardness results for both similar and dissimilar welding are listed in Table 3. The maximum hardness of 398 HV has been obtained at laser speed of 100 mm/sec for dissimilar welding of stainless steel and plain carbon steel in the weld zone, however at lower travelling speed a significant decrease in hardness observed. On comparison the properties of the base, HAZ and weld, it may be seen that both hardness values of the HAZ and weld zone are higher than the hardness of base metal regardless of the laser travelling speed. Again, the great fluctuation in hardness values in the weld metal zone is due to the microstructure variations in the weld zone.

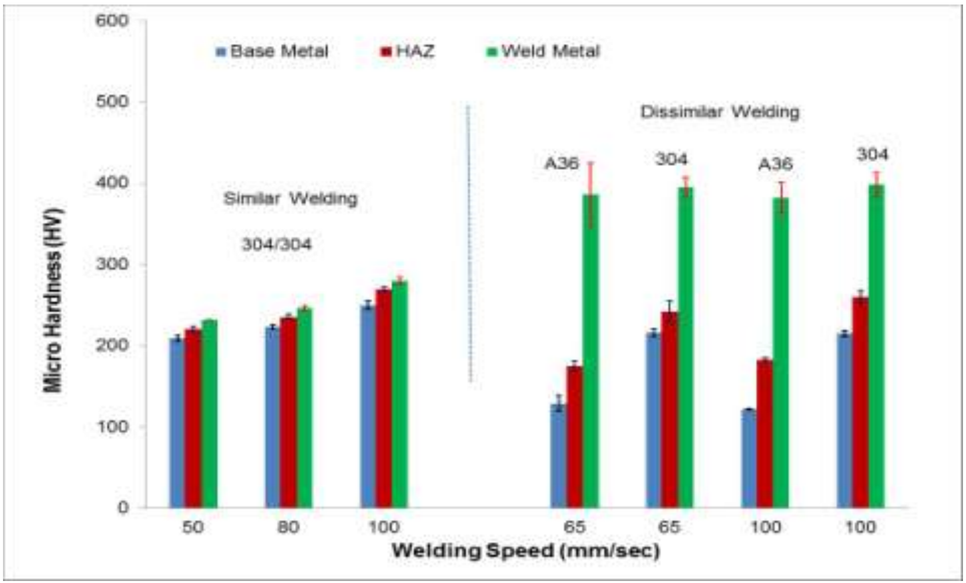
Table 2 Micro-Hardness (HV) results as a function of welding speed for similar and dissimilar welding.

Welding Type	Welding Speed	Location	**Hardness (HV)**		
			Base	HAZ	Weld
Similar Welding 304/304	50 mm/sec	304	209± 4	220 ± 4	232 ± 0
	80mm/sec	304	223 ±2.5	235±3.5	246± 3
	100mm/sec	304	250± 5	269± 3	280± 4.5
Dissimilar Welding 304/A36	65mm/sec	A36	129± 10	175 ± 6	386 ±39
		304	216± 5	242 ± 13	395±12
	100mm/sec	A36	122± 1	182± 3	382± 19
		304	215± 4	260± 8	398± 15

