Laser welding of galvanized DP980 steel assisted by the GTAW preheating in a gap-free lap joint configuration

Shanglu Yang and Radovan Kovacevic[a)]
Center for Advanced Manufacturing, Southern Methodist University, Dallas, Texas, USA 75205

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With the increasing need for reducing the vehicle's weight, improving fuel efficiency and safety, as well as the corrosion resistance, more and more galvanized high-strength steels have been used in the automotive industry. However, the successful laser welding of galvanized steels in gap-free lap joint configuration is still a big challenge. The high-pressurized zinc vapor is readily developed at the interface of the two metal sheets due to the lower boiling point of zinc (around 906 °C) than the melting point of steel (over 1300 °C). The failure of mitigating the high-pressurized zinc vapor at the interface leads to the formation of different weld defects such as the spatters and blowholes, which not only damage the weld surface quality but also deteriorate the mechanical properties of welds. Until now, there is no open literature on successfully obtained the defect-free welds of galvanized high-strength steels by using only laser welding. In this paper, a new welding procedure based on using GTAW as an auxiliary preheating source with a fiber laser as a main heat source is introduced. The controlled heat management during the preheating by GTAW will transform the zinc coating at the top surface of galvanized DP 980 steel metal sheet into the zinc oxides, which will dramatically improve the coupling of the laser power to the welded material. By the formation of the zinc oxides generated by the preheating of GTAW, the keyhole is readily formed, which provides the weld with a full penetration and allows the high-pressurized zinc vapor at the interface to be vented out through the keyhole. The completely defect-free laser welds have been obtained by using this welding method. Furthermore, a charge-coupled device video camera with the frame rate of 30 frames per second is used to on-line monitor the molten pool. By the analysis of the molten pool images, it is revealed that when the welding process is stable, the keyhole is kept open. However, the keyhole is readily collapsed when the welding process is unstable. In addition, the microhardness and tensile shear tests are carried out to evaluate the mechanical properties of laser welded joints. It is demonstrated that the welds of high strength are obtained in the laser welds. © *2009 Laser Institute of America.*

Key words: GTAW, Laser welding, preheating, galvanized DP 980 steel, high strength steels, gap-free, lap joint, CCD camera

I. INTRODUCTION

In order to meet the automotive industry demands for increased fuel efficiency and enhanced the mechanical and structural performance of vehicles, more and more advanced high-strength steels have been used to fabricate automobile parts such as panels, bumpers, and front rails. In order to improve corrosive resistance, steels used for the car parts are usually galvanized. When welding of galvanized steels, the welding process especially for the lap joint configuration tends to become dramatically instable in the presence of highly pressurized zinc vapor because of the lower boiling point of zinc, around 906 °C, compared to higher melting point of steel, over 1500 °C. A large number of spatters are produced by expelling the liquid metal from the molten pool. Different weld defects such as spatters, blowholes, and porosity appear in the welds.

To eliminate the effects caused by the highly pressurized zinc vapor, over the past several decades a number of techniques have been tested. The simplest approach to mitigate the effect of the Zn coating is to remove it completely by mechanical means prior to welding,[1] as one of the American Welding Society standards for welding galvanized steel suggests.[2] Another technique that has been proven effective is to intentionally form a small gap between the two metal sheets.[3] Mazumder *et al.*[4] patented and described in the papers[5,6] a technique that places a thin copper sheet between two steel sheets along the welding line. The copper has a melting temperature of 1083 °C (between the melting temperature of steel and the boiling temperature of zinc) and can be alloyed with the zinc before the steel is melted. However, the presence of copper in the steel could generate additional problems, such as hot cracking and corrosion concerns.[7] The method of redesigning the lap joint, which allows the zinc vapor to be evacuated before the molten pool reaches the interface, is another way of mitigating the effect of the zinc vapor.[8–10] Pennington *et al.*[11,12] removed the zinc coating in

[a)]Author to whom correspondence should be addressed. Tel.: +1(214) 768 4865. Electronic mail: kovacevi@engr.smu.edu.

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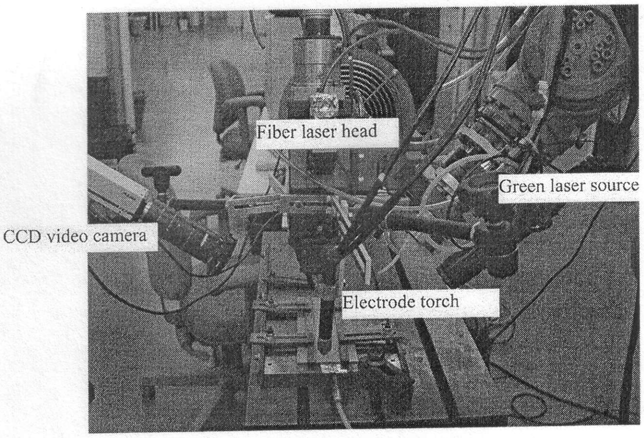


FIG. 1. Experimental setup.

the weld area before laser welding and instead deposited the nickel coating in the weld zone, which has the higher melting point of 1453 °C than that of zinc. By replacing the zinc coating with nickel coating in the weld area, the welding process is not affected by the highly pressurized zinc vapor and still provides the corrosion protection. However, this will increase the additional cost and lower the productivity. In addition, the pulsed laser,[13] dual laser beam[14–17] or two lasers,[18] and hybrid laser welding[19,20] were also applied to the welding of galvanized steels. Recently, Li *et al.*[21] patented and described in the paper[22] a technique that sets the aluminum foil layer in the weld zone at the interface of two galvanized steel sheets to form the Al–Zn alloy, thus lowering the effect of the zinc vapor pressure. In order to use this method to weld galvanized steels in lap configuration, there is a requirement of tightly clamping the two metal sheets. If there is the existence of gap at the interface of two metal sheets, the weld defects are formed.[22] Furthermore, the dissolution of aluminum-steel alloy into the weld, which makes the weld brittle, has the potential to deteriorate the weld quality. Although the methods mentioned above can mitigate the presence of the highly pressurized zinc vapor at the interface of two metal sheets or suppress it to some extent, there exist some of disadvantages among all of these methods. Some of the proposed methods need the preprocessing or postprocessing. Some of them require high investment of using the two laser beams or splitting one beam into two beams. The other methods introduce the new issues. Until now, there is no reported a cost-effective, efficient, and easy-to-use welding technique in the open literatures for the welding of galvanized high-strength steels in gap-free lap joint configuration. Therefore, it is important to develop an efficient and effective welding technique for welding of galvanized steels in gap-free lap joint configuration and to fully understand the mechanisms of the welding process.

