4th International Conference on Welding Technologies and Exhibition (ICWET'16)
11-13 May 2016, Gaziantep-TURKEY

INVESTIGATION OF WELDABILITY ON THE GALVANIZED SHEET STEELS BY LASER WELDING METHOD

İrem Burcu Algan[1,a], Elif Selen Atmaca[1,b], Adem Kurt[1,c]

1a,1b,1c Gazi University

[a]irembalgan@gazi.edu.tr, [b]elifselenatmaca@gmail.com, [c]ademkurt@gazi.edu.tr

Abstract

The laser beam has a high power density that allows high speed welding, a deep penetration and a small heat affect zone (HAZ). In this study, 0,8 mm galvanized sheed steel with pulsed Nd-YAG laser welding without filler wire under Ar assisting gas ambient was successfully applied to joining a galvanized sheet steel. Welding parameters of laser power 400 A, 4 ms pulse duration and 8.4 Hz frequency were used and 20 mm/min, 50 mm/min and 70 mm/min weld speed applied then the weld-bead geometry, depth of penetration (DOP), weld bead width (BW) were investigated. In addition, the welded specimens radiography and metallographic examinations with strenght were performed. Zn losses in the weld zone were observed.

Keywords: Laser welding, welding of galvanized steels

1. Introduction

Galvanised steels have been using for many years in many parts of our lives. But galvanised steels mostly use in automotive industry. Unfortunately, the main problem of welding galvanised steel's is evaporation of Zn. Since the boiling point of Zn (approximately 960°C) is below the melting point of steel (approximately 1530°C). During the welding process, with highy energy input, Zn vapors transform to welding pool and give rise to some weld defects such as welding pores.

The numerous types of laser available today, two still dominate the materials processing area: CO_2 and Nd:YAG lasers. Currently, only they can provide a sufficient high-power beam in a packaged form that can be economically integrated into a production line [1]. Compared with other welding processes, Nd:YAG pulsed laser welding is expected to be the most suitable method because it allows more precise heat input control and reduces the heat-affected zone (HAZ), the residual stress and the residual distortion [2-4].

Pulsed laser welding has the characteristics of both continuous welding (CW) and spot welding conditions. Thus, pulsed laser welding allows melting and solidification to occur consecutively because of the periodic heating of the weld pool, which is caused by an incident high peak power [5]. In pulsed laser welding, the energy applied to an area comes from both a single pulse and overlapping pulses on the same spot. In other words, each pulse reheats and remelts a portion of the previous spot that is not yet significantly cooled, which makes the reheated area of the previous spot act as the HAZ for the next spot. To characterize this feature of pulsed laser

welding, the overlapping factor is introduced to consider the contribution of the set of pulses that hit the area of a spot[6,7].

When welding with a laser beam, it is necessary to differentiate between two forms of welding: heat conduction welding and deep penetration welding. Conduction welding occurs at lower power densities or higher welding speeds. The absorbed energy is transferred by heat conduction into the volume of the workpiece and produces a broad, shallow pool of molten material. In deep penetration welding, the laser beam is focused to a small spot and the power density can exceed $5x10^6$ Watts/m^2. Sufficient energy is input to vaporise the material and a vapour-filled channel is formed through which the laser energy penetrates deep into the workpiece. Deep seams are produced which increase the absorption efficiency and make greater use of the laser beam. The energy required to melt and vaporise the material depends on the physical properties of the material (absorption coefficient, heat conduction), the wavelength of the laser light and the properties of the surface of the workpiece. These welds typically have deep, narrow weld profiles, a small HAZ and little distortion [8]. As a result of the better energy utilisation and larger depth to width ratios of welds attainable with deep penetration welding, this is the prime method of welding used in industry with the conventional laser sources. Heat is absorbed from the laser beam through the top surface of the metal. Steady state conditions are reached quickly (~2.5ms). The heat input is balanced by losses through the metal by conduction. The aspect ratio of the weld is determined by thermal conduction and surface-tension-driven fluid flow in the weld pool. As the surface tension decreases with temperature, outward flow of the molten metal occurs [9]. Penetration depths are determined by heat conduction and convection in the weld pool.

