A Study on the Database Development of GMA Welding for Die Remodeling

J. T. Kim, S. J. Na, D. W. Kim and M. S. Seo

Abstract

Almost every die for automobiles must be corrected or remodeled for minor geometrical changes or for better hardness characteristics by an arc welding process. Although many other kinds of arc welding processes have been automated with robots, the molten metal deposition process for die remodeling still depends entirely on experienced welders.

In this study, a database for bead shapes with respect to welding parameters is constructed through experiments to automate molten metal deposition by the arc welding process. Changes in the welding parameters for inclined base metal are studied to consider the effect of die geometries on the welding process.

Key Words : Die remodeling, GMAW, Molten metal deposition, Experimental design

1. Introduction

Die remodeling is becoming increasingly important because of rapid model changes in the automobile industry. Consequently, most automobile companies have adopted molten metal deposition by welding processes and machining method to make minor changes in die remodeling, as is this one of the most inexpensive and effective processes. However, automation of this process has not yet been studied due to the complexity of die remodeling. As a result, the weld quality or process time is still entirely dependent on the skill of welders.

To automate the molten metal deposition for die remodeling, a database of bead shapes in GMA welding should first be constructed. In this study, appropriate welding parameters were selected, and then bead shapes with respect to the selected parameters were measured. Finally, mathematical models were developed to predict the molten metal deposition with these measured data.

2. Database of bead shapes on flat base metal

J. T. Kim and *S. J. Na* are with Department of Mechanical Engineering, Korea Advanced Institute of Science and TechnologyDaejeon 305-701, Korea

D. W. Kim and *M. S. Seo* are with Die Technology Department, Hyundai Motors, Ulsan 681-791, Korea

E-mail : sjna@kaist.ac.kr, TEL :+82-42-869-3256

2.1 Experimental design

To determine the bead shapes with respect to the welding parameters, appropriate ranges of welding parameters should be selected first. Table 1 shows fixed and variable welding parameters. Welding voltage was considered as a dependent variable, because it generally has a linear relationship with the welding current.

Table 1 Fixed and variable welding parameters

Fixed parameters	- Shielding gas (Ar 80% + CO_2 20% , flow rate : 18 l/min) - Power source (Inverter type) - Torch angle (90°) - No additional heat treatment
Variable parameters	- Welding current (voltage) - Welding speed - Nozzle-plate distance

After parameter ranges were selected, an experimental design matrix was set up. The experiments were based on the Central Composite Design Matrix of three-factor five level rotatable factorial technique (2^3 factorial design + 4 center points + 6 star points)[7]. The selected levels of the process parameters and the design matrix are given in Table 2.

Table 2 Factor level and Design matrix

(a) Welding parameter factor level

Parameter	unit	Factor level				
		-2	-1	0	1	2
Voltage/current	V/A	30/250	32/270	34/290	36/310	38/330
Welding speed	mm/s	5	6	7	8	9
Nozzel-plate distance	mm	10	12	14	16	18

(b) Design matrix

No.	Design matrix		
	V/A	Speed	Distance
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-2	0	0
10	2	0	0
11	0	-2	0
12	0	2	0
13	0	0	-2
14	0	0	2
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0

2.2 Measurement of bead shapes and result analysis

After conducting the experiments as per the design matrix, bead shapes were measured by a structured light laser vision sensor. Specifications of this vision sensor are listed below.

- Focal length : 15mm
- Field of view : 94mm × 43mm
- Resolution : 0.192mm × 0.048mm

From the images captured by the vision board, bead width, height and area were acquired in the following steps : (i) finding center of the laser strip by thinning process; (ii) finding feature points, such as bead ends and mid-point by noise reduction and linear regression technique; (iii) transforming 2D coordinates of the feature points to 3D range data through a calibration matrix; (iv) extracting bead dimension data with pre-defined bead geometry. An example of this process is shown in Fig.1.