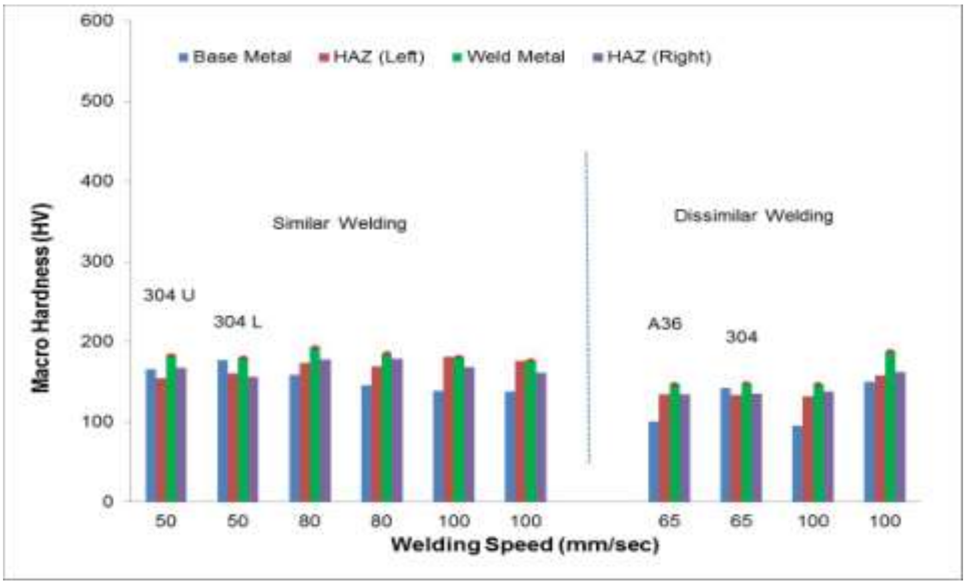
Table 3 Macro-Hardness (HV) results as a function of welding speed for similar and dissimilar welding.

Welding Type	Welding Speed	Location	**Hardness (HV)**			
			Base	HAZ (Left)	Weld	HAZ (Right)
Similar Welding 304/304	50 mm/sec	304 Upper	166	154	183	167
		304 Lower	177	160	180	156
	80mm/sec	304 Upper	159	173	193	178
		304 Lower	146	169	186	179
	100mm/sec	304 Upper	139	181	181	168
		304 Lower	138	176	177	161

Dissimilar Welding 304/A36	65mm/sec	A36	100	134	147	134
		304	142	133	148	138
	100mm/sec	A36	95	132	147	135
		304	150	158	188	162



(a)



(b)

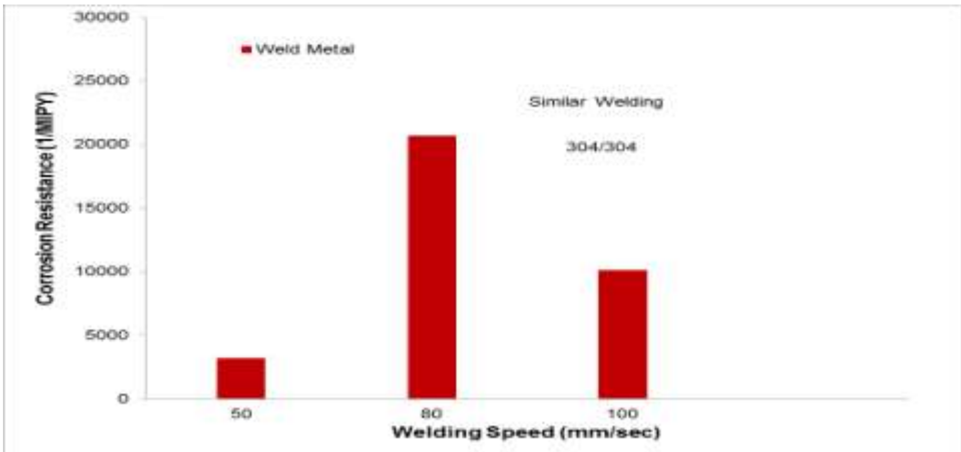
Figure 1 Hardness profile for similar and dissimilar welding in the base metal, HAZ and weld metal when using laser welding speed of 50, 80 and 100 mm/sec for welding stainless steel 304 alloy sheets of 1 mm thickness and 65 and 100 mm/sec for welding stainless steel 304 alloy sheet of 1 mm thickness and plain carbon steel alloy A36 of 1.3mm thickness, respectively (a) micro hardness profile (b) macro hardness profile. N.B location U=upper and L=lower.