A high energy-density laser beam vaporises the workpiece during the welding process to form a hole (keyhole), which allows the laser beam to penetrate into the metal to produce a deep, narrow melt pool. The absorption of the laser beam increases drastically once the keyhole has formed, as multiple reflections of the laser light occurs within the hole until most has been absorbed by the metal. Only a fraction (typically 0.5-0.8) of the absorbed energy causes melting of the metal to occur, the rest is dissipated by thermal conduction into the base of the metal, radiation, or convection in the melt pool [10]. Marangoni convection, or surface-tension-driven convection, occurs in the melt pool. Fluid flows outwards from the centre of the weld pool along the upper surface to the outside edge and returns below the surface. Increasing beam power makes the fluid flow shallower but faster. Decreasing the beam diameter makes the flow deeper and faster [11]. The amount of heat lost in these ways is a determining factor in the ultimate penetration depth of the weld. At low travel speeds the conduction loss through the base metal is very large [10]. The pressure of the vapour in the keyhole contributes to the penetration by stabilising the keyhole and keepingit open for further penetration, while the surface tension tends to close it at the surface. At low travel speeds, however, the vapour cavity tends to collapse resulting in reduced penetration. A plasma forms above the surface of the workpiece due to the interaction of the laser beam with the metal vapour and also with atoms in the shielding gas. This absorbs laser beam energy, thus lowering the maximum attainable weld penetration. The plasma also acts like a lens and degrades the optical quality of the laser beam [12]. A keyhole cavit is formed only if the beam is sufficiently intense. It is filled by gas or vapour, created by continuous evaporation of the material by the beam. The absorption of energy depends on the degree of ionisation and density and hence on the temperature. At low temperatures the absorption coefficient is proportional to the degree of ionisation and increases rapidly with

temperature. At higher temperatures ionisation is essentially complete and the absorption coefficient decreases with increasing temperature, as a result of the lower electron and ion densities. This absorption is by inverse Bremsstrahlung. So at low beam intensities beam penetration is limited, whereas at high beam intensities the penetration grows with beam power [13].

In previous study, only welding speed were changed in pulsed Nd-YAG laser weld without filler wire under Ar assisting gas ambient of galvanized sheet steel plates. After welding, affects of speed on weld metal were observed.

2. Experimental

In this study, 0.8 mm galvanized sheed steel welded with pulsed Nd-YAG laser welding without filler wire under Ar assisting gas ambient. 400 A laser power, 8.4 Hz frequency,9 lt/min shielding gas atmosphere and 4ms pulse duration were used in experiments but weld speeds were changed that are 20 mm/min, 50 mm/min and 70 mm/min. Plate samples, 100mm×150mm in size welded with by the aid of support plates for the purpose of prevent to make axial alignment of pieces. Welding direction is selected with the same as the sheets rolling direction. Connection of samples shown in Figure 1. Sample named according to weld speed as S20, S50 and S70.