The automotive industry has shown tremendous interest in using laser welding to join the galvanized high-strength steels because of the lower heat input, the higher welding speed, and the higher productivity compared to the traditional welding processes. To address the demand of the automobile industry, in this study, a new welding procedure based on using GTAW as an auxiliary preheating source with

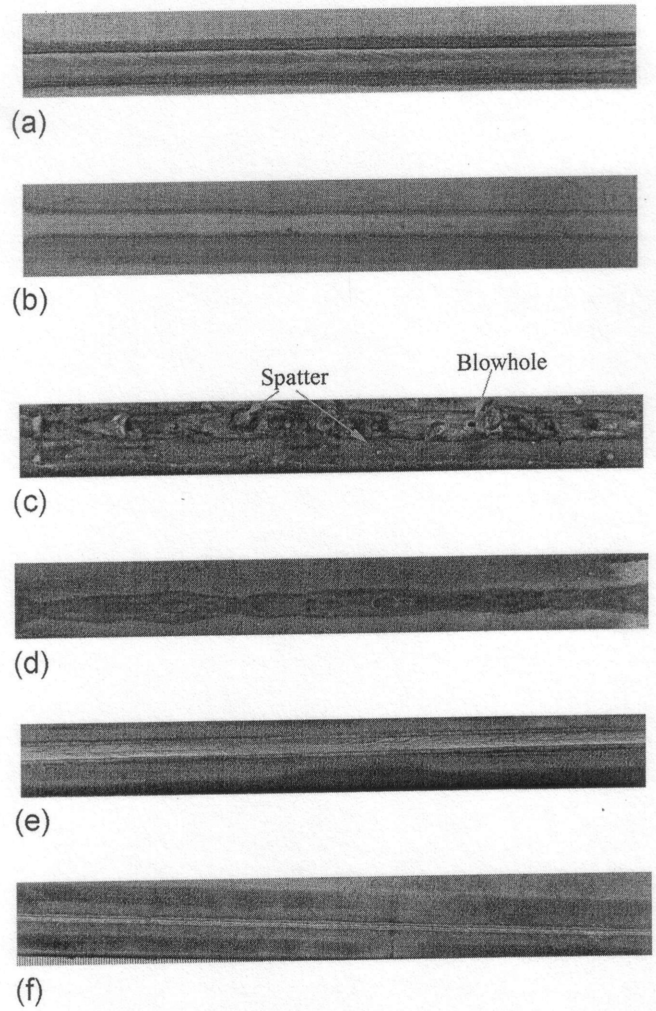


FIG. 2. Top and back views of laser welds and laser/GTAW preheating welds. (a) Top view of laser weld without zinc at the interface, (b) back view of laser weld without zinc at the interface, (c) top view of laser weld with zinc at the interface, (d) back view of laser weld wit zinc at the interface, (e) top view of laser/GTAW preheating weld, and (f) back view of laser/GTAW preheating welds [(a)–(d): laser power of 3000 W, welding speed of 1.8 m/min, the shielding gas flow rate of 30 CFH; (e)–(f): laser power of 3000 W, welding speed of 1.8 m/min and arc current of 200 A; the shielding gas flow rate of 30 CFH].

a fiber laser as a main heat source is introduced. The thermocouple was used to measure the temperature at the interface of two metal sheets during the preheating by GTAW. The x-ray photoelectron spectroscopy (XPS) tests were carried out to analyze the chemical composition at the top surface as well as along the interface of the metal sheets. Furthermore, a charge-coupled device (CCD) video camera with the frame rate of 30 frames per second was used to on-line monitor the molten pool behavior. In addition, the microhardness and tensile shear tests were carried out to evaluate the mechanical properties of laser welded joints.

II. EXPERIMENTAL SETUP

The material used in this study is galvanized DP 980 steel sheets. The dimensions of the metal sheets used in this work are 200 mm × 85 mm × 1.2 mm and 200 mm × 85 mm × 1.5 mm. The metal sheet with the dimensions of 200 mm × 85 mm × 1.2 mm is selected as the top sheet dur-

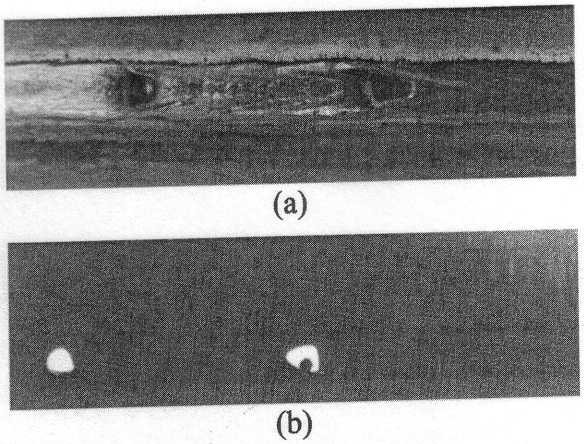


FIG. 3. Types of blowholes: (a) shallow blowhole, (b) burn-through blowhole.

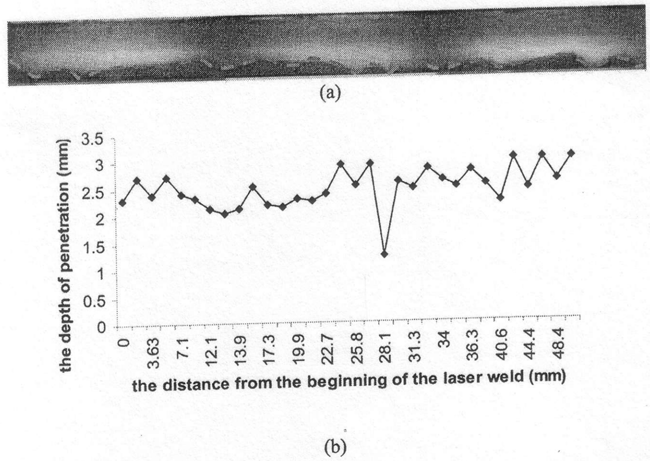


FIG. 4. The effect of the zinc vapor plume on the depth of the weld penetration. (a) the longitudinal cross-view of the laser welded lap joint, (b) the depth of the laser weld penetration over the distance.

ing the lap joint welding process. The gap between two metal sheets is kept tight during welding, assuming that the gap is equal to zero. The laser/GTAW hybrid welding experiments are performed by using the fiber laser with the 4 kW in power and the GTAW welding machine (300 DX AC/DC inverter argon arc welder). The pure argon gas with the flow rate of 30 SCFH is used as the shielding gas. The GTAW electrode of the 3 mm diameter is used. A CCD color video camera is used to monitor the welding process. The video frame rate is set at 30 interlaced frames per second. The equipment used for XPS analysis of the laser/GTAW preheating welds is the PH1 5000 VersaProble scanning ESCA Microprobe equipment, which is produced by the ULVAC-PH1. The band-pass green laser (Model: Coherent TracER green forensic laser system) with the center wavelength of 532 nm and a maximum output power of 6 W is selected as the illumination source to obtain the clear images of the molten pool. The experimental setup is shown in Fig. 1. During the welding process, the GTAW is used as the preheating heat source and the trailing laser beam is applied to provide the welding.

