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Influence of Gas Tungsten Arc Welding Parameters on the Formability of Aluminum Tailor Welded Blanks

R. Safdarian[a*]

[a] Department of Mechanical Engineering, Behbahan Khatam Alanbia University of Technology, Behbahan, Khoozestan, Iran.

Abstract: Automobile designers are always looking for new technologies to reduce vehicle weight and manufacturing costs. An opportunity to meet these seemingly conflicting requirements is through the use of Tailor-Welded Blanks (TWBs). Welding method and its parameters have an important effect on the formability and mechanical properties of TWBs. In this study, gas tungsten arc welding (GTAW) is used to join aluminum TWBs. Aluminum TWBs consist of 6061 aluminum sheets with different thicknesses of 1mm and 2mm. Main parameters of GTAW consist of welding current, shielding gas pressure, welding speed and diameter of filler material are investigated in the present study. Design of experiment based on the Tauguchi method is used to investigate the effect of each parameter and also parameters interaction. Erichsen formability test (out-of-plane forming test) is used for formability investigation of aluminum TWBs. Forming height of Erichsen test is used as a criterion to study the effect of GTAW parameters on the quality of aluminum TWBs. The obtained results indicate that shielding gas pressure and welding speed have the greatest impact on the formability of aluminum TWBs.

Keywords: Tailor welded blanks (TWBs), Gas tungsten arc welding; Formability, Erichsen, Design of experiment

1. Introduction

A Tailor-Welded Blank (TWB) consists of two or more sheet metal plates with same or different thicknesses or strength types which was welded together to produce a single blank before other manufacturing processes. Automobile designers are always looking for new methods to reduce vehicle weight and manufacturing costs. An opportunity to meet these seemingly conflicting requirements is through the use of Tailor-Welded Blanks (TWBs). The advantages of TWB technology can be summarized as (1) cost reduction by elimination of some forming dies; (2) weight reduction by using sheet with different thicknesses or strength for performance requirements; (3) increasing of corrosion resistance by eliminating of lap joints [1].

The use of lightweight materials can help to reduce vehicle weight and improve fuel economy. Aluminum usage in automotive applications has grown more than 80% in the past 5 years. A total of about 110 kg of aluminum vehicle in 1996 is predicted to rise to 250 or 340 kg, with or without considering of body panel or structure applications, by 2015 [2]. Using aluminum, TWB is another way to automotive weight reduction. There are different welding methods to join tailor welded blanks. In the first part of this section some researches are presented on the TWBs and their applications. Some researches in the field of GTAW of aluminum and its effective parameters are presented in the second part of literature. Safdarian Korouyeh et al. [3] investigated the efficiency of different numerical criteria for Forming Limit Diagram (FLD) prediction of TWB. Second derivative of thinning was a good numerical criterion for FLD prediction of TWB. Safdarian et al. [4] used Nd:YAG laser welding to weld steel TWBs with different thickness ratio. FLD of TWBs was investigated in their study. Their results showed that FLD's level was

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*Corresponding author (safdarian@bkatu.ac.it)

increased by thickness ratio decreasing. Parente et al. [5] investigated the effect of weld line orientation on the formability and FLD level of aluminum TWBs. They used friction stir welding to join aluminum TWBs which consist of AA 6061 and AA 5182 with equal thickness as base metals. Their results showed that the level of FLD and formability of aluminum TWBs will be decreased by increasing the weld line orientation.

Gas Tungsten Arc Welding (GTAW), commonly call TIG (tungsten inert gas), is a process that uses a non consumable tungsten electrode and an inert gas for shielding [6]. Heat source is an electric arc established between the tungsten electrode and the metals. The electrode and the weld are protected by a shielding gas, and filler metal may or may not be used. The filler metal will be melted by the heat of the arc. Because of the tungsten high melting point (3410˚ c), it is a good electrode material. Gas tungsten arc welding applicable to all metal in a wide range stock of thickness and also can be used for joining various combinations of dissimilar material. The most common application of GTAW is for stainless steel and aluminum. The advantages of TIG in its applications are suitable to produce high quality welds and also no weld spatter, because no filler metal is transferred across the arc.

Welding parameters have a great impact in the quality of a weld joint. Generally, the quality of a weld joint is directly influenced by the welding parameters during the welding process. Aesh [7] investigated the effect of GTAW on the weld bead dimensions. Their results showed that optimum GTAW bead dimensions can be achieved by good selection of tungsten electrode parameters and process variables. Chuaiphan and Srijaroenpramong [8] investigated the effect of welding speed on the microstructures, mechanical and corrosion properties in the welding of AISI 201 stainless steel. They used three different welding speeds in the gas tungsten arc welding. Their results indicated that using the high welding speed exhibited smaller weld bead size, higher tensile strength, elongation and higher hardness than those welded with medium and low welding speeds. Hong-gang et al. [9] used gas metal arc welding to join AZ31B magnesium alloy sheets. Microstructure and mechanical properties of welded samples were investigated. Their results showed that pores appeared at the top or bottom part of the weld and cracks could be generated due to the connection of pores. The tensile strength of the magnesium joints was close to the base metal despite the existence of pores in the weld. Fracture happened in the heat-affected zone or in base metal during tensile testing. Shiri et al. [10] used different filler materials in the GTAW of CP-copper to stainless steel. Their results showed that using Cu filler material caused no macro and micro crack formed in the fusion zone. Devendranath Ramkumar et al. [11] did an optimization on the GTAW parameters such as current and welding speed to achieve maximum penetration in the welding of super-duplex stainless steel thick plates. Two factors with three levels (Taguchi L9 orthogonal array) were used to determine the maximum penetration. Results showed that maximum penetration of 3.4439 mm with a heat input of 1.17 kJ/mm was obtained by current of 250 A and welding speed of 150 mm/min.

Kiaee and Aghaie-Khafri [12] did an optimization on the GTAW parameters such as current, welding speed and shielding gas flow rate in the welding of boiler parts made of A516-Gr70 carbon steel. They used Response Surface Methodology (RSM) for optimization. Tensile strength and hardness were considered as responses. Desired tensile strength and hardness were achieved at optimum current of 130 A, welding speed of 9.4 cm/min and gas flow rate of 15.1 l/min. Sudhakaran et al. [13] studied the effect of GTAW parameters on the pitting corrosion on AISI 202 chromium manganese stainless steel. Welding current, speed, gun angle and gas flow rate were GTAW parameters. Their results showed that welding speed and shielding gas flow rate have strong positive effect on pitting corrosion, but welding current and welding gun angle have strong negative effect on pitting corrosion. Safdarian et al. [14] investigated the effect of Nd:YAG laser welding parameters on the weld quality and mechanical properties of TWBs. They suggested the optimum welding parameters to join steel TWBs. Many other researchers have focused on the optimization of welding process parameters to obtain favorable mechanical properties [15-19].