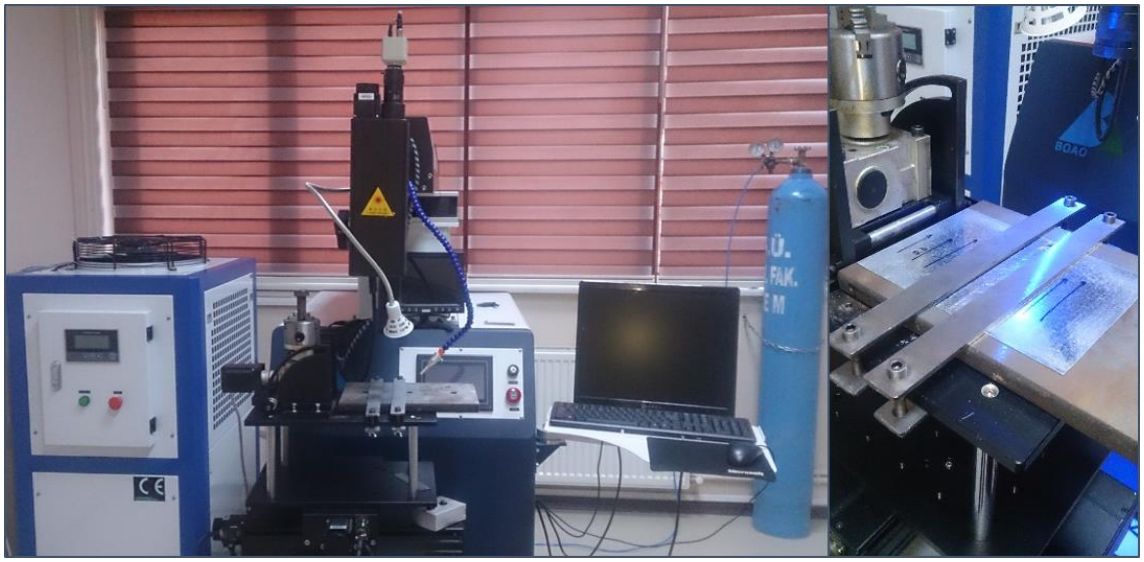


Figure 1.Laser welding machine(left) and connection of samples(right)

3. Results and Discussion

Microstructures of welded specimens were analyzed with Leica CTR 6000 inverted metallurgical metal microscope. Fig. 2 shows that the grain structure is protected up to approximately 15µm distance to transition zone for S20. There are 150-200 µm in size coarse grains in the transition zone and it separeted questionably from the base metal. Weld metal occured 2 mm wide and homogenous distribution of grain structure were observed.

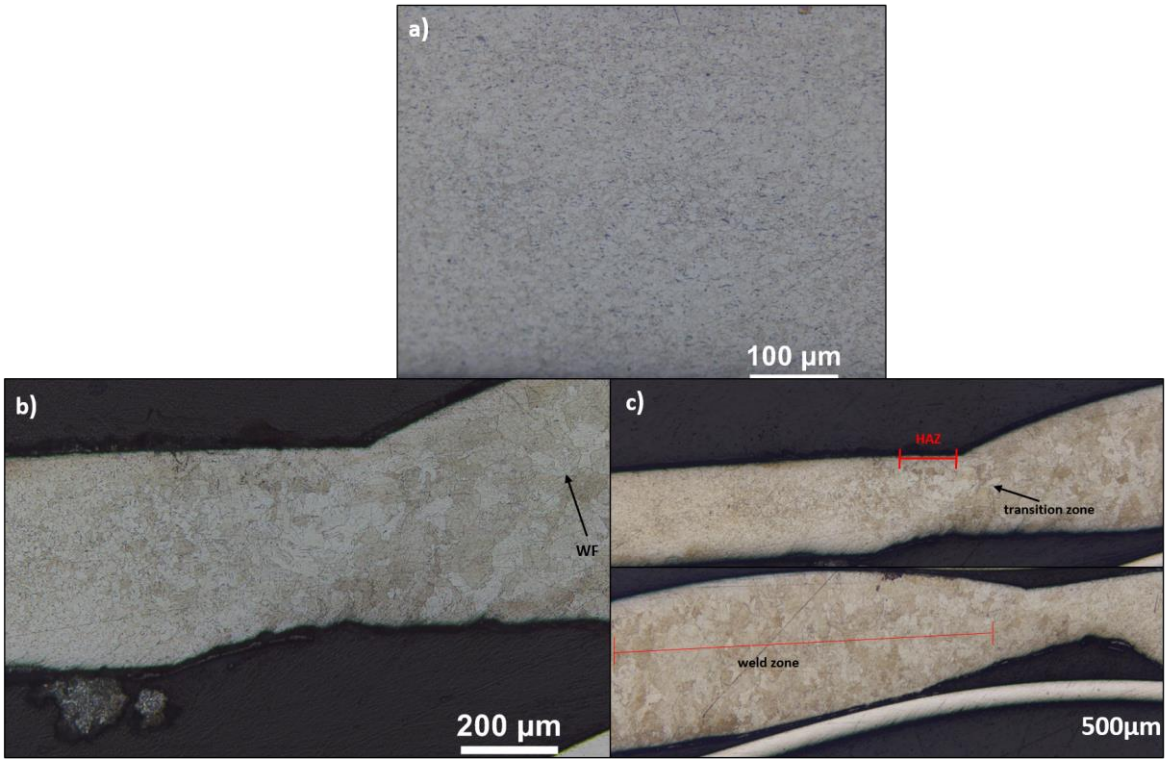


Figure 2. Microstructure photographs of S20, base metal grains (a), ITAB and transition zone (b) and weld zone, transition zone and base metal (c)

Microstructure of S50 given in Fig. 3 that weld metal consists of widmanstatten ferrit predominantly in nearby of weld center however weld metal solidified in the form of ferrite on the external surfaces depending on cooling rate.