III. RESULTS AND DISCUSSION

A. Laser welding and laser/GTAW preheated welding of galvanized DP 980 steel in a gap-free lap joint configuration

Figures 2(a) and 2(b) shows the top and back views of laser-welded lap joint with the removal of the zinc coating at the interface of two sheet metals and keeping the zinc coating at the top and bottom surfaces of sheet metals; Figures 2(c) and 2(d) demonstrate the top and back views of laser-welded lap joints without any preprocessing; Figures 2(e) and 2(f) shows the GTAW torch preheated-laser welded lap joint. As shown in Fig. 2(a), the defect-free sound lap joint of galvanized DP 980 steels is obtained when the zinc coating at the interface of two sheet metals is removed. When the zinc coating at the interface of two metal sheets is not removed prior to laser welding process; however, a large number of spatters and blowholes are produced, as shown in Fig. 2(c). Due to the lower boiling point of zinc (906 °C) than the melting point of steel (over 1300 °C), the highly pressurized zinc vapor is readily developed at the interface of two metal sheets. If the highly pressured zinc vapor at the interface can not completely be vented out, it violently expands, expels from the molten pool, and blows the liquid metal out of the molten pool.[23] The removed liquid metal out of the molten pool is condensed in the air and produces spatters of the different sizes that scatter in all directions and deposit around the weld zone. Moreover, "the explosion may lead to a cavity in the weld zone. If the cavity can not be refilled by the sufficient liquid metal, then a shallow blowhole is produced," as illustrated in Fig. 3(a). There are two ways for the highly pressurized zinc vapor to escape from the zero-gap interface: through the keyhole or through the molten pool. Another reason for the blowhole formation is that too much heat is inputted into the specimen that directly creates a burn-through hole in the weld, as shown in Fig. 3(b). Additionally, it is found that the plume produced by the zinc vapor on the top surface of the specimen fluctuates dramatically, which affects the coupling of the laser beam with the specimen. This fluctuation has an influence on the depth of penetration of the welds. Figure 4 shows the longitudinal cross-sectional view and the penetration depth of the laser welded joint as a function of the location from the start point of the welding process. As shown in the Fig. 4(b), the depth of the weld penetration is changed over the distance.

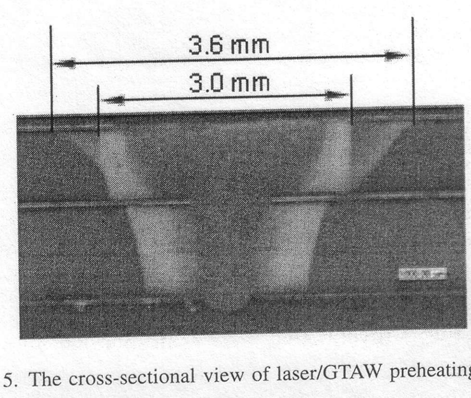
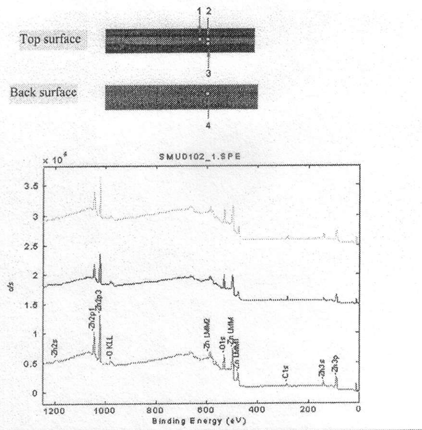


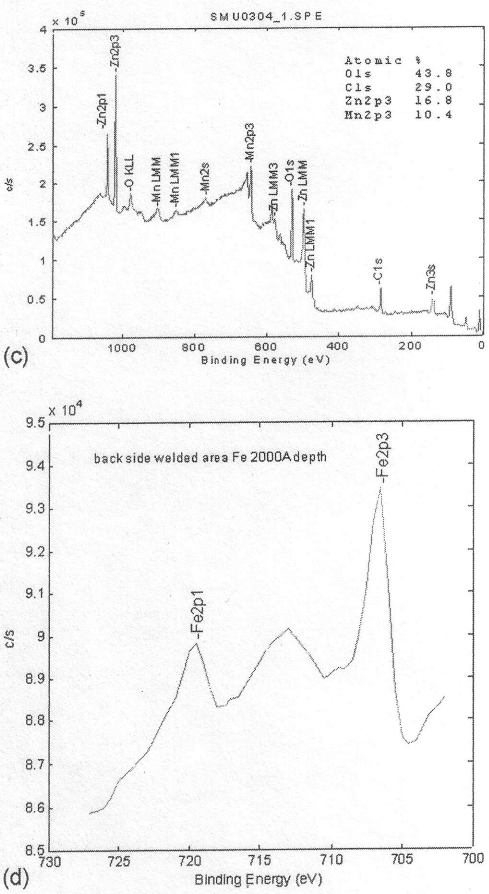
FIG. 5. The cross-sectional view of laser/GTAW preheating weld.

(a)



Atomic Concentration Table			
	C1s	O1s	Zn2P3
Point 1	18.98	47.67	33.35
Point 2	33.79	46.14	20.08
Point 3	19.27	50.33	30.40

(b)



(c)

(d)

FIG. 6. The XPS analysis results of the heated surface of DP 980 galvanized steel by GTAW torch. (a) The measured points (1–4), (b) the XPS analysis results on the top surface, (c) the XPS analysis results at the point 4 at the back surface, and (d) the XPS analysis of the backside area under the 2000 angstrom (Preheated at the arc current of 200 A, welding speed of 1.8 m/min, the thickness of 1.2 mm for the top metal sheet and the thickness of 1.5 mm for the bottom metal sheet).