3.1.1. Corrosion Resistance Results

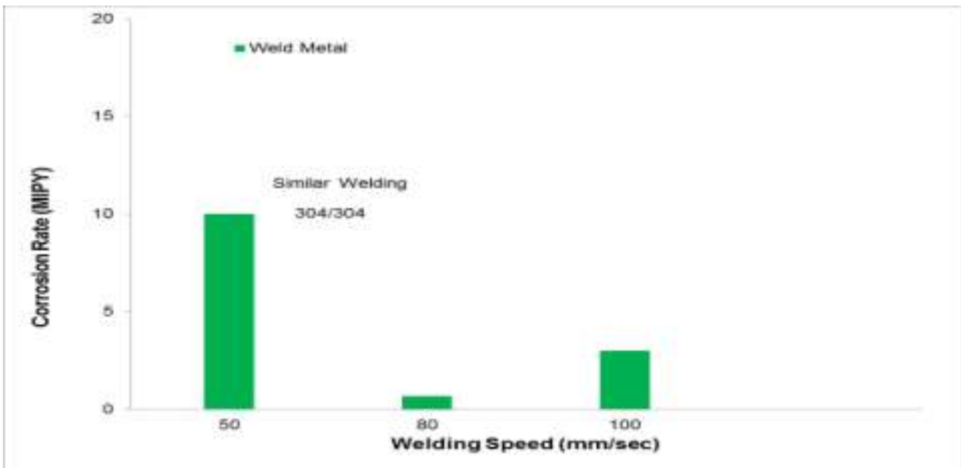
Variation in corrosion behavior as a function of travelling speed for similar welding is shown in Fig. 2. The effect of laser speed (50-100 mm/sec) on both corrosion resistance and corrosion rate is presented in Fig. 2(a, b). Similar behavior is observed in dissimilar welding, the results for both corrosion rate and corrosion resistance are listed in Table 3.

In comparison for 50, 80 and 100 mm/sec travelling speed, the 80 mm/sec exhibit higher corrosion resistance levels than do the 100 mm/sec at similar laser welding of stainless steel 304 alloys. However, the 100 mm/sec show higher micro hardness results than 50 and 80 mm/sec travelling speeds, Fig 1.

It is observed from Fig. 2 that the maximum corrosion resistance is corresponding to the minimum corrosion rate, also increasing travelling speed (50-80 mm/sec) increases the corrosion resistance and following a decrease in corrosion resistance when using 100 mm/sec travelling speed. This can be attributed to the increase in hardness and the variation in microstructure produced at 100 mm/sec travelling speed in the weld metal zone. The fluctuation in hardness values at 100 mm/sec indicates the non-homogeneity or variations in microstructure produced in both heat affected zone and weld metals at 100 travelling speed.



(a)



(b)

Figure 2 Corrosion resistance and corrosion rate of base and weld metal as a function of welding speed for similar welding using laser welding speed of 50, 80 and 100 mm/sec a) corrosion resistance and (b) corrosion rate.

Table 4 Corrosion Resistance and Corrosion Rates for Similar and Dissimilar Welding

Welding Type	Welding Speed	Location	Corrosion Resistance		Corrosion Rate (MPY)	
			W	B	W	B
Similar Welding 304/304	50 mm/sec	304 Upper	3208	23.7	9.8	97.1
	80mm/sec	304 Upper	20650	23.7	0.6771	97.1
	100mm/sec	304 Upper	10110	23.7	3.06	97.1
Dissimilar Welding 304/A36	65mm/sec	A36	26.1	-	1778	-
		304	2699	23.7	9.47	97.1
	100mm/sec	A36	16	-	2338	-
		304	101	23.7	198	97.1