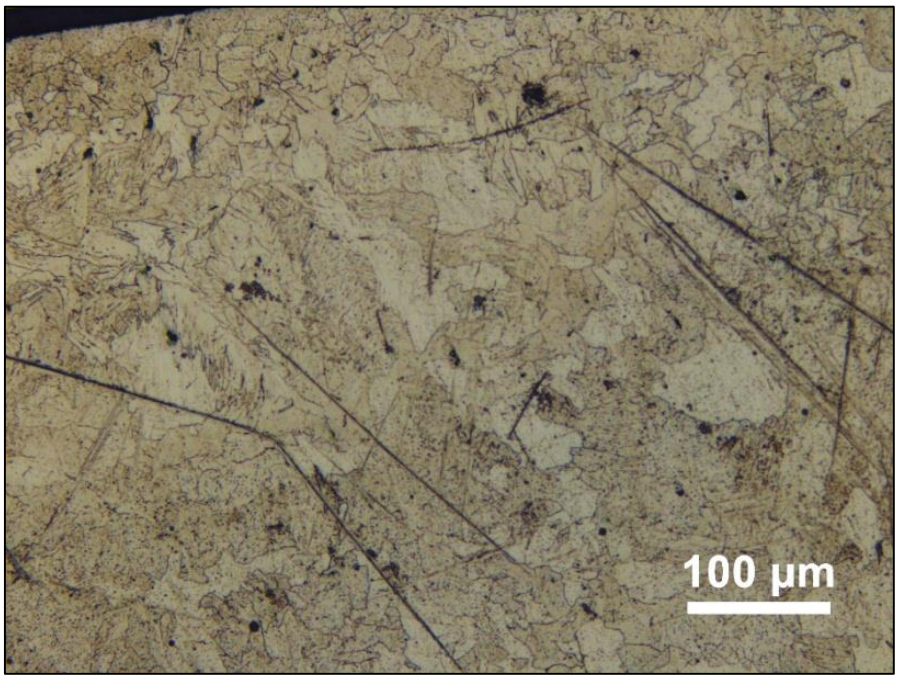


Figure 3. Microstructure of S50 (20X)

Fig.4 indicates that welding seam solidified collapse into transition zone and weld metal grows from the base metal epitaxially. Oriented ferritic grains occured which their bead width is approximatelly 20 µm and length is 100 µm. Weld roots' grain structure is finer than the other side.

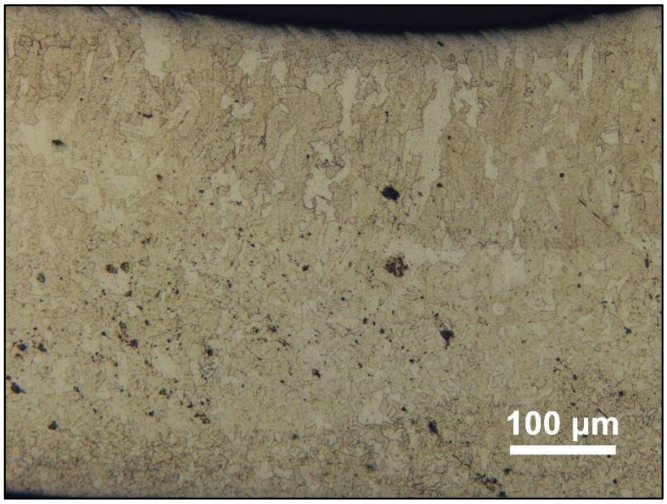


Figure 4. Microstructure of S70 (20X)

80 kV high volt, 1250 µm anode current, 10 second exposure time and 5 second warming time parameters were used in radiographic analysis with X-RIS imaging solution GemX 200. Fig.5a shows that weld metal burnthroughs in consequence of the low weld speed and high heat input. In Fig. 5b there are a few pores since zinc evaporate at high temperatures and high heat input easily. As apperant from Fig. 5c incomplete fusion occured some districts because of high weld speed.

