An Investigation of Transverse Shrinkage in Single V and Bevel-Groove Butt Joints Using GMAW Process

Thi-Thao Ngo, Jin H. Huang, Chi-Chang Wang, and Van-The Than

Abstract This paper presents an investigation of transverse shrinkage in single V and bevel-groove butt joints using Gas Metal Arc Welding (GMAW) process. Comsol software is applied to set up a thermal model and simulate welding temperature as well as transverse shrinkage of two welded joint types with changing the groove angle and root opening. Results indicate that the transverse shrinkage increases with increasing the groove angle and root opening for both single V and bevel-groove butt joints. In addition, simulated transverse shrinkages are compared to experimental finding of previous publication. A good agreement of simulated and experimental transverse shrinkages is observed for both welded joints. It can be seen that the simulated model, initial conditions, boundary conditions, and setting heat sources on the simulation software is similar to the actual experimental conditions. The simulation method can be used to quickly predict not only the shrinkage of the butt weld, but also stress and distortion of other welds types using other welding processes.

Keywords Transverse shrinkage · Single V-groove · Bevel-groove · Root opening

1 Introduction

Welding distortion is an unavoidable factor that affects the workability and aesthetics of a structure. The welding distortion which caused by uneven heating and cooling of the weld and base metal can appear in a butt joint as longitudinal and transverse shrinkage [1]. The distribution of transverse shrinkage in the weld joint is uneven and depends on factors weld length, root opening, weld joint, weld process, groove angle, weld condition, etc. [2]. B. N. Sathyanarayana Reddy and N. Lakshmana

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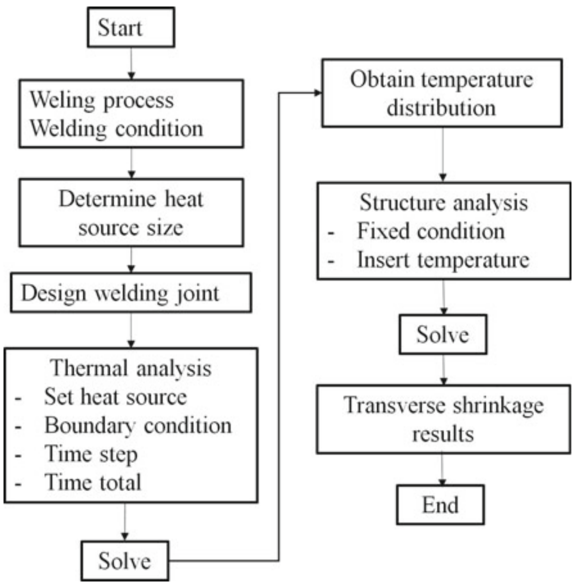
Swamy [3] studied on effect of groove angle in single V and double V-groove butt joints on transverse shrinkage in gas arc welding process. Besides, influence of bevel angle in bevel groove butt joints on shrinkages in CO_2 arc welding process was also researched and discussed [4]. In above literatures, many experiments were obtained to evaluate the imfact of the parameters on the transverse shrinkage of the welded joint. This gave reliable results, but it was costly and time consuming. In this study, the transverse shrinkages of single V and bevel-groove joint are quickly determined by applying Comsol software based on the finite element method. To evaluate the reliability of the proposed method, simulation results are compared with experimental results in previous researches [3, 4].

2 Simulation of GMAW

In this work, Comsol software is utilized to simulate the GMAW process based on finite element method. The Comsol software can quickly simulate and achieve high accuracy in the engineering field. In particular, material properties, process data, and boundary conditions can be arbitrary functions based on variables. A GMAW welding simulation sequence is briefly described in the following diagram as seen Fig. 1.

In order to obtain the result of the transverse shrinkage, a thermal problem must first be solved. A heat transfer problem is used to model the GMAW process with governing and boundary equations as below [5].

Fig. 1 A process to simulate welding transverse shrinkage



$$\frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k(T)\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)+q=\rho(T)C_p(T)\frac{\partial T}{\partial t} \quad (1)$$

where ρ, k and Cp are the density, thermal conductivity and heat capacity of the workpiece; t and T stand for time and temperature, respectively. In Eq. (1), q records an input arc heat according to the volumetric heat source. The general boundary condition can be expressed as:

$$k_n(T)\frac{\partial T}{\partial x}+h(T-T_0)+\sigma\varepsilon\left(T^4-T_0^4\right)=0 \quad (2)$$

A double semi-ellipsoid heat source is considered in this study with a smaller and a larger semi-ellipsoid at the back to calculate the arc heat energy in welding pool. The generated heat can be given as:

$$q=\frac{6\sqrt{3}f_i P\eta}{\pi\sqrt{\pi}a_i bc}\exp\left(-\frac{3x^2}{a_i^2}-\frac{3y^2}{b^2}-\frac{3z^2}{c^2}\right) \quad (3)$$

The semi-major, minor axes and depths of the front and rear ellipsoid are described as (a_1, b, c) and (a_2, b, c) which can be calculated as $a_1 = f_1 a$; $a_2 = f_2 a$; $c = \sqrt{\left(a^2-(a-a1)^2\right)}$; $b = (2a^3)/[(a_1+a_2)/c]$.