3.2. Microstructure

Structure of the base metal, HAZ/weld metal and the weld metal for different welding speed for both similar and dissimilar welding of stainless and plain carbon steels are shown in Fig. 3 and Fig. 4. Optical micrographs obtained from 304 stainless steel samples for the base metal, HAZ and weld metal when welding speed is 50 and 100 mm/sec are shown in Fig. 3. Similarly, optical micrographs for the base metal, HAZ and weld metal zones when dissimilar materials are laser welded at 100 mm/sec are shown in Fig. 4. EDS Spectrum of different zone for dissimilar welding (carbon steel A36/stainless steel 304) is presented in Fig. 5. Figs. 5 (a-c) show EDS Spectrum in the weld zone/base A36 interface, in the weld zone close to A36 interface and in the half weld zone, respectively. On the other hand, Figs. 5 (d-g) show EDS Spectrum in the weld zone close to stainless steel 304 interfaces, in the interface of weld zone and stainless steel 304, in the HAZ/weld zone stainless steel 304 interface and in the base stainless steel 304, respectively. It is observed that the microstructure of the base metal of stainless steel 304 show austenitic grains. The results in Fig. 5 show that Cr and Ni peaks starts to appear when moving towards stainless steel side, see Figs. 5 (d-g). Optical micrographs obtained from laser welding of dissimilar materials (stainless steel 304/ plain carbon steel A36) show different zones (A, b and C) in Fig 5(h) where the corresponding EDS are shown in Figs 5(a-g).

(a)

(b)

(c)

(d)

Figure 3 Optical micrographs obtained from laser welding of stainless steel 304/304 sheets of 1mm thickness (a) Weld metal at 100X, (b) weld metal+ base metal at 200X. (c) Weld metal at 100X, (d) weld metal+ HAZ+ base metal at 200X. Laser welding speed is 50 mm/sec in (a, b) and 100 mm/sec in (c, d).

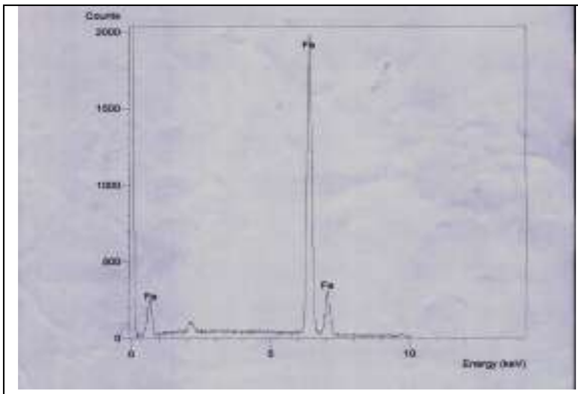
(a)

(b)

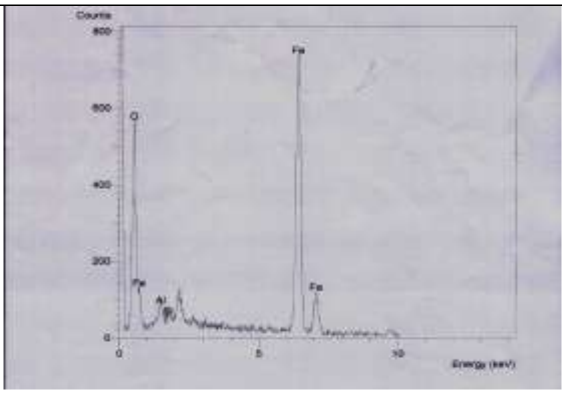
(c)

(d)

Figure 4 Optical micrographs obtained from laser welding of dissimilar materials (stainless steel 304/ plain carbon steel A36, sheet thickness of 1mm and 1.3 mm, respectively) (a) Weld metal for both stainless steel 304 and plain carbon steel A36 at 50X, (b) weld metal for plain carbon steel A36 at 100X, (c) weld metal for stainless steel 304 at 100X and (d) base metal of stainless steel 304 at 200X. Laser travel speed is 100 mm/sec.