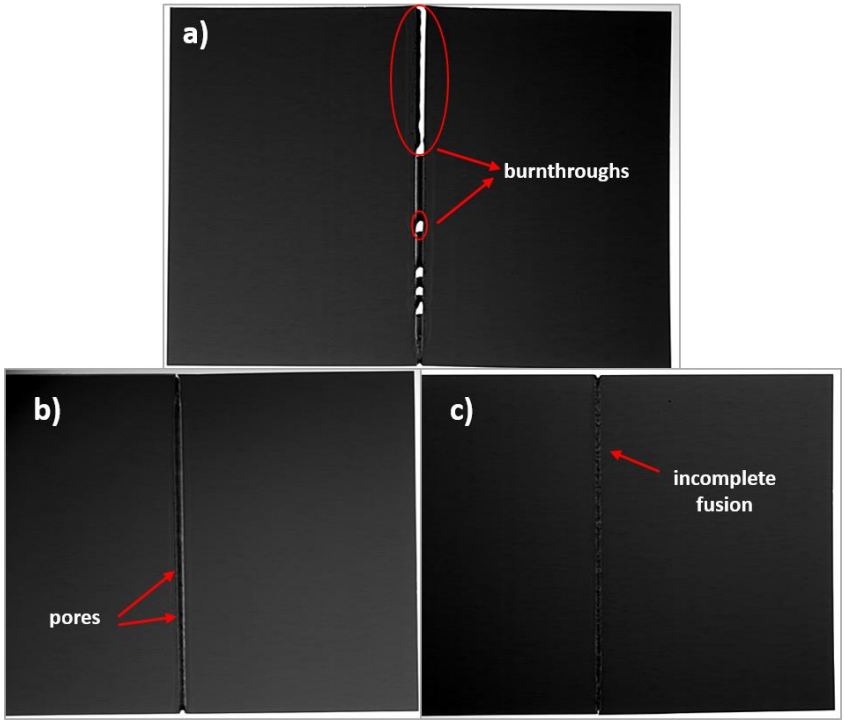


Figure 5. Radiographic images of samples, S20 (a), S50 (b) and S70 (c)

Tensile tests were performed by Instron 3369 Model test device and results given in Figure 6 with break forms. It clearly shows that tensile stress and strain increase with increasing of weld speed and S70 has the highest values. According to optical and radyographic images, when 70 mm/min weld speed applied impeccable joining were attained and specimen broke from the main metal break away. S20 and S50 were broke from the beside of weld zone that concerned with hardness values.