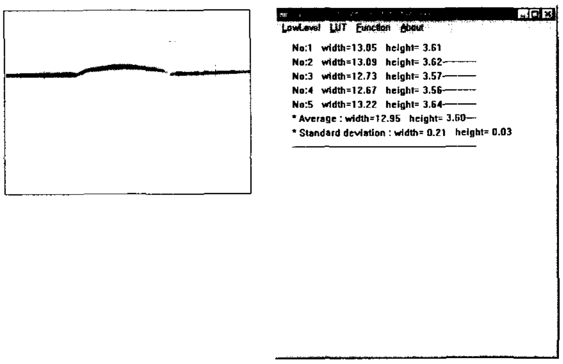


Fig.1 Measurement of bead shapes by laser vision sensor

This measurement was taken 30 times in one welding condition. Average and standard deviation were calculated as shown in Table 3.

Table 3 Results of bead shape measurement

No.	Width (mm), W		Height (mm), H		Area (mm^2), A	
	Average	SD	Average	SD	Average	SD
1	10.16	0.14	3.18	0.02	22.39	0.53
2	15.93	0.53	3.97	0.06	45.45	0.91
3	9.52	0.13	3.09	0.02	20.57	0.84
4	12.62	0.21	3.54	0.03	30.63	0.45
5	9.55	0.39	3.08	0.06	20.13	0.69
6	14.89	0.48	3.86	0.05	42.56	0.71
7	9.16	0.37	3.02	0.04	18.24	0.78
8	12.94	0.32	3.61	0.05	33.02	0.43
9	7.88	0.18	2.81	0.02	14.71	0.24
10	14.72	0.68	3.83	0.08	40.94	0.91
11	12.66	0.14	3.56	0.02	31.89	0.58
12	10.62	0.24	3.25	0.04	25.59	0.44
13	11.92	0.36	3.45	0.04	28.91	0.81
14	11.16	0.25	3.34	0.03	26.90	0.65
15	11.16	0.12	3.34	0.02	26.98	0.65
16	11.52	0.35	3.38	0.05	26.14	0.77
17	11.53	0.51	3.39	0.06	26.56	0.96
18	11.65	0.18	3.40	0.03	27.47	0.51

Regression analysis was used to develop the models. A response function representing any of the weld bead dimensions can be expressed as $Y = f(V, S, D)$, and a 2nd degree model was expressed as follows :

$$Y = b_0 + b_1 V + b_2 S + b_3 D + b_{11} V^2 + b_{22} S^2 + b_{33} D^2 + b_{12} VS + b_{13} VD + b_{23} SD \quad (1)$$

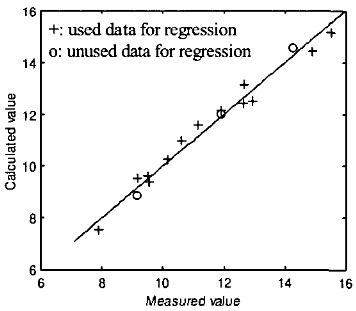
The final mathematical models as determined by the 2nd degree regression method were constructed by SAS computer program, and are represented below :

$$W = -63.5206 + 2.9891V + 5.8193S - 1.4216D - 0.0047V^2 + 0.0687S^2 + 0.0106D^2 + 0.2594VS + 0.0097VD + 0.0994SD \quad (2)$$

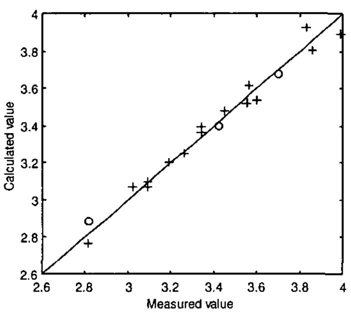
$$H = -8.7718 + 0.5502V + 0.7106S - 0.2458D - 0.0031V^2 + 0.0100S^2 + 0.0016D^2 + 0.0331VS + 0.0028VD + 0.0131SD \quad (3)$$

$$A = -179.3015 + 6.1664V + 29.5298S - 8.0426D + 0.07231V^2 + 0.5179S^2 + 0.0429D^2 - 1.2906VS + 0.12788VD + 0.3256SD \quad (4)$$