As shown in the Figs. 2(e) and 2(f), the completely defect-free laser/GTAW preheated welded lap joint is achieved. The cross-sectional view of the laser/GTAW weld shown in Fig. 5 reveals that there is no porosity in the weld. Therefore, the conclusion can be made that the sound welds

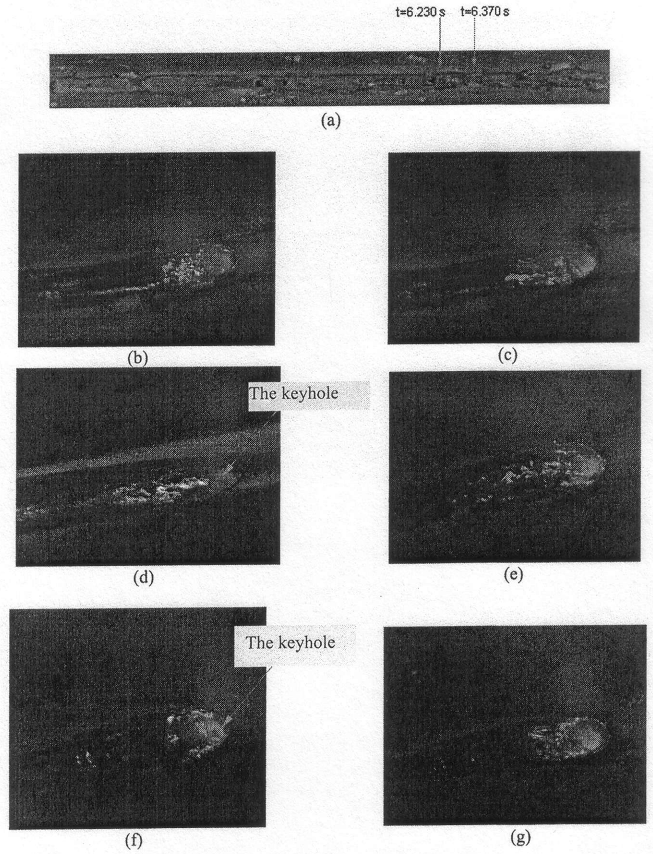


FIG. 7. The shape of the molten pool for an instable welding process. (a) The top view of the laser/GTAW weld, (b) $t=6.2$ s (collapsed), (c) $t=6.230$ s (collapsed), (d) $t=6.270$ s (open), (e) $t=6.30$ s (collapsed), (f) $t=6.330$ s (open), and (g) $t=6.370$ s (collapsed) (preheated at the arc current of 160 A, welded at the laser power of 3000 W and the welding speed of 1.8 m/min).

can be achieved in gap-free lap joint configuration of the galvanized steels by the laser/GTAW method under the optimized welding conditions. As shown in Fig. 5, the width of the preheating track at the top surface of the first sheet metal is 3.6 mm with the preheating current of 200 A and the preheating weld speed of 1.8 m/min, which is slightly higher than the top width of the laser welded lap joint (3.0 mm). Further study demonstrates that the size of the preheated track mainly depends on the preheating arc current and the GTAW preheating welding speed. To synchronously perform the GTAW torch preheating process with the following laser welding process, the optimal preheating arc current is selected according to the laser welding speed. Usually, the width of the preheated track at the top surface of the first sheet metal is slightly larger than the width of the laser-welded lap joint. Additionally, it is always larger than the diameter of the focused laser spot (0.6 mm). At the same time, it was also found that the width of the zinc oxides zone at the interface of two sheet metals obtained with the optimal preheating arc current is usually smaller than the width of laser-welded lap joint measured at the interface of two sheet metals. These facts guarantee that using this welding procedure for the welding of galvanized steels in a gap-free lap joint configuration will not introduce any of the issue relating to corrosion.

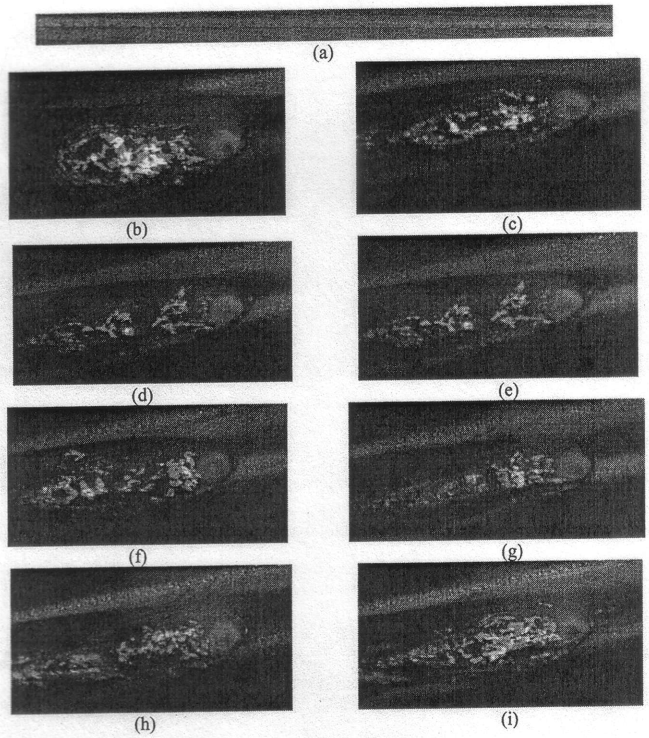


FIG. 8. The images of the keyhole in the stable welding process. (a) The top view of the weld surface in the stable welding process. (b) $t=0$ s, (c) $t=0.03$ s, (d) $t=0.07$ s, (e) $t=0.1$ s, (f) $t=0.13$ s, (g) $t=0.17$ s, (h) $t=0.2$ s, (i) $t=0.23$ s, and (g) $t=0.27$ s (the welding parameters: a laser power of 3 kW, a welding speed of 1.8 m/min, a preheating arc current of 200 A and an argon gas flow rate of 30 SCFH).

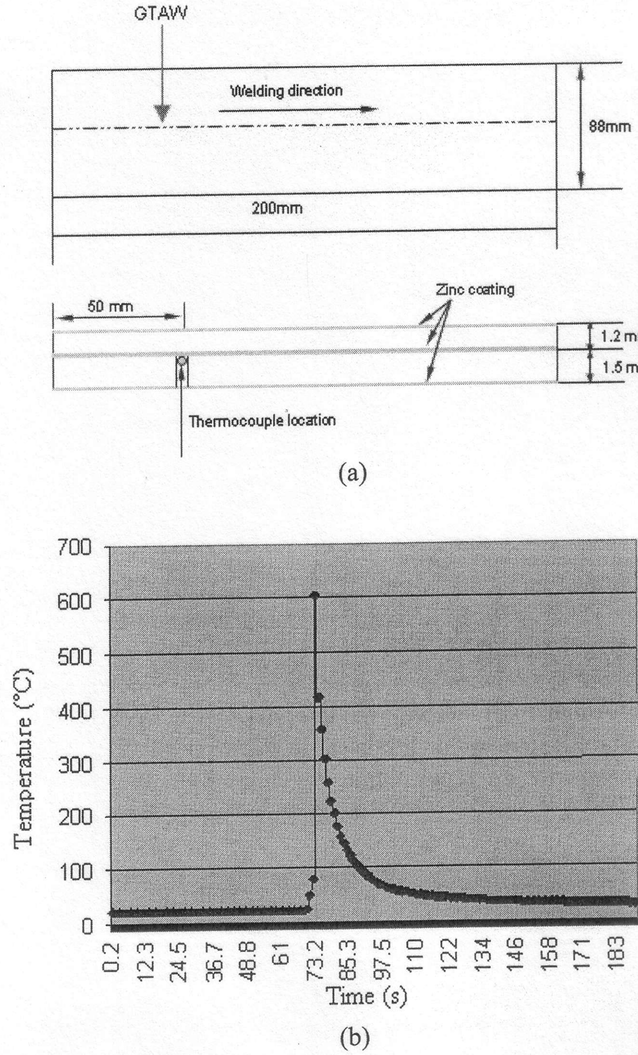


FIG. 9. (a) The temperature measurement along the interface of two galvanized metal sheets and (b) Temperature history at the selected position.