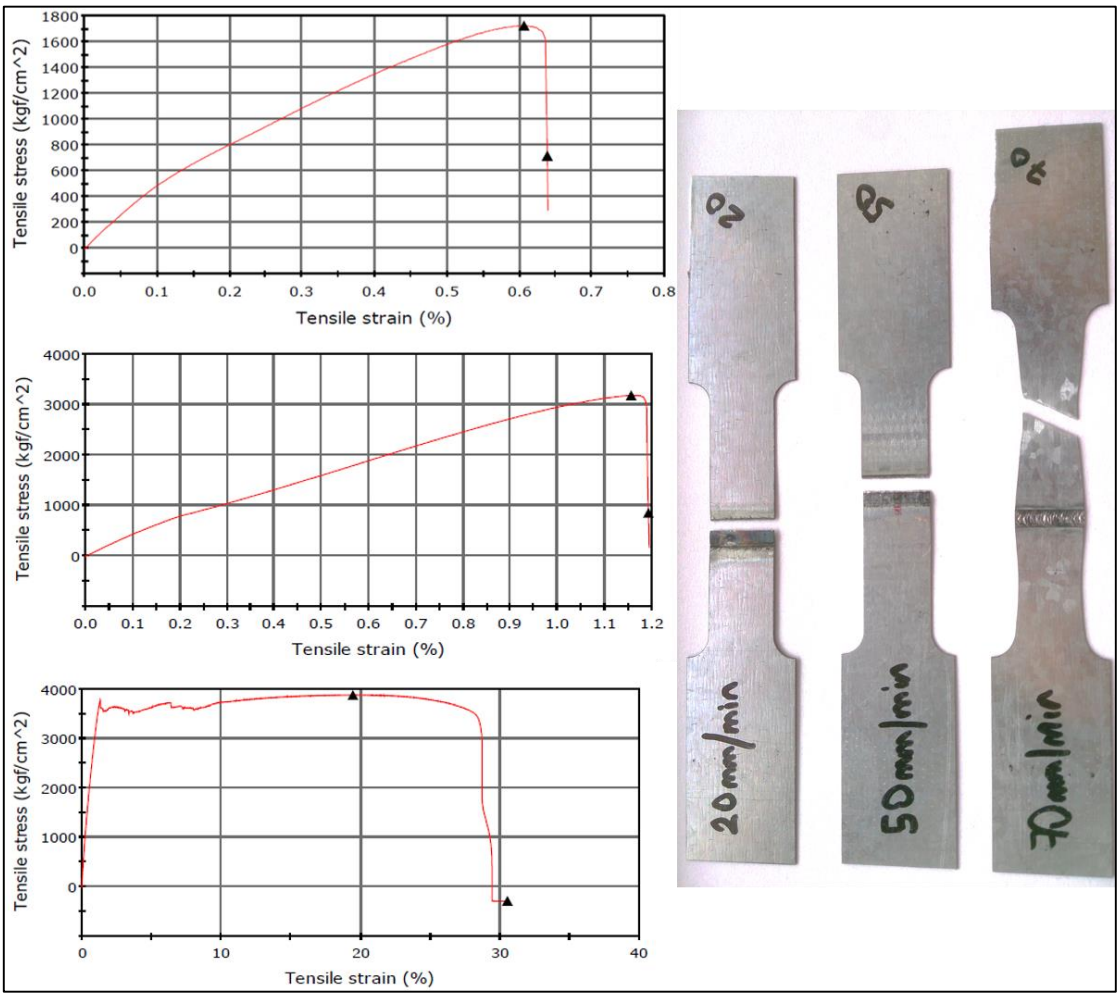


Figure 6. Tensile test results and break forms of specimens

Vickers hardness tests performed by Emco Test Duravision 2000 test device in Gazi University Mechanical Test Laboratory. And the results are showed in Fig.7. Hardness of specimens increased linearly from base metal towards to weld zone and maximum in the weld bead**.** According to results, S20 has the minimum hardness values as when the weld speed is low, heat input increases. In addition some parts of material melted because of this reason. Hardness of weld metal of S50 is higher than S70 therefore S50 broke from the side of weld metal end of tensile test. However S70 broke from the base metal because of lower hardness. Tensile and hardness test results demonstrated that ductility and strength decrease with increasing hardness.