Uniaxial tensile test was used in all previous researches for mechanical investigation of welded samples. Whereas welded samples are used in the forming process which is mainly out-of-plane forming, in the present study Erichsen test is used for mechanical and formability investigation of TWBs.

In the present study gas tungsten arc welding is used to join aluminum TWBs. Aluminum TWBs consist of 6061 aluminum sheets with different thickness of 1 mm and 2 mm. Analyzing the GTAW parameters effect on the formability of aluminum TWBs is the main purpose of present study. Therefore, main parameters of GTAW consist of welding current, pressure of shielding gas, welding speed and diameter of filler material are selected for investigation. Design of Experiment (DOE) based on the Tauguchi method is used to investigate the effect of each parameter and also interaction of parameters. Erichsen formability test (out-of-plane stretching forming test) is used for mechanical and forming behavior investigation of aluminum TWBs. Forming height of Erichsen test is used as a criterion to study the effect of GTAW parameters on the quality of aluminum TWBs. There is no study in the literature which studies the effect of GTAW parameters on the formability of TWBs. Whereas more tailor welded blanks are used in the out of plane forming process such as stamping or deep drawing, uniaxial tensile test which is used in other studies is not a proper test for formability investigation. Therefore, in the present study Erichsen formability test which is out-of-plane test is used for weld quality investigation of welded samples by GTAW. Investigation of GTAW parameters effect and their interaction on the formability of aluminum TWBs using Erichsen formability test is the novelty of present study. The main application of this study is in the aerospace and automotive industry.

2. Materials and Methods

2.1. Materials properties

The material used in this study was 6061 aluminum alloy, which is currently used in the Aircraft, aerospace and automotive industry. The chemical composition of this alloy is shown in Table 1.

Table 2 shows the mechanical properties of the AA6061 sheets studied in this work. The parameters – YS and UTS – were calculate using standard tensile test of ASTM-E8 at 2mm/min cross-head speed [20]. Base metals of TWBs were AA6061 with different thickness of 1 mm and 2 mm.

Table 1. Chemical composition of AA6061 used for experiments.

Mg	Si	Fe	Mn	Cr	Zn	Cu	Ti		Al
0.9	0.62	0.33	0.06	0.17	0.02	0.28	0.02		Bal

Table 2. Some mechanical properties of aluminum base metal from tensile tests.

Material	YS (N/mm^2)	UTS (N/mm^2)	Elongation (%)
AA6061	213	370	17.4

2.2. Welding of aluminum tailor-welded blanks

Gas tungsten arc welding (GTAW) was used for welding of 6061 aluminum alloy sheets which has different thickness and called tailor welded blanks (TWBs). TWBs consist of two or more blanks with different thickness or strength which are jointed together with one of the welding process and was formed in the forming processes. Figure 1 shows a schematic of TWB. Aluminum 4145 was used as filler material and Argon gas with purity of 99.99 percent as shielding gas in the GTAW of present study. As mentioned before, the main purpose of present study is the investigation of GTAW parameters effects on the quality of aluminum welded samples. Therefore, four parameters of this welding method which are the main parameters were selected with different levels. These parameters were welding current, shielding gas pressure, welding speed and diameter of filler wire. Two pressures of 4 and 5 bar were selected for shielding gas. Three values of 50, 53 and 57 ampere were selected for welding current and three sizes of 1.5, 2 and 3.2 mm for wire diameter of 4145 aluminum rod as filler material. Three values of 3, 8 and 12 mm/min were selected for welding speed. These parameters and their levels are shown in Table 3.

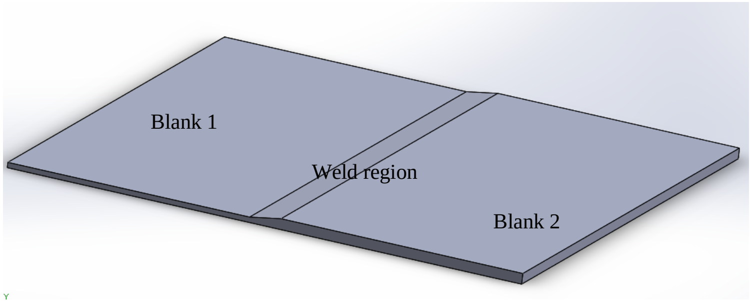


Fig. 1. Schematic of tailor welded blank.

Table 3. Factors and their corresponding levels.

Welding Parameters	Level 1	Level 2	Level 3
Gas pressure (bar)	4	5	-
Current (A)	50	53	57
Welding speed (mm/min)	3	8	12
Filler rod size (mm)	1.5	2	3.2

Design of experiment (DOE) is a structured method to determine the relationship between different factors and their effects on a process. The output of the process is determined by running tests at various levels of these factors. Tauguchi approach is a form of DOE with special application of principles. The DOE method is implemented by using Tauguchi approach, which is a standard form of experimental design technique. Based on the parameters of present study and their levels, L-18 Tauguchi array were used with four factors. Table 4 shows parameters arrangement for these 18 welding tests. For each TWB sample a blank of AA6061 with thickness of 1 mm and dimension of 100 mm×50 mm was welded to another blank with thickness of 2 mm and same dimension.

Table 4. L-18 Tauguchi array and experimental result.

Test num.	Gas pressure (bar)	Current (A)	Welding speed (mm/min)	Filler diameter (mm)	Forming height (mm)
1	4	50	3	3.2	5.0
2	4	50	8	1.5	5.2
3	4	50	12	2.0	6.6
4	4	57	3	3.2	5.7
5	4	57	8	1.5	6.7
6	4	57	12	2.0	5.4
7	4	53	3	3.2	5.9
8	4	53	8	1.5	5.6
9	4	53	12	2.0	6.5
10	5	50	3	3.2	5.2
11	5	50	8	1.5	5.6
12	5	50	12	2.0	6.7
13	5	57	3	3.2	6.2
14	5	57	8	1.5	7.1
15	5	57	12	2.0	7.2
16	5	53	3	3.2	5.3
17	5	53	8	1.5	7.1
18	5	53	12	2.0	7.5

Figure 2 shows some of samples after gas tungsten welding. It is clear from this figure that welded samples have good quality and there is no weld spatter because no filler metal is transferred across the arc. Thickness of weld line is the visible difference between the samples in Fig. 2 which is affected by thickness of filler material. Effect of other GTAW parameters on the formability of samples has been presented in Figs. 5, 7 and 8. It is clear from Fig. 2 that samples which were welded with filler material with diameter of 1.5 mm have a narrow weld line (samples 3, 6, 8, 11, 14 and 17), but samples with filler size of 3.2 mm (samples 1, 4, 7, 10 and 13) have a wider weld line. Decrease of filler diameter influence on the lack of fusion of weld region which is visible in samples 3, 6, 8, 11, 14 and 17.