The success in achieving the sound weld is contributed to the formation of metal oxides on the top surface of specimen. In general, most of laser beam energy is usually reflected by the metal sheet surface during laser welding of metal sheets and only very small portion of the laser beam energy is coupled into the specimen when the laser welding process is performed under the conductive mode.[24] However, the absorption of laser beam energy is dramatically enhanced through the multiple reflection mechanism when the laser welding is in the keyhole mode.[25] In addition, it was found that the coupling efficiency of laser beam energy can be significantly raised by 1.5–3 times when some of the metal oxides such as zinc and iron oxides and the soot of substances are formed on the surface of the metal sheets before the laser welding process is started.[26] In the case of the GTAW preheated galvanized steels based on the optimized welding parameters, one portion of the zinc coating is removed from the top surface of the metal sheet and the other portion is transferred into the zinc oxides. The generated zinc oxidation layer and the other metal oxides on the top of the specimen dramatically enhances the coupling of laser energy into the specimen and keeps the coupling rate of laser beam energy almost constant, which sustains the opening and stability of the keyhole. The stable keyhole provides the venting out channel for the highly pressurized zinc vapor at the interface of two metal sheets. Furthermore, the stable keyhole "decreases the mean fluid velocity inside the melt pool" and "facilitates the achievement of the better welds."[27,28] Additionally, the generation of zinc oxides at the interface during the GTAW preheating process has the higher melting point (1975 °C for ZnO) than the boiling point of zinc, which further helps to stabilize the laser welding process of galvanized steel.[20] The XPS measurements were performed at the top surface and the interface of the GTAW preheated welds, as shown in Fig. 6(a). Before carrying out the XPS measurement, the sample is required to remove the surface contamination. As shown in Fig. 6(b) and 6(c), the survey scan exhibited intense peaks of C-1s, O-1s, and Zn2P3. No Fe element was found on the top surface of the GTAW preheated weld. Moreover, the XPS analysis of the backside surface of the melted sheet under the 2000 Å also illustrates that no kind of Fe element was found at the interface on the GTAW preheated welds, as shown in Fig. 6(d). Based on the above XPS analysis for the Fe element, it is apparent that no oxides is produced at the top surface of specimen and no Fe–Zn intermetallic compound is formed at the interface of two metal sheets during GTAW preheating process. From these XPS analysis results, it is evident that the zinc oxides are formed at the top surface and at the interface surfaces of the metal sheets when they are exposed to the heat generated by GTAW torch. In

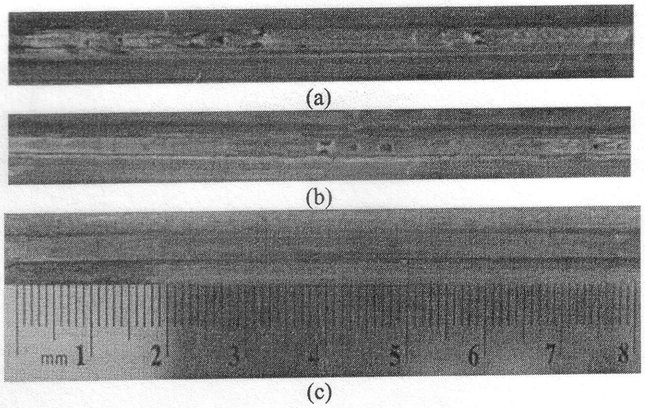


FIG. 10. The effect of the distance between the GTAW torch electrode and laser beam on the quality of the laser/GTAW welds (a) at the distance of 60 mm, (b) at the distance of 120 mm, and (c) at the distance of 180 mm.

addition, the proportion of C1*s*, O1*s*, Zn2P3, and Mn2p3 for the GTAW preheated welds were presented in the Atomic Concentration Table shown in Figs. 6(b) and 6(c) on the basis of the relative area under the specific element peaks.

Another advantage of the laser/GTAW preheated process is that the laser welding process is free from the influence of the instable zinc vapor plume, which increases the instability of the welding process. In addition, the GTAW electrode tip is safe from the damage of the spatters. It was found that when the keyhole is generated, the welding process is very stable and no spatter is produced. Once the keyhole is collapsed; however, lots of spatters are produced. Therefore, one of the most important factors in achieving the sound weld is to keep the open keyhole during the welding process. In the instable welding process, the open keyhole alternates with the collapsed keyhole. The keyhole is presented at the captured images of the molten pool as the black spot in the frontal side of the molten pool. Figure 7 shows the images of the keyhole extracted from the instable welding process. Figure 8 shows the images of the keyhole extracted from the stable welding process. In comparison of the welding result in Fig. 7 with that in Fig. 8, it is apparent that the sustained opening of the keyhole is the critical factor that guarantees the achievement of the high-quality welds.