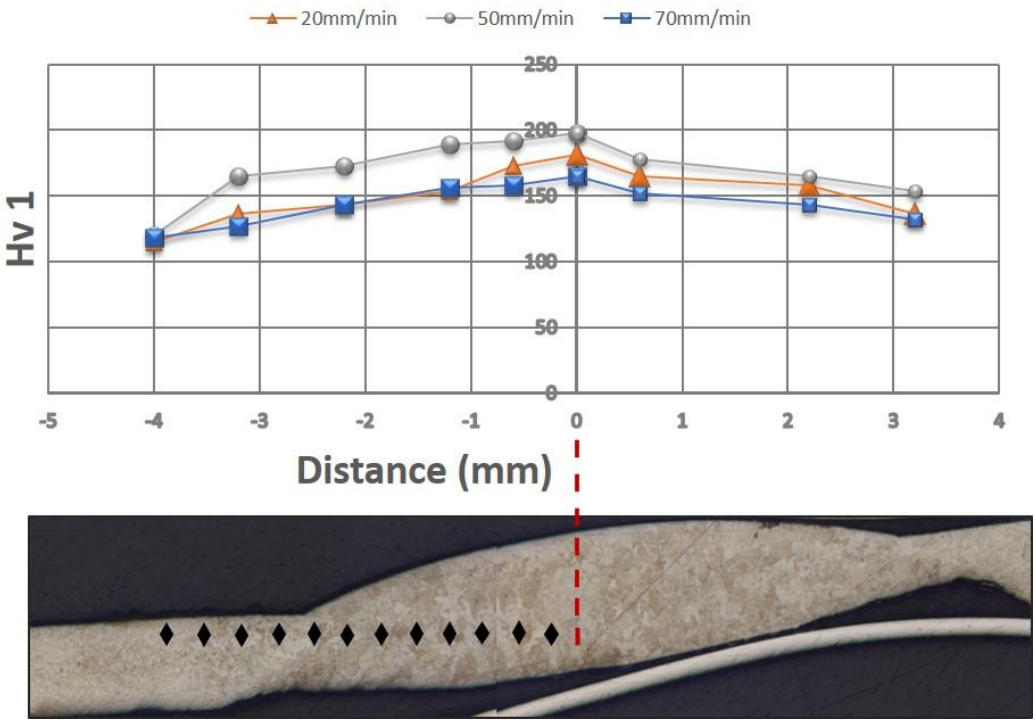


Figure 6. Hardness of vickers values of specimens

SEM analysis were performed by Jeol JEM 6060 LV scanning electron microscobe and EDS results of S70 given in Fig.7 exemplary. According the results, it was found that zinc in weld metal and oxide layer which comes from the galvanize sheet on the metal it shows that weld metal were protected by Zn and strength of the metal increases.

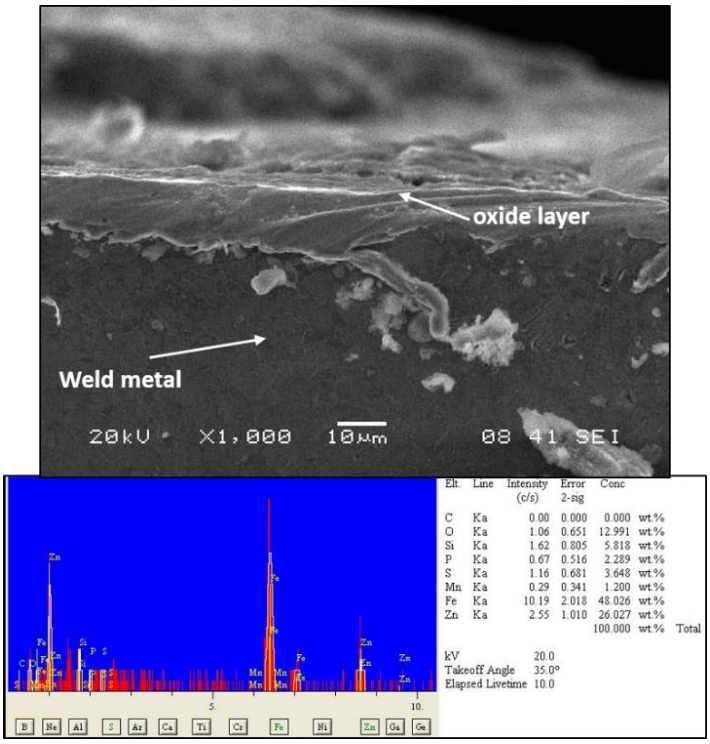


Figure 7. SEM photograph and EDS results of S70

4. Conclusion

Obtained results from previous study indicated that when the weld speed increase, heat input decrease in pulsed Nd-YAG laser welding of galvanized sheet steel. According to this result, mechanical strength decrease. During the welding, Zn in the galvanized sheet metal penetrate into the weld metal. After vaporuzation oxides continued its existance both of weld surface and weld metal. In S20, according to high heat input, some of weld defects occured such as burnthroughs were observed. Although S70 has the highest tensile strength values, S50 has the maximum hardness values. Probably, during the lower weld speed, the heat input was higher than the others and hence oxides formed. Best results were mentioned in highest weld speed and lowest heat input.

5. Acknowledgement

This study was carried out under 01/2013-02 coded project that supported by Gazi University Bilimsel Araştırma Projeleri (BAP) agency. The authors thank to Gazi University BAP agency for supports.

6. References

[1] Y.F. Tzeng: Process Characterisation of Pulsed Nd:YAG Laser Seam Welding, "The International Journal of Advanced Manufacturing Technology",16 (2000), pp 10-18.