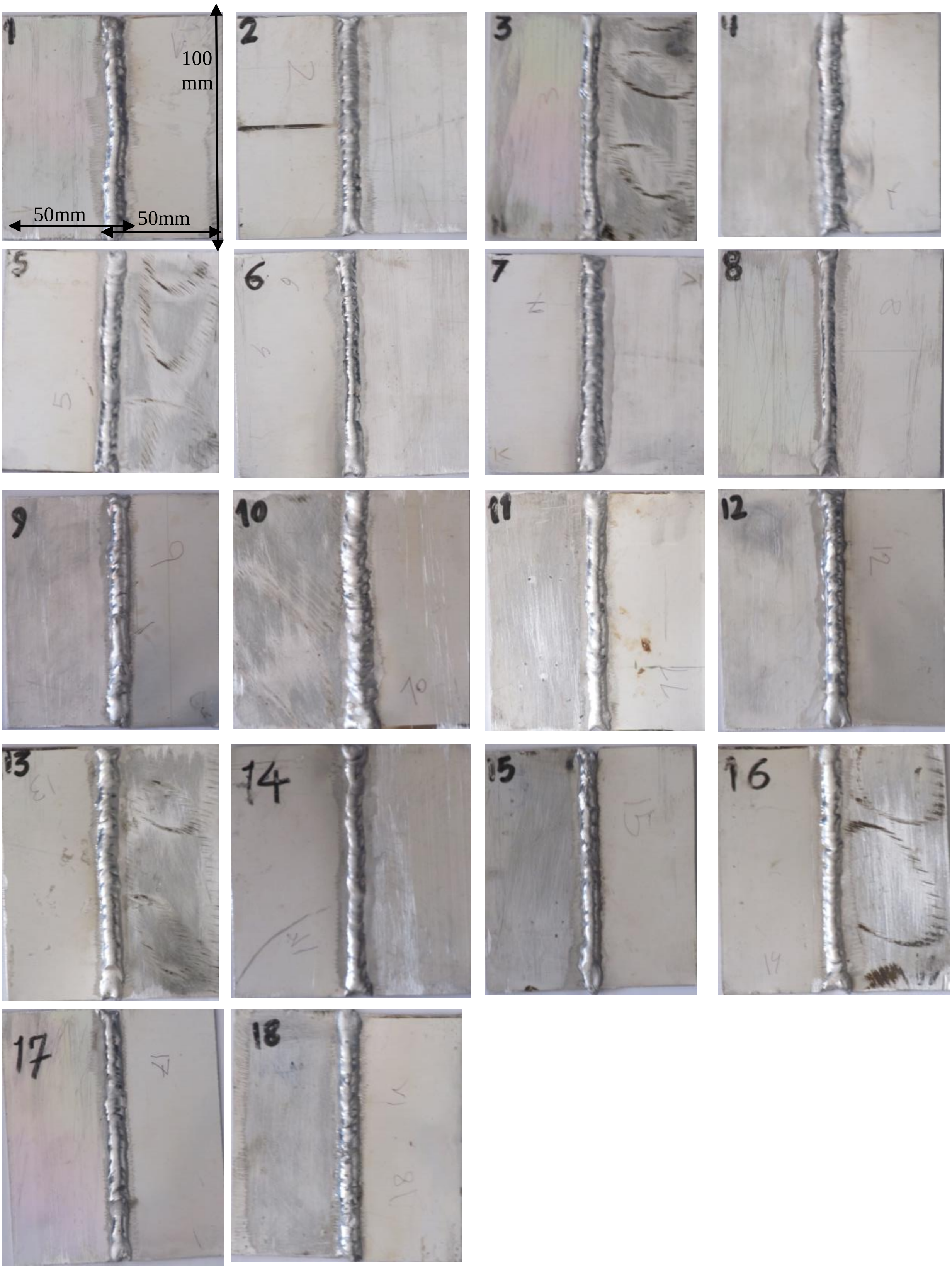


Fig. 2. TWB samples after GTAW.

2.3. Experimental setup for Erichsen Test

The first test for formability evaluation of sheet metal was proposed by Erichsen (ASTM E 643 [20]). The test consists of stretching a sheet specimen by means of a hemispherical punch until the occurrence of fracture. The depth of the punch penetration in the sheet specimen expresses the formability of sheet metals. Whereas welded samples are used in the forming processes which is mostly out-of-plane forming, in the present study Erichsen test was used for formability investigation of TWB samples. The schematic arrangement of the Erichsen tool and experimental setup (punch, die, blank holder) are shown in Fig. 3. This test consists of a hemispherical punch with diameter of 22.2 mm.

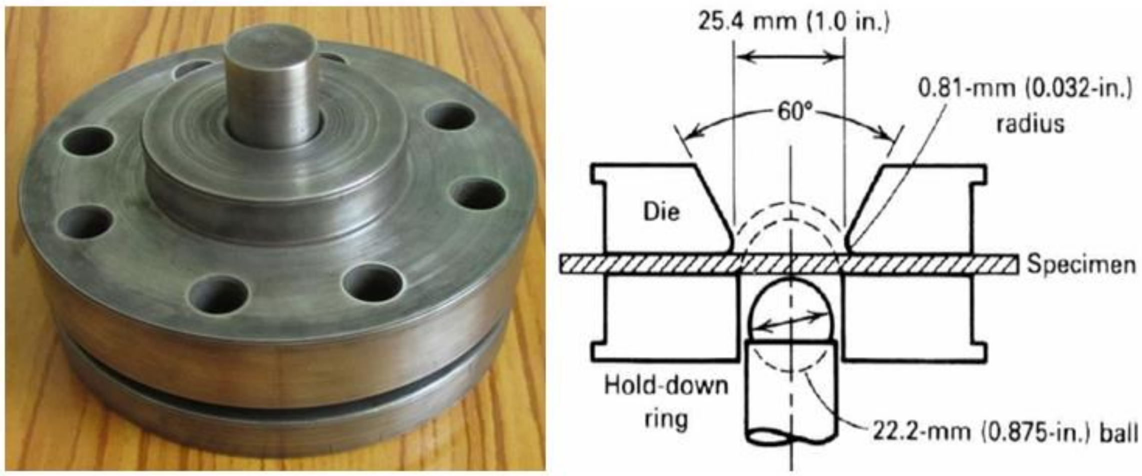


Fig. 3. Erichsen formability test setup.

3. Results and Discussion

3.1. Forming height of TWBs

Some of the aluminum TWBs after Erichsen test is shown in Fig. 4. This figure shows that fracture happened in the weld zone of all samples. This phenomenon can be explained by the formation of brittle phase in the fusion zone which resulted from existence of silicon element in the 6061 aluminum. As it is clear from Table 1, percent of Si in the 6061 aluminum is more than other elements. Therefore, lower ductility of weld zone caused by the high content of Si of the base metal which, when melted, leads to formation of brittle phase of eutectic silicon and affects the mechanical properties of the weld. Moreover, 6061 aluminum is highly crack sensitive because the majority of silicon and magnesium alloys which formed brittle Magnesium Silicide (Mg_2Si) particles in the fusion zone. This results was concluded by Dietrich et al. [21]. Forming height of samples from Erichsen test has been reported in the last column of Table 4.