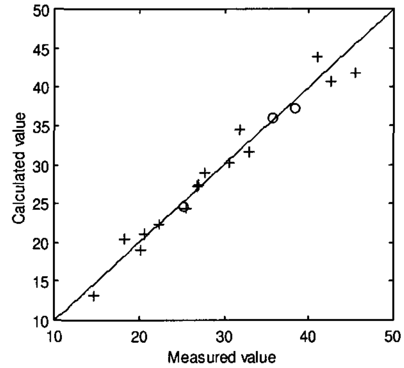
The mathematical models furnished above can be employed to predict the geometry of the weld bead for the range of parameters used in the investigation. Fig. 2 shows comparisons between measured and calculated data, and all of the models are considered adequate according to these figures.



(a) Width



(b) Height



(c) Area

Fig.2 Comparison between measured and calculated data

3. Bead shapes on inclined base metal

Welding voltage in inclined base metal reportedly should be lower than that in flat base metal to ensure the best welding quality[6]. The best welding condition was found to be 1V lower in the inclined base metal than the flat base metal condition. To compensate for bead run down by gravity force, the torch angle was inclined to the base metal, which makes a pushing-up effect by the arc pressure. However, too much incline angle seemed to cause more spattering and less shielding effect. Hence a torch angle of 80° to the base metal was decided in accordance with the experimental results.

Generally, a bead shape in inclined base metal has a tendency of run down in the gravity direction. This run down effect becomes greater as the bead area becomes larger, as in Fig. 3.

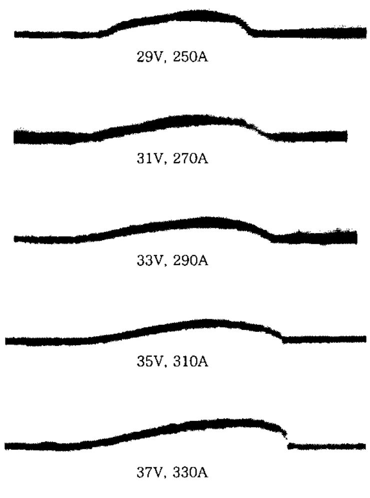


Fig.3 Bead shapes with 60° inclined base metal

To analyze this effect quantitatively, the horizontal incline angle and vertical incline angle were defined to the gravity direction as shown in Fig. 4. Experiments were conducted in inclined base metal with bead area increasing at each of the incline angle directions. Table 4 shows the 7 levels of bead area conducted.

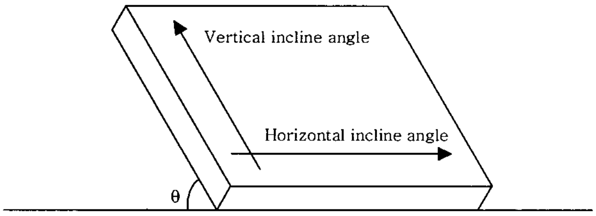


Fig.4 Definition of incline angles

Table 4 Selected bead areas and corresponding welding parameters

No.	Area(mm^2)	Parameters (voltage/current, speed, nozzle distance)
1	15	30V/250A, 7mm/s, 14mm
2	20	32V/270A, 8mm/s, 12mm
3	25	34V/290A, 9mm/s, 14mm
4	30	36V/310A, 8mm/s, 12mm
5	35	36V/310A, 7mm/s, 16mm
6	40	38V/330A, 7mm/s, 14mm
7	45	36V/310A, 6mm/s, 12mm

3.1 Marginal bead cross-section area for horizontal angle of inclination

A weld bead with a horizontal incline angle direction has different bead-end-angles at each end as shown in Fig. 5. Thus each side bead-end-angles were measured and the marginal bead angle difference was defined to distinguish an appropriate range of the weld bead area, because too much angle difference can cause defects when a multi-pass weld is conducted. Table 5 shows this marginal bead area, the shadowed region, at each incline angle.