[2] S.H. Baghjari, A. M. SAAA: Effects Of Pulsed Nd:YAG Laser Welding Parameters And Subsequent Post-Weld Heat Treatment On Microstructure And Hardness Of AISI 420 Stainless Steel, Mater Des, 43 (2013), pp.1–9.

[3] M. SAAA, S. AR: Metallurgical Investigations Of Pulsed Nd:YAG Laser Welding Of AISI 321 And AISI 630 Stainless Steels, Mater Des, (2009), 30:3150–7.

[4] J. X. Zhang, Y Xue, S.L. Gong: Residual Welding Stresses In Laser Beam And Tungsten Inert Gas Weldments Of Titanium Alloy: Sci Technol Weld Join, (2005),10:643–6.

[5] F. Malek, M. J. Hamedi, M. J. Torkamany, J. Sabbaghzadeh: Weld Metal Microstructural Characteristics In Pulsed Nd:YAG Laser Welding, Scr Mater, (2007),56:955–8.

[6] M. J. Torkamany, M. J. Hamedi, F. Malek, J. Sabbaghzadeh: The Effect Of Process Parameters On Keyhole Welding With A 400 W Nd:YAG Pulsed Laser, J Phys D Appl Phys, (2006), 39:4563–7.

[7] H. Lapsanska, H. Chmelickova, M. Hrabovsky: Effect Of Beam Energy On Weld Geometric Characteristics In Nd:YAG Laser Overlapping Spot Welding Of Thin AISI 304 Stainless Steel Sheets, Metall Mater Trans B, (2010), 41B:1108–15.

[8] E. Schubert, M. Klassen, I. Zerner and G. Sepold: Materialbearbeitung Mit Hochleistungsdioden-Lasern, Laser Magazin, 4 (1998), 17-20.

[9] A. Kar, M.D. Langlais: Optothermal Effects Of Laser Modes In Laser Materials Processing, Optical and Quantum Electronics, 27 (1995), 1165-80.

[10] S. Chiang, C.E. Albright: The Limit Of Joint Penetration In High Energy Density Beam Welding, Welding Journal, 72 (1993), No. 3, pp. 117-121.

[11] C. Limmaneevichitr, S. Kou: Experiments To Simulate Effect Of Marangoni Convection On Weld Pool Shape, Welding Journal, 79 (2000), pp. 126-135.

[12] P. Pecas, M. Henrique, R.M. Miranda and L. Quintino: Laser Welding Of Low-Thickness Zinc Coated And Uncoated Carbon Steel Sheets, Optical and Quantum Electronics,27 (1995), pp. 1193-1201.

[13] P.G. Klemens: Heat Balance And Flow Conditions For Electron Beam And Laser Welding, J. Appl. Phys.,47 (1976), pp. 2165-2174.

CORRESPONDENCE ADDRESS: Gazi University Technology Faculty Metallurgy& Material Engineering Department, 06810, Teknikokullar-Ankara, +903122028750, irembalgan@gazi.edu.tr

SHORT BIOGRAPHIES

İrem Burcu Algan – İrem Burcu Algan was born in Ankara in 1989. She graduated from Karadeniz Technical University Engineering Faculty Metallurgy and Material Engineering in 2012 then completed her master's degree in Gazi University Graduate School of Natural Applied Science Metallurgy and Material Engineering Department in 2015. She work as a research assistant in Gazi University Technology Faculty since February, 2013 in addition continue her doctorate in Gazi University since September, 2015.

Elif Selen Atmaca – Elif Selen Atmaca was born in Kars in 1989. She graduated from Kocaeli University Engineering Faculty Metallurgy and Material Engineering in 2012 then completed her master's degree in Gazi University Graduate School of Natural Applied Science Metallurgy and Material Engineering Department in 2015. She is still continue her doctorate in the same department since September, 2015.

Adem Kurt – Adem Kurt was born in Çorum Alaca in 1958. He graduated from Gazi University Technical Education Faculty in 1983 then he completed his master's degree in Gazi University Graduate School of Natural Applied Science Education in 1992, his doctorate in Fırat University Graduate School of Natural Applied Science Education of Metallurgy Department in 1996. He took his associate professor degree in 1999 Gazi University and he is professor since 2005 in Gazi University Technology Faculty.