3.2. Effect of GTAW parameters on the formability of aluminum TWBs

Forming height of Erichsen test is criterion of formability in this study. Effect of gas tungsten arc welding (GTAW) parameters on the forming height of Erichsen test is shown in Fig. 5. The effect of GTAW parameters on the forming height were investigated using Minitab software. It is clear from this figure that the increase in gas pressure, welding current and welding speed increases the forming height of TWBs. As this figure illustrates, the increase in filler diameter from 1.5 mm to 2 mm, increase the forming height, but filler with diameter of 3.2 mm has the lowest forming height.

As Fig. 5(a) shows, forming height of aluminum TWBs is increased by increasing the shielding gas pressure. The shielding gas pressure in the welding affects the processes of the nucleation, development and suppression of porosity of the weld metal [22]. Gas pressure increasing, reduces porosity, because of reduction in the diameter of the pores and increase the forming height of aluminum TWBs.

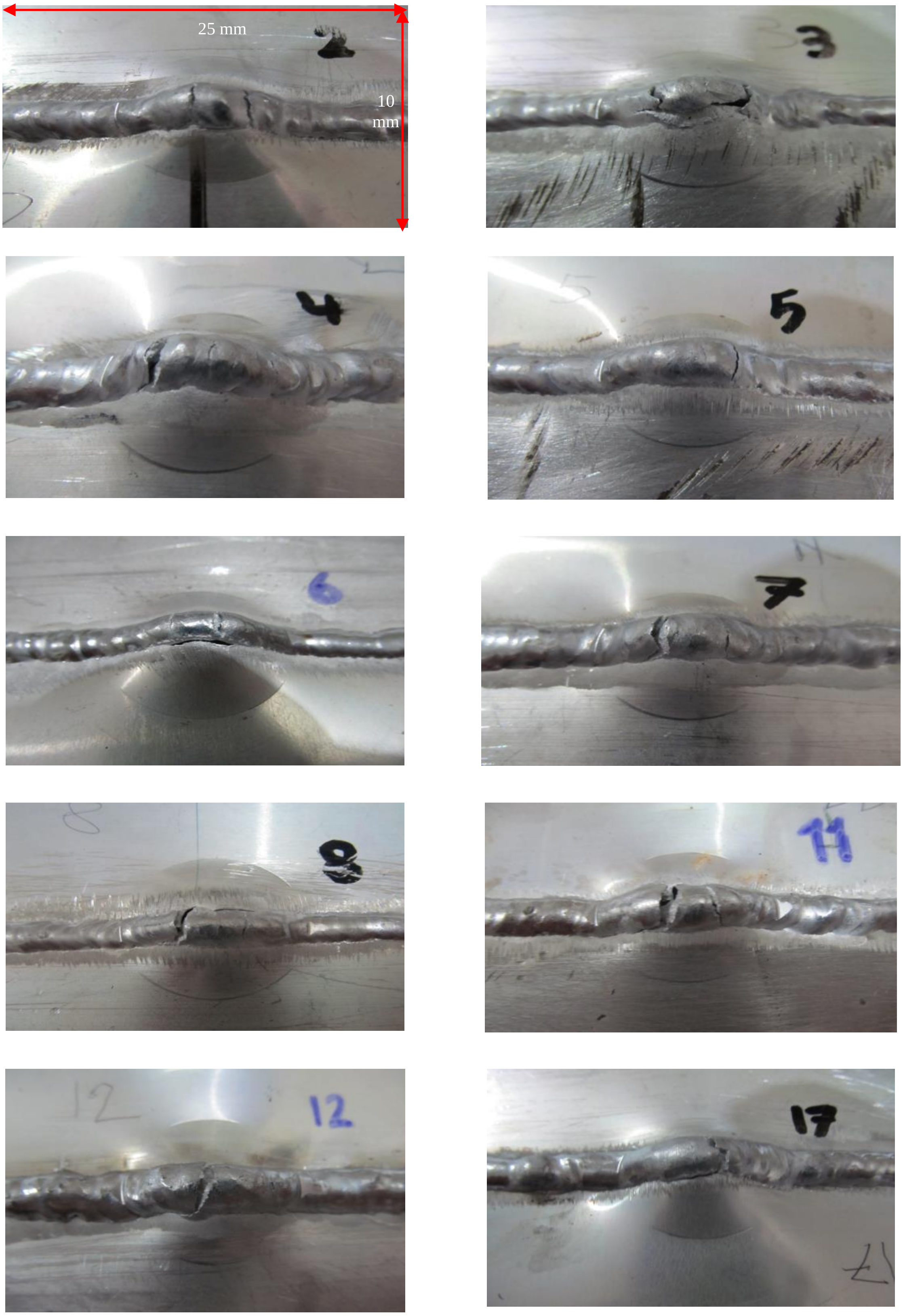


Fig. 4. TWB samples after Erichsen formability test.