Counts
Fe
Energy (keV)

(a)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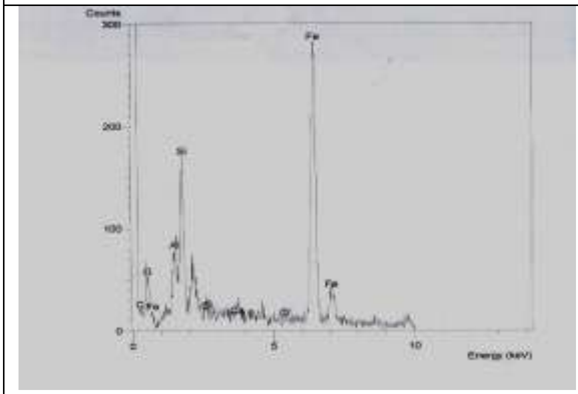
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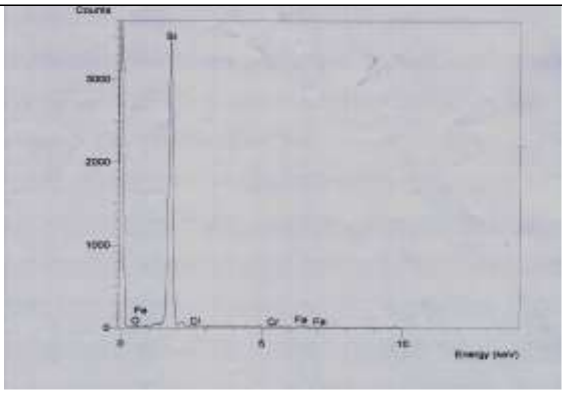
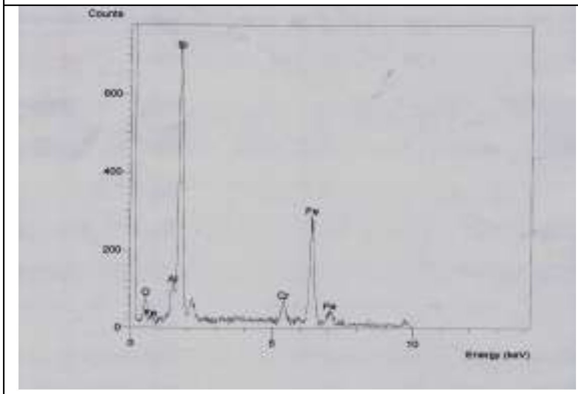
Fe
Si
Energy (keV)

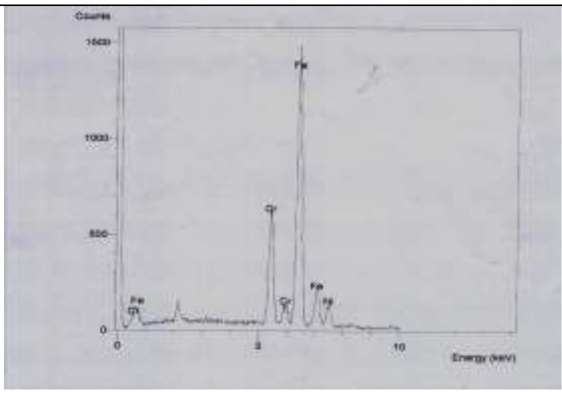
(c)


Counts
Si
Energy (keV)

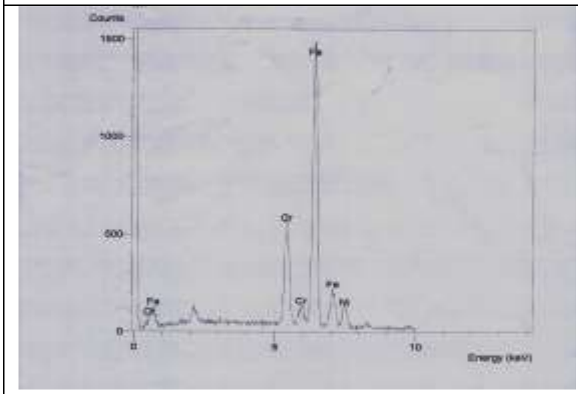
(d)