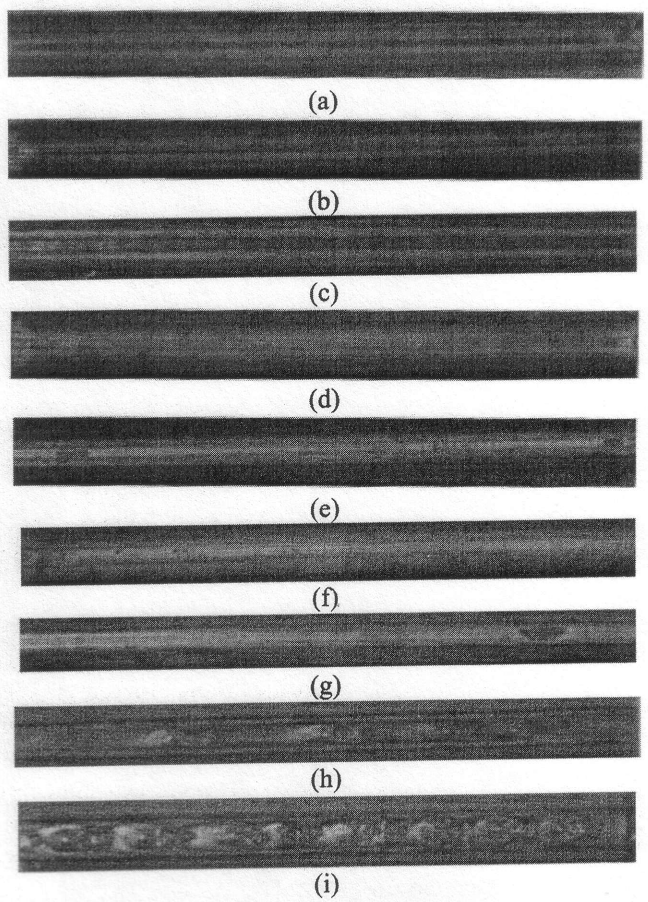


FIG. 11. The effect of arc current on the chemical composition of the top surface of the preheating samples. (a) Arc current of 100 A, (b) arc current of 120 A, (c) arc current of 140 A, (d) arc current of 160 A, (e) arc current of 180 A, (f) arc current of 200 A, (g) arc current of 220 A, (h) arc current of 240 A, and (i) arc current of 260 A.

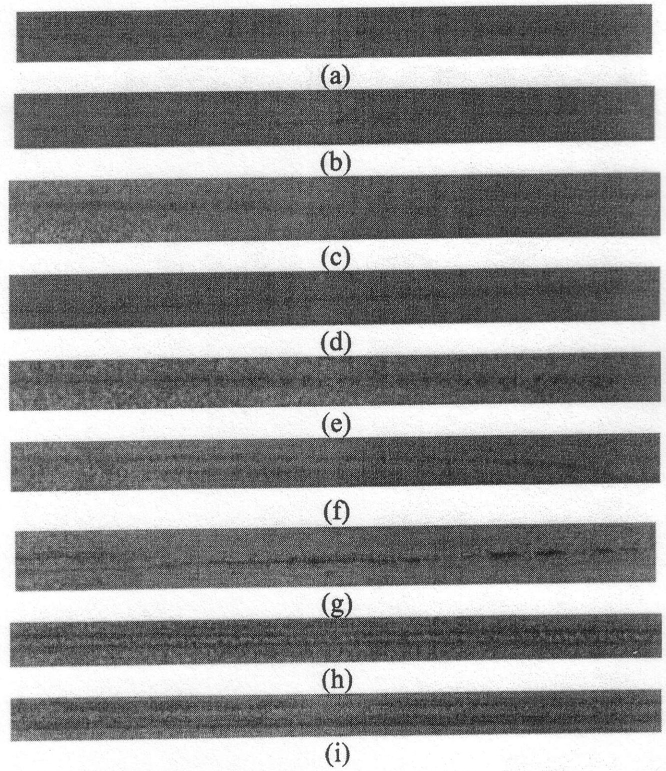


FIG. 12. The back side of the preheating samples. (a) Arc current of 100 A, (b) arc current of 120 A, (c) arc current of 140 A, (d) arc current of 160 A, (e) arc current of 180 A, (f) arc current of 200 A, (g) arc current of 220 A, (h) arc current of 240 A, and (i) arc current of 260 A.

In order to study the temperature characteristics of the zinc coating at the interface during the GTAW preheated process, the thermocouple is welded at the interface. Figure 9(a) shows the schematic of thermocouple location at the interface of two galvanized metal sheets. The temperature history at the designed point is shown in the Fig. 9(b) with respect to the arc current of 200 A and welding speed of 1.8 m/min, respectively. As shown in the Fig. 9(b), the maximum temperature is 604 °C, which is more than the melting temperature of zinc but lower than its boiling temperature. Therefore, the zinc coating in the weld area at the interface is partially melted and transformed into the zinc

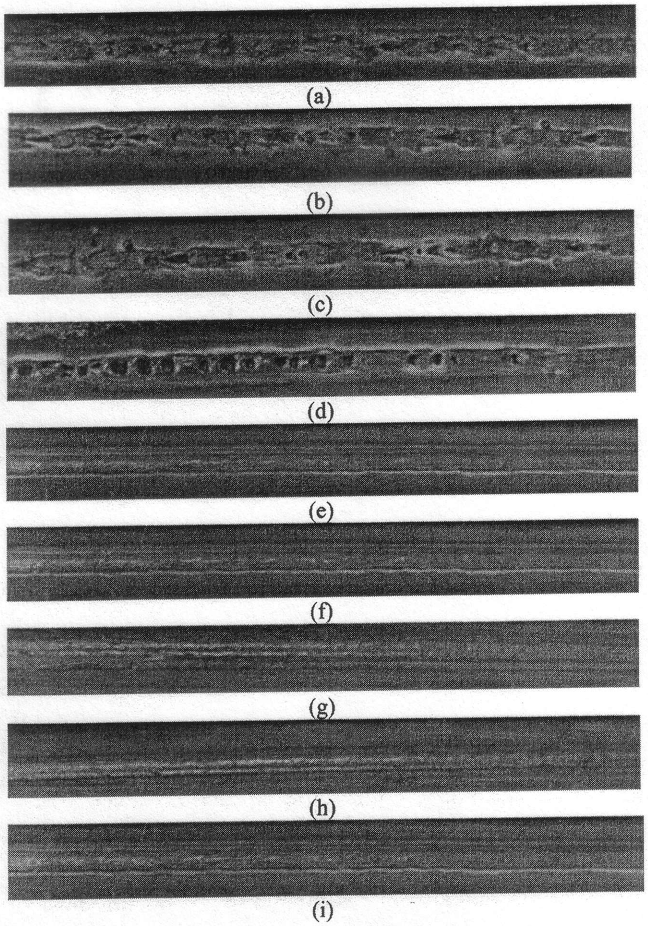


FIG. 13. The effect of the preheating arc current on the weld quality obtained by laser (laser power of 3000 W and welding speed of 1.8 m/min). (a) Arc current of 100 A, (b) arc current of 120 A, (c) arc current of 140 A, (d) arc current of 160 A, (e) arc current of 180 A, (f) arc current of 200 A, (g) arc current of 220 A, (h) arc current of 240 A, and (i) arc current of 260 A.

oxides. Due to the high melting point of zinc oxides, the formation of zinc oxides at the interface also improves the stability of laser welding process.