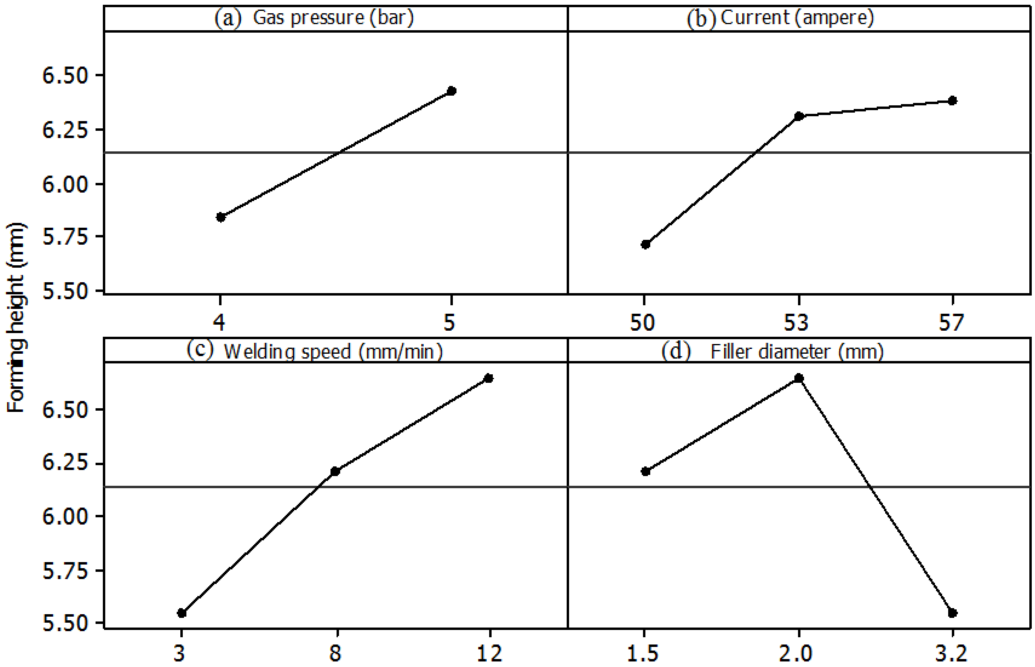
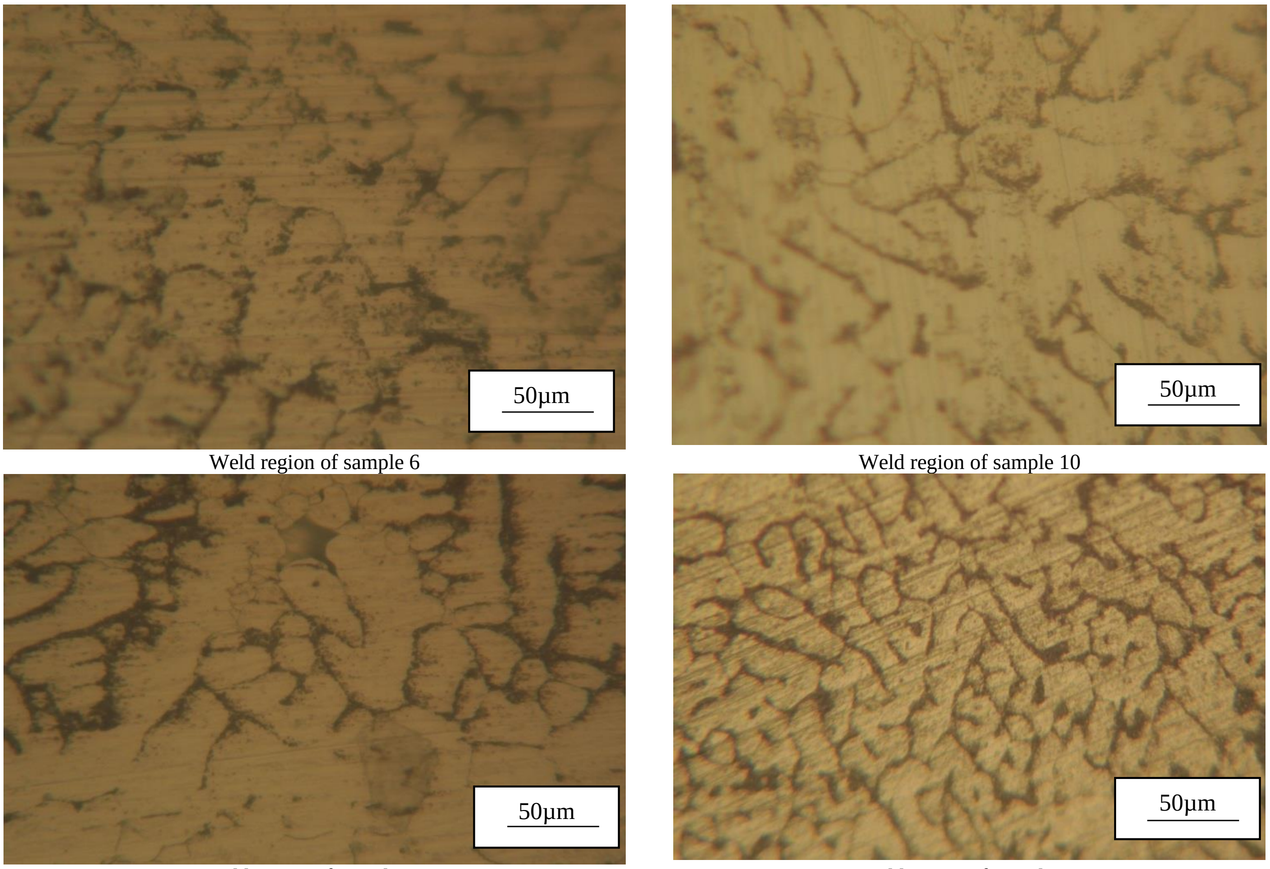


Fig. 5. Main effect plots for welding parameters via forming height of Erichsen test.

When the current was increased from 50 A to 53 A, the forming height of aluminum TWBs was increased (Fig. 5 (b)). This is the result of increasing the input heat to the fusion zone which causes increase of penetration and also formation of fine equiaxed grains in the fusion zone. By increasing of current from 53 A to 57 A, forming height doesn't increase as before. This phenomenon can be explained by the change of cooling rate. It is known that an increase in the heat input by increasing of current, results in slow cooling rate. Moreover, the slower the cooling rate during solidification, the longer the time available for grain coarsening. The formation of coarser grains in the fusion zone is responsible for slightly increase of forming height. As Fig. 5 (c) shows by welding speed increasing, heat input to the fusion zone decrease which leads to faster cooling rate and subsequently finer grain size in the fusion zone and increase the forming height. This result is similar to the results of Chuaiphan and Srijaroenpramong [8] that by increasing of welding speed, tensile strength was increased. Grain refinement is an important parameter which influences on the mechanical properties of welded samples. The smaller the grains, the more the grain boundary area forms a barrier against the propagation of atomic slipping from one grain to another. Furthermore, a high dislocation density increases the yield strength [23]. For better understanding of grain size effect on the forming height of TWBs, microstructure of weld metal region of some samples are shown in Fig. 6. Samples 6, 10 and 16 with coarse grain size in the weld region have low value of forming height. Using welding current of 57 ampere for sample 6, welding speed of 3 mm/min and filler diameter of 3 mm for samples 10 and 16 influenced on the weld grains structure of these samples. Heat input to the weld region of samples 6, 10 and 16 increased by using these parameters and caused formation of coarse grain structure in the weld region. Sample 17 with fine grain structure in the weld region has the highest value of forming height in the Erichsen test. Heat input to the weld region of sample 17 decreased by using welding speed of 8 mm/min, filer diameter of 1.5 mm and caused formation of fine grain size in this sample. However, increasing of welding speed in this study increased the forming height, but excessive increasing of this parameter decreases the penetration and weld quality.



Weld region of sample 6 | Weld region of sample 10

Weld region of sample 16 | Weld region of sample 17

Fig. 6. Microstructure of weld region of different TWBs produced by GTAW.

When diameter of filler material was increased from 1.5 mm to 2 mm, the forming height increased (Fig. 5 (d)). This increasing can be resulted from increasing of penetration and lack of fusion decreasing. By increasing of filler material diameter from 2 mm to 3.2 mm, forming height decreased which is resulted from decreasing of penetration. The effect of filler diameter on the weld penetration can be related to drop size separated from filler top. With increasing the filler diameter, weld drop size increases in constant arc length and heat input and big drops decrease penetration in compare to small drops. Moreover, the intensity of arc focusing on joint root decreases with increasing the filler metal diameter.