Counts
Si
Fe
Energy (keV)

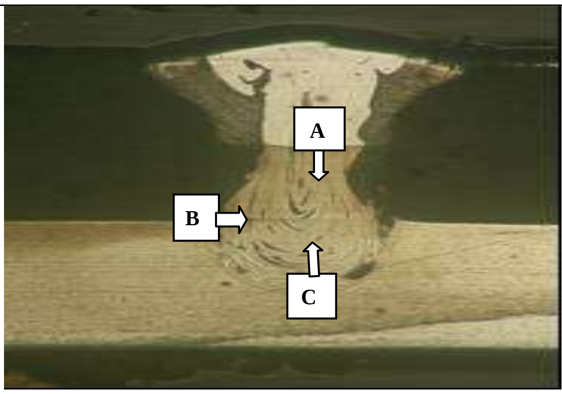
(e)


Counts
Fe
Cr
Energy (keV)

(f)


Counts
Fe
Cr
Energy (keV)

(g)


A
B
C

(h)

Figure 5	EDS Spectrum of different zone for dissimilar welding (carbon steel A36/stainless steel 304) i.e. in the following position; a) In the weld zone/base A36 interface, b) In the weld zone close to A36 interface, c) In the half weld zone, d) In the weld zone close to stainless steel 304 interface, e) In the interface of weld zone and stainless steel 304, f) In the HAZ/weld zone stainless steel 304 interface and g) In the base stainless steel 304. (h) Optical micrographs obtained from laser welding of dissimilar welding of (stainless steel 304/plain carbon steel A363 sheet thickness of 1mm and 1.3 mm, respectively), Welding laser speed= 65 mm/sec and Magnification 50X. A=A36 weld zone, B=A36/304 Interface and C= 304 weld zone.

IV. CONCLUSION

1. Increasing laser welding speed (50-100 mm/sec) increase the hardness of the weld metal and heat affected zone (HAZ). Low heat input and high cooling rate is produced when using laser welding with increasing speed.
2. Increasing laser welding speed from 50 to 80 mm/sec increases the corrosion resistance. However, speed in the range of (80-100 mm/sec) decrease the corrosion resistance when laser welding of stainless steel 304 alloys.
3. The weld metal has the highest level of hardness in both similar and dissimilar welding by using laser welding.

ACKNOWLEDGMENT

In-kind received support from Corrosion Control and Surface Protection, Metals Technology Department, at Central Metallurgical Research and Development Institute (CMRDI), EGYPT is gratefully acknowledged. Financial and in-kind received support from the Deanship of Scientific Research, Vice Rectorate for Post Graduate and Scientific Research, Salman bin Abduaziz University (SAU) is gratefully acknowledged. This project was supported by the deanship of scintfic research at SAU under the Research Project #. 2300/01/2014.

REFERENCES

[1] R. D. Medlock, “Qualification of Welding Procedures for Bridges: An Evaluation of the Heat Input Method”. PhD Thesis, University of Texas, May 1998.

[2] Welding Handbook, Vol. 4, 8th Edition. American Welding Society, pp. 43-45, 1998.

[3] E. Seaman, "Role of Shielding Gas in Laser Welding," Technical Paper No. MR7, 982, Society of Manufacturing Engineer Dearborn, Michigan, 1977.

[4] T. Rockstroh and J. Mazumder, J. Appl. Phys., Vol 61 (No. 3), p 917-923, 1987.

[5] J. Mazumder, “Laser Welding, Laser Materials Processing,” M. Bass, Ed., North Holland, Amsterdam, p II 3-200. 1983.

[6] J.E. Harry, “Industrial Application of Lasers,” McGraw-Hill, United Kingdom. 1974.

[7] A. Klimpel and A. Lisiecki “Laser Welding of Butt Joints of Austenitic Stainless Steel AISI 321,”. Journal of Achievements in Materials and Manufacturing Engineering, 25, 1, 2007.