B. Effects of the distance between the laser beam and the GTAW torch on the quality of laser/ GTAW preheating welds

In order to investigate the influence of the distance between the laser beam and the electrode of GTAW torch, three tests are carried out under the following welding conditions: laser power of 3000 W, welding speed of 1.8 m/min, and the distances of 60 mm, 120 mm, and 180 mm between the GTAW torch electrode and laser beam. For these experiments, the GTAW torch is only used to provide the preheating of the metal sheets that will be laser welded afterwards. Figure 10 shows the experimental results. As shown in Figs. 10(a) and 10(b), there are still some of the blowholes for the laser-welded joints at the distance of 30 mm and 60 mm. The completely defect-free weld is achieved in the laser weld at the distance of 180 mm, as illustrated in the Fig. 10(c). No spatters, blowholes, and porosity are presented at the two weld surface. It was found that the longer distance between the torch electrode and laser beam, the less spatters are produced and the more stable the welding process is. In all of the three welds, the full penetration is achieved. Therefore, the distance between the torch electrode and laser beam play a critical role in guarantying the achievement of the sound welds for the laser/GTAW preheated welding process. This phenomenon can be explained by the fact that when the distance between the GTAW electrode torch and laser beam is far enough, the pressure of zinc vapor is significantly decreased due to the heat lost. The decreased pressure of the zinc vapor helps to stabilize the welding process. It should be mentioned that the distance between the laser beam and the GTAW torch could be decreased by the introducing the cooling media such as cold air or copper sheet.

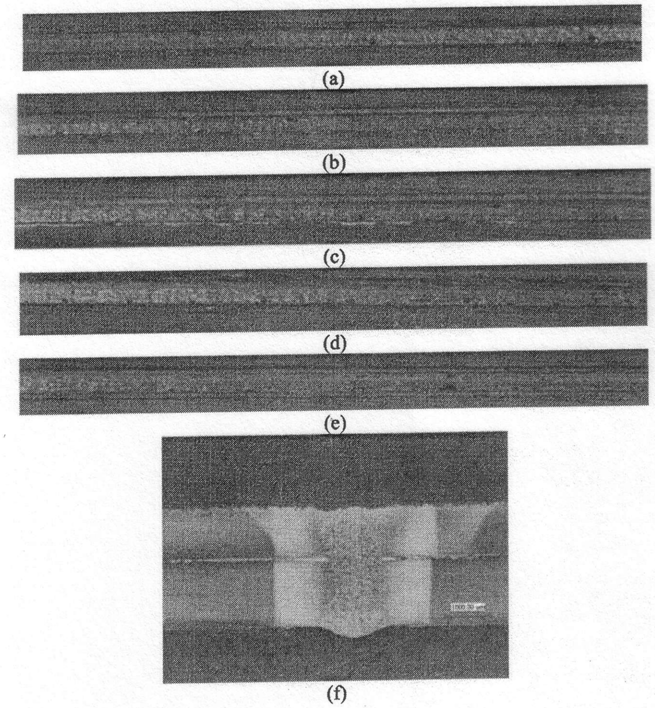


FIG. 14. The effect of the welding speed on the weld quality. (a) $v=1.8$ m/min, (b) $v=2.1$ m/min, (c) $v=2.4$ m/min, (d) $v=2.7$ m/min, (e) $v=3.0$ m/min, and (f) the cross-section view of the laser/GTAW preheated welds at the welding speed of 3.0 m/min.

C. Effects of the preheating arc current on the quality of laser/GTAW preheated welds

During the GTAW preheating process, it is found that different chemical compositions are formed at the top surface of galvanized DP 980 steel. In order to study the effect of the GTAW preheating arc current on the weld quality, a series of tests are carried out. The arc current is gradually increased from 100 A to 260 A with the interval of 20 A. Figure 11 shows the top view of the preheated surfaces obtained by using the various arc currents with the constant traverse speed of 1.8 m/min and the shielding gas flow rate of 30 SCFH. As shown in the Figs. 11(a)–11(c), the top surface at the metal sheet is covered only by the thin layer of black soot when the arc current is below or equal to 140 A. For arc current from 160 A to 220 A, there exist different colors of heat marks at the top surface, which

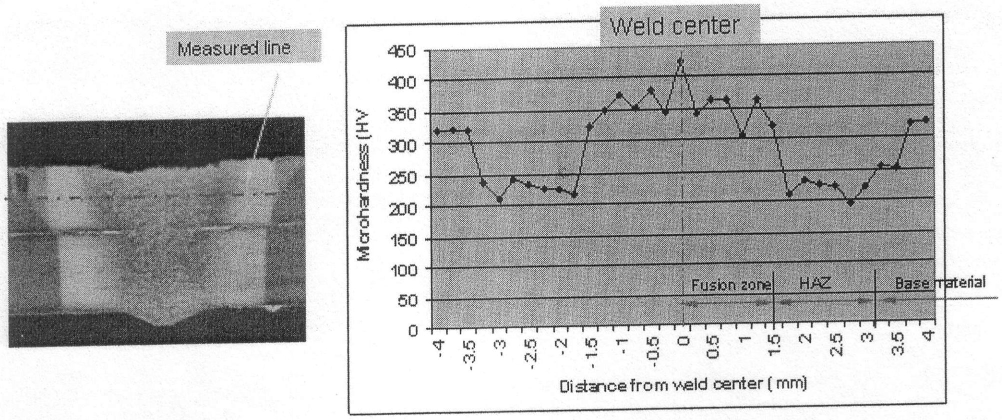


FIG. 15. Vickers micro-hardness profile of laser/GTAW preheated weld (the laser power of 3000 W, the arc current of 200 A, and the welding speed of 1.8 m/min).

indicate that various chemical compositions are produced during heating by GTAW torch. When the arc current is 240 A, small humping is formed at the top surface indicating that melting of top surface occurs. When the arc current reaches 260 A, an excessive melting of the top surface is presented, causing the formation of humping. By directly observing the surfaces of the metal sheets along the interface, it is found that the portion of the zinc coating is melted and oxidized, as shown in Fig. 12.

After the metal sheet is preheated by the GTAW welding process, the laser beam in power of 3000 W and travel speed of 1.8 m/min is used to join the preheated samples in gap-free lap joint configuration. As shown in Fig. 13, the weld quality significantly differs among these laser welds. When the arc current is below or equal to 160 A, lots of spatters and blowholes are generated in the welds. The same occurs in the laser welding process and the hybrid laser/arc welding process of the galvanized metal sheets. The sound welds without the spatters and blowholes are produced at the arc currents of 200, 220, and 240 A. In the case of arc current of 260 A, the sound weld is still obtained; however, the weld surface is not as smooth as in the welds obtained when arc currents are 200, 220, and 240 A. Some of ripples appeared in the weld zone, caused by the presence of humping produced by the high arc current during preheating.