The population normality can be checked with a normal probability plot of residuals. This graph shows the residuals (the difference between the observed and the fitted response value) versus respective cumulative frequency percent. If the distribution of residuals is normal, the plot will resemble a straight line. The normal probability plot of the residual for forming height is shown in Fig. 7, which reveals the residual falling on the straight line. This shows that errors are normally distributed and the empirical relationship is correctly developed.

3.3. Interactive Effect of GTAW parameters on the formability of TWBs

Interactive Effects of GTAW parameters on the forming height of aluminum tailor welded blank are shown in Fig. 8. First row of this figure shows the interactive effect of shielding gas pressure and other welding parameters on the forming height. It is clear that forming height increases by gas pressure increasing from 4 to 5 bar and variation of other parameters. When the shielding gas pressure is maintained at 5 bar, by variation of filler diameter from 1.5 to 3.2 mm, the maximum of forming height happened at filler diameter of 2 mm. Using shielding gas pressure of 5 bar and increasing of welding speed from 3 to 12 mm/min increase the forming height. When the shielding gas pressure is maintained at

5 bar and as the welding current increases from 50 A to 53 A, the forming height increased, but it does not significantly change by increasing of current from 53 A to 57 A.

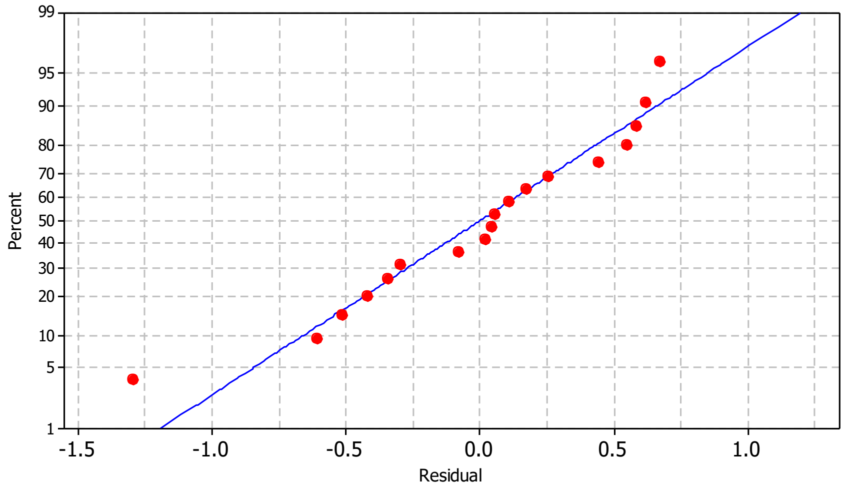


Fig. 7. Normal probability plot of residuals for forming height.

Interactive effects of welding current, filler diameter and welding speed are shown in the second row of Fig. 8. It is clear that by increasing of current from 50 to 53 A, trend of variations of forming height is similar and has the maximum value for filler diameter of 2 mm, but forming height has a different trend for welding current of 57 A and has the maximum height for filler diameter of 1.5 mm. Using welding current of 53 A and increasing of filler diameter from 1.5 mm to 2 mm, increases the forming height, but filler diameter increasing from 2 mm to 3.2 mm decreases it. As mentioned before, penetration reduction causes forming height decreasing. Third row of Fig. 8 shows interactive effect of welding speed and filler diameter. This figure shows that choosing welding speed of 3 mm/min and filler diameter of 3.2 mm lead to the lowest forming height, whereas using filler diameter of 2 mm and welding speed 12 mm/min lead to the highest forming height.

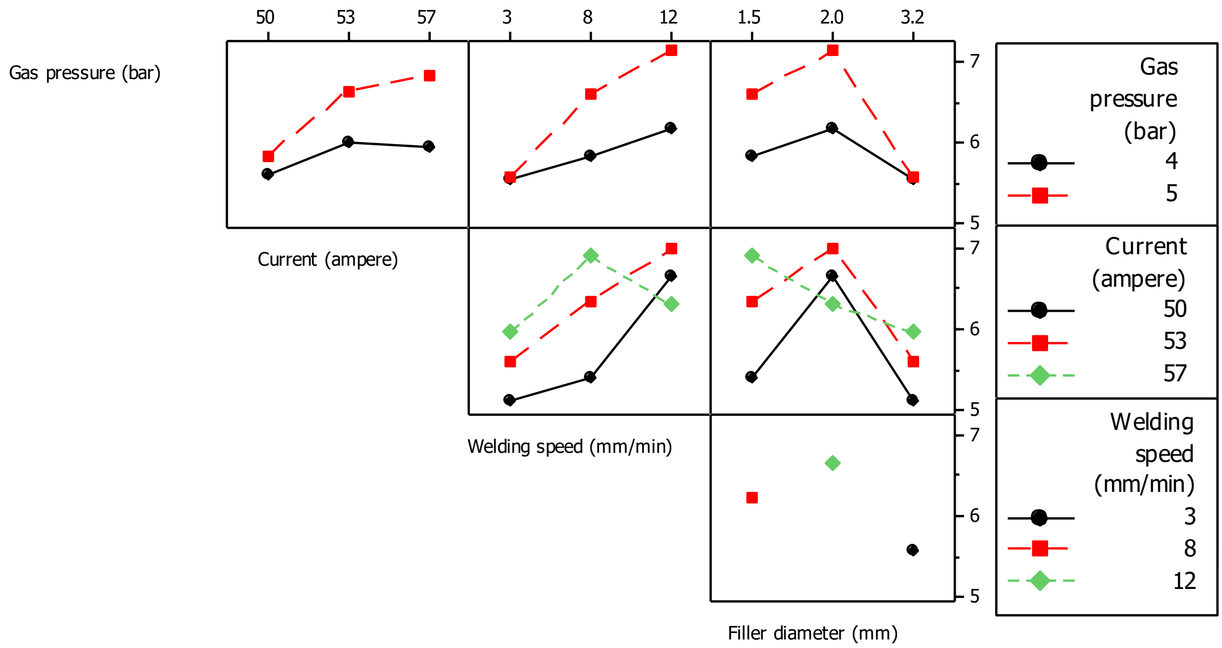


Fig. 8. Interactive effect of welding parameters on the forming height.

Another analysis was done by considering two input parameters with the forming height value as shown in Fig. 9(a-f). Fig. 9(a) shows that higher forming height can be obtained at welding speed of 10 - 12 mm/min and filler diameter of 1.6 – 2.5 mm. Figure 9(b) shows that the highest forming height i.e., > 7 mm can be obtained at shielding gas pressure of 5 bar and filler diameter of 1.8 – 2.25 mm. When considering gas pressure and welding speed, it is found that the highest value of forming height i.e., > 7 mm can be obtained at 12 mm/min welding speed and 5 bar gas pressure as shown in Fig. 9(c). When considering gas pressure and welding current, it is found that higher forming height can be obtained at gas pressure of 4.5 - 5 bar and welding current of 53 – 57 A as shown in Fig. 9(d). From Fig. 9(e) it is found that forming height value more than 7 mm can be obtained at welding current of 53 A and at filler diameter of 2 mm. Similarly from Fig. 9(f) it is found that higher value of forming height can be obtained at welding current of 53 – 56 A and at welding speed 10 - 12 mm/min.