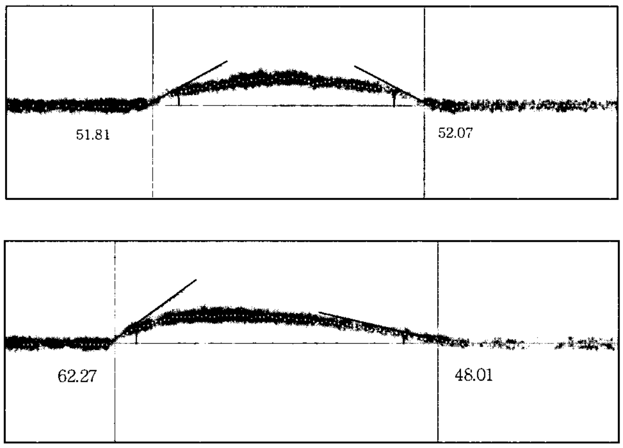


Fig.5 Measurement of bead edge angles

Table 5 Measured bead edge angles and maximum bead areas with respect to horizontal incline angles

Bead Area (mm^2)	30°			45°			60°		
	Edge angles		Difference	Edge angles		Difference	Edge angles		Difference
15	52.25	50.94	1.31	51.57	50.36	1.21	52.26	50.67	1.59
20	52.51	51.02	1.49	52.11	51.86	0.25	53.36	46.54	6.82
25	53.09	51.67	1.42	54.64	52.28	2.36	**60.99**	**46.51**	**14.48**
30	54.21	52.84	1.37	**60.38**	**49.96**	**10.42**	**68.77**	**37.97**	**30.80**
35	54.20	51.12	3.08	**65.35**	**43.23**	**23.12**	-	-	-
40	**62.27**	**48.01**	**14.26**	**70.13**	**21.08**	**49.05**	-	-	-
45	**69.80**	**40.38**	**29.42**	-	-	-	-	-	-

3.2 Marginal bead cross-section area for vertical angle of inclination

In welding with a vertical incline angle, the gravity direction is identical to the welding bead direction. Hence the weld bead shape is usually uneven due to the run down of molten metal. If the welding direction is opposite to the gravity direction, however, this run down effect could be lesser. Thus the welding direction was fixed to be opposite to the gravity direction.

Fig. 6(a) shows an uneven bead surface due to run down of molten metal. To analyze this quantitatively, experiments were conducted with variable incline angles. Table 6 shows the marginal bead area at each incline angle.

(a) Bead shape with run down of molten metal

(b) Normal bead shape

Fig.6 Bead shapes of vertical inclined welding

Table 6 maximum bead areas with respect to vertical incline angles

Angle	Max. Area
30°	25 mm^2
45°	20 mm^2
60°	NA

As shown in the above results, horizontal incline angle direction is more efficient than vertical angle in the sense of productivity. If there is no geometrical limitation, therefore, a horizontal incline angle direction should be selected.

4. Conclusion

The following conclusions were achieved from the results of the present investigation :

1. A five-level factorial technique can be employed easily for developing mathematical models for predicting the weld bead geometry within the region of control parameters.
2. Marginal weld bead areas were found in inclined base metal, and should be considered for the selection of appropriate welding condition.

After this study, an automatic pass and parameter generator should be developed. Development of an expert system should follow to find the optimum molten metal deposition method, for the given geometries of the current and remodel dies. Finally, an effective control system should be introduced to apply an automatic die remodeling machine in a production line.

Acknowledgments

This research was supported by BK21 and HMC's financial aid. The authors are grateful for their financial support.

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