The analysis of results recorded by the CCD video camera revealed that the keyhole was always present when the arc current was between 180 and 260 A. However, the keyhole was not formed when the arc current was changed from 100 to 160 A. Based on the obtained results, it could be concluded that the presence of keyhole provides the conditions to achieve the weld of high quality. By comparing the depth of weld penetration in Fig. 4 with that in the welds obtained by the laser/GTAW preheated welding method, it could be concluded that the zinc oxides produced by the GTAW preheating process significantly improves the coupling efficiency of the laser beam energy into the specimen. This leads in turn to the full weld penetration during laser welding.

In order to investigate the influence of the welding speed on the weld quality of the laser/GTAW preheated welded joints, the welding speed is changed from 1.8 m/min to 3 m/min with the increment of 0.3/min, while laser power and the arc current are kept at the 3000 W and 200 A, respectively. Figure 14 shows the experimental results. As shown in Fig. 14, the completely defect-free welds are achieved under the welding speeds ranging from 1.8 m/min to 3 m/min. The direct observation of the backside of the laser/GTAW preheated welds indicated that the full penetration is achieved in all of these welds. Figure 15(f) shows the cross-section view of the weld obtained at the welding speed of 3 m/min. It looks like that the welding speeds in the range from 1.8 m/min to 3.0 m/min does not affect the weld quality.

D. Testing the mechanical properties of the laser/GTAW preheating welds

The microhardness distribution of the welds provides valuable information about the structural changes in the welded joint.[29] This distribution is also associated with the mechanical properties of the welded joints such as a failure location and the tensile strength. Microhardness of the weld bead is measured along the line indicated in Fig. 15. The indenter load used in the microhardness test is 200 g. The impressions are made along the line at the distance of 0.25 mm away from the interface of two metal sheets as shown in the red line in the weld cross section. Figure 14 shows the microhardness profile across the cross section of the weld. It can be seen that the hardness distribution is not uniform along the weld. The maximum hardness value (426.2 HV) is located at the center of the weld. The minimum hardness value (195.1 HV) is found in the HAZ, which indicates that the HAZ is softened. It can be seen that the hardness value in the fusion zone is relatively uniform.

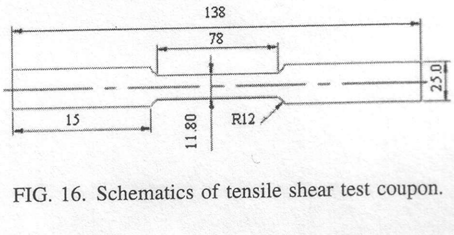


FIG. 16. Schematics of tensile shear test coupon.

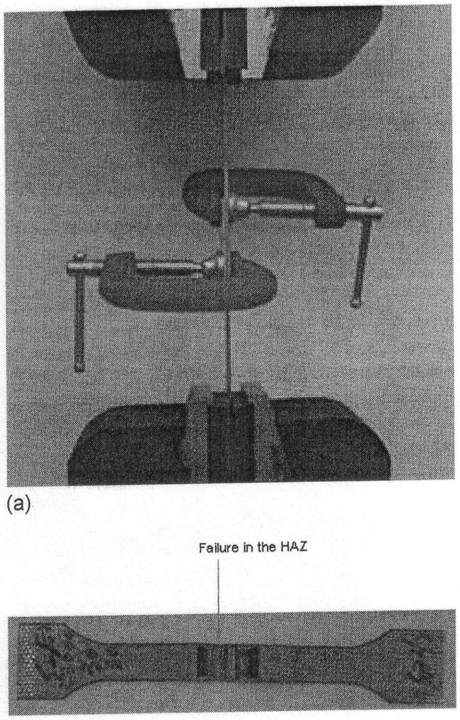


FIG. 17. (a) The tensile shear test experimental setup and (b) the test result.

Furthermore, the tensile shear tests are carried out to evaluate the strength of the welds and characterize the weld deformation. The specimen geometry is shown in Fig. 16. Figure 17 demonstrates the experimental setup and the failure location in the weld. In order to perform tensile shear test, three samples are cut by using the water jet from every weld. Figure 18 shows the relationship between the tensile shear strength and the welding speed ranging from 1.8 m/min to 3 m/min). It can be seen that with the increase in the welding speed, the strength of the welds has a slight decrease and then increased by a small value. However, the strength of the welds does not fluctuate in a wide range. Therefore, the welding speed does not show a significant influence on the welded joints strength.

IV. CONCLUSION

An efficient and cost-effective welding technique based on the conditions of GTAW as a preheating source and a fiber laser as a main heat source is developed for welding of galvanized high-strength steels in gap-free lap joint configuration. The results are summarized as follows:

(1) The completely defect-free smooth laser/GTAW preheated-welded lap joints are obtained. No spatter or blowhole is produced in the welds. The welding process is very stable. No porosity is observed at the cross section of weld.

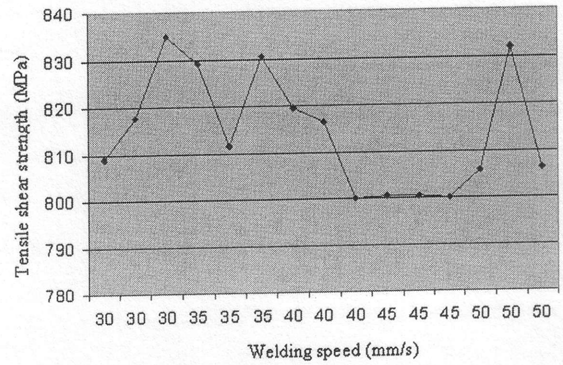
(2) Chemical compositions at the surfaces of the melted sheets by heating them by different arc currents showed the change in the coupling capacity of the laser beam into the specimen. This had the tremendous influence on the final weld quality. The controlled heat management during the preheating by GTAW will transform the zinc coating at the top surface into the zinc oxides, which will dramatically improve the coupling of the laser power to the welded material. By the formation of the zinc oxides generated by the GTAW torch, the keyhole is readily formed, which provides the weld with a full penetration and allows the high-pressurized zinc vapor at the interface to escape through the keyhole.

(3) The weld quality depends on the distance between the laser beam and the torch's electrode. Only beyond the threshold value of the distance between laser beam and torch's electrode can be achieved the defect-free welds.

(4) Temperature measurement results confirmed that the zinc coating at the interface of two metal sheets is partially melted during the GTAW preheating process.

(5) The microhardness profiles of the welded joints shows that the HAZ is softened during laser/GTAW preheated welding process.

(6) For the tensile shear test, the welded joints usually failed in the HAZ zone and the test results indicated that the high strength had been achieved for the welds. Additionally, it was shown that the welding speed has no significant effect on the weld strength.



(*The tensile strength of the base materials is 980 MPa)

FIG. 18. The relationship between the average tensile shear strength and the welding speed.

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