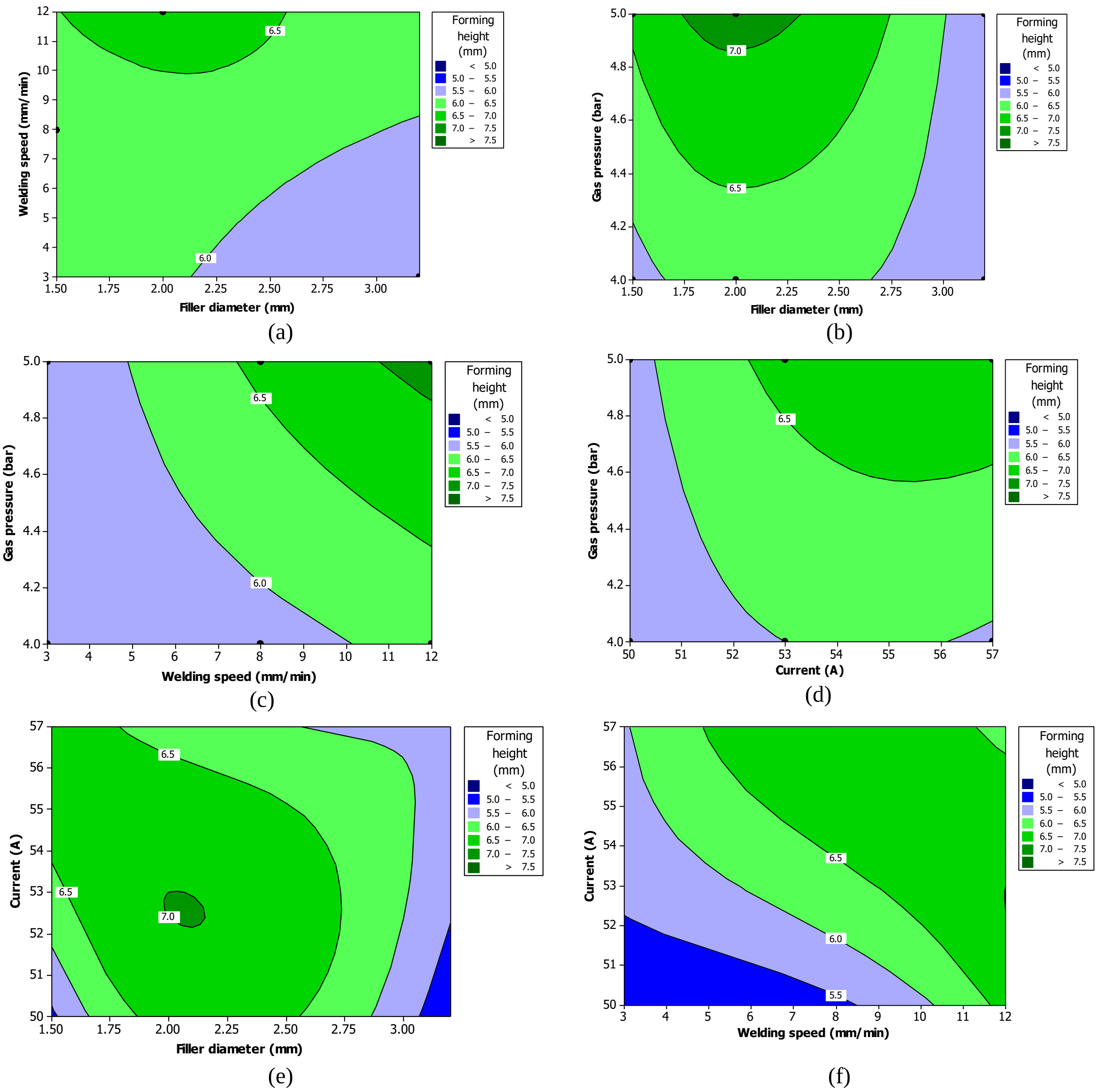


Fig. 9. Analysis of the forming height by Tauguchi method.

4. Conclusion

In the present study effects of GTAW parameters were investigated on the mechanical behavior of 6061 aluminum TWBs. These parameters were shielding gas pressure, welding current, welding speed and filler material diameter. Standard test of Erichsen was used for mechanical and formability investigation of welded samples. Results of this study can be summarized as follow:

1) Formation of brittle phase in the fusion zone which resulted from existence of silicon element in the 6061 aluminum caused fracture of TWB samples from fusion zone.
2) Because of pores diameter decreasing by increasing of shielding gas pressure, porosity was decreased and forming height of aluminum TWBs increased. Results of this study showed that gas pressure of 5 bar was better than 4 bar for GTAW of aluminum TWBs.
3) Increasing of welding current from 50 A to 53 A increased the forming height of aluminum TWBs. Increasing of input heat to the fusion zone which causes increase of penetration and also formation of fine equiaxed grains in the fusion zone caused increasing of forming height. By current increasing from 53 A to 57 A, forming height didn't increase as before which resulted from increasing of heat input to the fusion zone and cooling rate decreasing. The slower the cooling rate during solidification, the longer the time available for grain coarsening. The formation of coarser grains in the fusion zone is responsible for slightly increase of forming height. Therefore, welding current of 53 A is the best current for GTAW of 6061 aluminum.
4) By welding speed increasing, heat input to the fusion zone decreases which leads to faster cooling rate and subsequently finer grain size in the fusion zone and increases the forming height. Results showed that 12 mm/min was the best welding speed in GTAW of aluminum TWBs.
5) Increasing of filler material diameter from 1.5 mm to 2 mm increased the forming height which resulted from increasing of penetration and decreasing of lack of fusion.

With filler diameter increasing from 2 to 3.2 mm, weld drop size increases in constant arc length and heat input and big drops have poor penetration ability comparing with small drops. This phenomenon caused decreasing of forming height. Therefore, 4145 aluminum alloy filler material with diameter of 2 mm is the best selection for GTAW of 6061 aluminum.

5. References

[1] Z.Q. Sheng, Formability of tailor-welded strips and progressive forming test. *Journal of Materials Processing Technology* 205 (2008) 81-8.

[2] W.S. Miller, L. Zhuang, J. Bottema, A.J. Wittebrood, P. De Smet, A. Haszler, Recent development in aluminium alloys for the automotive industry. *Materials Science and Engineering: A*. 280 (2000) 37-49.

[3] R. Safdarian Korouyeh, H. Moslemi Naeini, G. Liaghat, Forming Limit Diagram Prediction of Tailor-Welded Blank Using Experimental and Numerical Methods. *J. of Materi Eng and Perform* 21 (2012) 2053-61.

[4] R. Safdarian Korouyeh, H. Moslemi Naeini, M.J. Torkamany, G. Liaghat, Experimental and theoretical investigation of thickness ratio effect on the formability of tailor welded blank. *Optics & Laser Technology* 51 (2013) 24-31.

[5] M. Parente, R. Safdarian, A. Santos, A. Loureiro, P. Vilaca, R.M.N. Jorge, A study on the formability of aluminum tailor welded blanks produced by friction stir welding. *Int J Adv Manuf Technol* (2015) 1-13.

[6] S. Kou, Welding metallurgy. John Wiley and Sons, New York, 1987.

[7] M.A. Aesh, Optimization of weld bead dimensions in gtaw of aluminum–magnesium alloy. *Materials and Manufacturing Processes*. 16 (2001) 725-36.

[8] W. Chuaiphan, L. Srijaroenpramong, Effect of welding speed on microstructures, mechanical properties and corrosion behavior of GTA-welded AISI 201 stainless steel sheets. *Journal of Materials Processing Technology*. 214 (2014) 402-8.

[9] H.-g. Dong, C.-q. Liao, L.-q. Yang, Microstructure and mechanical properties of AZ31B magnesium alloy gas metal arc weld. *Transactions of Nonferrous Metals Society of China*. 22 (2012) 1336-41.

[10] S.G. Shiri, M. Nazarzadeh, M. Sharifitabar, M.S. Afarani, Gas tungsten arc welding of CP-copper to 304 stainless steel using different filler materials. *Transactions of Nonferrous Metals Society of China*. 22 (2012) 2937-42.

[11] K. Devendranath Ramkumar, D. Mishra, B. Ganesh Raj, M.K. Vignesh, G. Thiruvengatam, S.P. Sudharshan, Effect of optimal weld parameters in the microstructure and mechanical properties of autogeneous gas tungsten arc weldments of super-duplex stainless steel UNS S32750. *Materials & Design* 66, Part A (2015) 356-65.

[12] N. Kiaee, M. Aghaie-Khafri, Optimization of gas tungsten arc welding process by response surface methodology. *Materials & Design* 54 (2014) 25-31.

[13] R. Sudhakaran, P.S. Sivasakthivel, S. Nagaraja, K.M. Eazhil, The Effect of Welding Process Parameters on Pitting Corrosion and Microstructure of Chromium-manganese Stainless Steel Gas Tungsten Arc Welded Plates. *Procedia Engineering* 97 (2014) 790-9.

[14] R. Safdarian Korouyeh, H.M. Naeini, M.J. Torkamany, J. Sabaghzadee, Effect of Laser Welding Parameters on Forming Behavior of Tailor Welded Blanks. *Advanced Materials Research* 445 (2012) 406-11.

[15] E. Gharibshahiyan, A.H. Raouf, N. Parvin, M. Rahimian, The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding. *Materials & Design* 32 (2011) 2042-8.

[16] A. Honarbakhsh-Raouf, H.R. Ghazvinloo, Influence of Wire Feeding Speed, Welding Speed and Preheating Temperature on Hardness and Microstructure of Weld in RQT 701-british Steel Produced by FCAW, 2010.

[17] E. Karadeniz, U. Ozsarac, C. Yildiz, The effect of process parameters on penetration in gas metal arc welding processes. *Materials & Design* 28 (2007) 649-56.

[18] B. Acherjee, D. Misra, D. Bose, K. Venkadeshwaran, Prediction of weld strength and seam width for laser transmission welding of thermoplastic using response surface methodology. *Optics & Laser Technology* 41 (2009) 956-67.

[19] M. Vasudevan, M.V. Kuppuswamy, A.K. Bhaduri, Optimising process parameters for gas tungsten arc welding of an austenitic stainless steel using genetic algorithm. *Trans Indian Inst Met* 63 (2010) 1-10.

[20] A.S.f.T.a.M. (ASTM), Metals Test Methods and Analytical Procedures, 1999 78–98, 501–8.

[21] D. Dietrich, D. Nickel, M. Krause, T. Lampke, M.P. Coleman, V. Randle, Formation of intermetallic phases in diffusion-welded joints of aluminium and magnesium alloys. *Journal of Materials Science* 46 (2011) 357-64.

[22] A.N. Ol'Shanskii, B.P. Morozov, Evaluation of the effect of increased pressure of shielding gas on the decrease in porosity of welded joints in aluminium alloys. *Welding International* 18 (2004) 304-6.

[23] P. Schempp, C.E. Cross, R. Häcker, A. Pittner, M. Rethmeier, Influence of grain size on mechanical properties of aluminium GTA weld metal. *Welding in the World* 57 (2013) 293-304.

تاثیر پارامترهای جوشکاری قوسی با گاز محافظ (GTAW) بر روی شکل پذیری ورقهای ترکیبی آلومینیم

رسول صفدریان

گروه مهندسی مکانیک، دانشکده فنی مهندسی، دانشگاه صنعتی خاتم الانبیاء بهبهان، بهبهان، خوزستان، ایران

چکیده: طراحان خودرو معمولاً بدنبال تکنولوژی های جدید برای کاهش وزن خودرو و هزینه ساخت هستند. یک فرصت برای دستیابی به این دو هدف ظاهراً متناقض، استفاده از ورقهای ترکیبی در ساخت بدنه خودرو می باشد. روش جوشکاری و پارامترهای آن دارای تاثیر مهمی بر روی شکل پذیری و خواص مکانیکی ورقهای ترکیبی می باشد. در این مقاله، از جوشکاری قوسی با گاز محافظ یا همان جوشکاری آرگون برای اتصال ورقهای ترکیبی آلومینیم استفاده می شود. ورق ترکیبی آلومینیم متشکل از دو ورق آلومینیم 6061 با ضخامتهای 1 و 2 میلیمتر می باشد. مهمترین پارامترهای جوشکاری آرگون شامل جریان الکتریسته، فشار گاز محافظ، سرعت جوشکاری و قطر فیلر در این مقاله بررسی می شود. طراحی آزمایش بر اساس روش تاگوچی برای بررسی تاثیر هر پارامتر و همچنین اثر متقابل پارامترها بر روی پارامتر پاسخ استفاده می شود. آزمایش شکل‌پذیری اریکسون (آزمون شکل دهی خارج از صفحه) برای بررسی شکل پذیری ورقهای ترکیبی آلومینیم استفاده می شود. ارتفاع شکل دهی آزمون اریکسون بعنوان معیاری در مطالعه تاثیر پارامترهای جوشکاری آرگون بر روی کیفیت ورق ترکیبی آلومینیم استفاده می شود. نتایج این مطالعه نشان می دهد که فشار گاز محافظ و سرعت جوشکاری دارای بیشترین اثر بر روی میزان شکل پذیری ورق ترکیبی هستند.

واژه های کلیدی: ورق ترکیبی (TWB)، جوشکاری آرگون، شکل پذیری، آزمون اریکسون، طراحی آزمایش