In addition, $P = \alpha U_h I_h$ is the arc power, α α, I_h and U_h are efficiency coefficient, current and voltage. α and η are set at 0.75 and 0.8, respectively [6]. The heat source is inserted in Comsol software as a function to determine temperature distribution in the workpiece.

In this work, mild steel (AISI 1018) is used as the base material. Single V and bevel-groove butt joint with different angle for various root openings are prepared in a single pass using the GMAW process for both of simulation and experiment. Workpieces with 250 × 250 × 8 in mm (length × width × thickness) are welded under welding conditions of 100 Amp current, 22 V voltage, 6 m/min wire feed rate using for all cases.

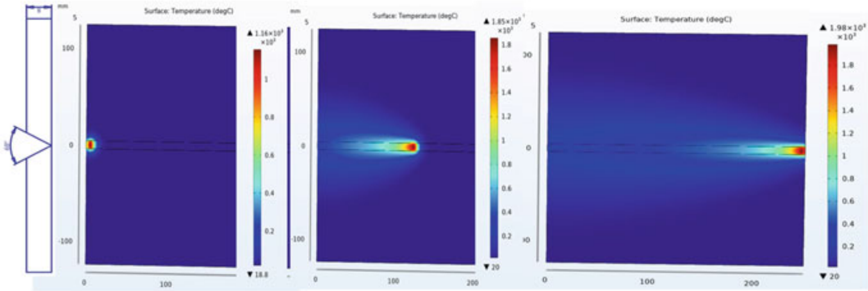
3 Results and Discussion

3.1 The Transverse Shrinkage in V Groove Butt Joint

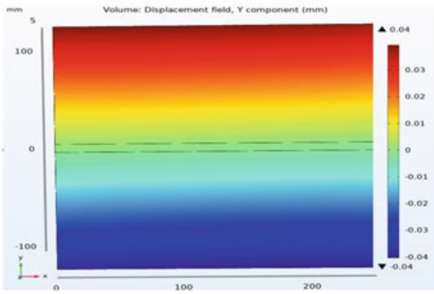
In order to investigate the transverse shrinkage in single V and bevel-groove butt joints, 12 cases are used to simulate for receiving the temperature distribution and shrinkage for each joint type. Table 1 shows 12 cases under groove angle of 0, 30, 45, 60 degree and root opening of 0, 1, 2 mm, respectively, for single V butt joint. Based on the welding conditions including current, voltage, velocity and joint type, the heat source dimensions are determined for each case. The heat source as given in Eq. (2) is inserted to Comsol software with related boundary condition, initial condition, etc. Figure 2 illustrates simulated results using the second case in Table 1. Obtained temperature distributions in the workpiece at various times are found in Fig. 1a. As seen, at beginning, the temperature is still low at about 1160 °C because of the unstable arc. This can be explained by the large amount of heat transferred to the initial workpiece, thus, the temperature is lower. Stable welding temperature is about 1850 °C. It is clear that the highest temperature reaches 1980 °C at the end of the weld line because there is overheating and heat transfer area is narrowed. Figure 2b represents the transverse shrinkage distribution of single V-groove butt joint. Results show that the symmetrical transverse shrinkage through the welding axis is 0.04 mm each side. Simulation transverse shrinkage of the other 11 cases is also summarized in Table 1. Table 1 shows that changing the groove angle, the transverse shrinkage tends to increase. At a groove of 0° and 60° the transverse shrinkages are the smallest and the largest, respectively. Thus, it shows that the transverse shrinkage increasing with increasing in the groove angle. According to Table 1, the root opening changes relative to the transverse shrinkage, it shows that increasing the root opening, the transverse shrinkage increases about 2.6 times compared to the absence of root opening (refer to case 1 and case 4). Thus, it can be seen that the shrinkage increases with increasing the groove angle and root opening. Therefore, in order to reduce the transverse shrinkage of the workpiece, the groove angle and root opening need be decreased.

Table 1 Heat source size and simulated transverse shrinkages for single V-groove butt joints

No.	Groove angle	Root opening	Heat source size				Transverse shrinkage (mm)
	β (deg)	α (mm)	b (mm)	C (mm)	a_1 (mm)	a_2(mm)	
1	0	0	8.9	7.5	4.9	11.5	0.07
2	30	0	8.9	7.48	4.9	11.4	0.08
3	45	0	8.99	7.55	4.94	11.5	0.13
4	60	0	9.01	7.65	5	11.6	0.18
5	0	1	8.88	7.46	4.88	11.3	0.18
6	30	1	8.92	7.49	4.9	11.4	0.23
7	45	1	8.99	7.55	4.92	11.5	0.24
8	60	1	9.08	7.65	4.99	11.6	0.3
9	0	2	8.88	7.46	4.88	11.3	0.28
10	30	2	8.92	7.49	4.91	11.4	0.34
11	45	2	8.98	7.54	4.93	11.5	0.38
12	60	2	9.06	7.61	4.98	11.6	0.46



a. Temperature distribution at different times



b. Transverse shrinkages

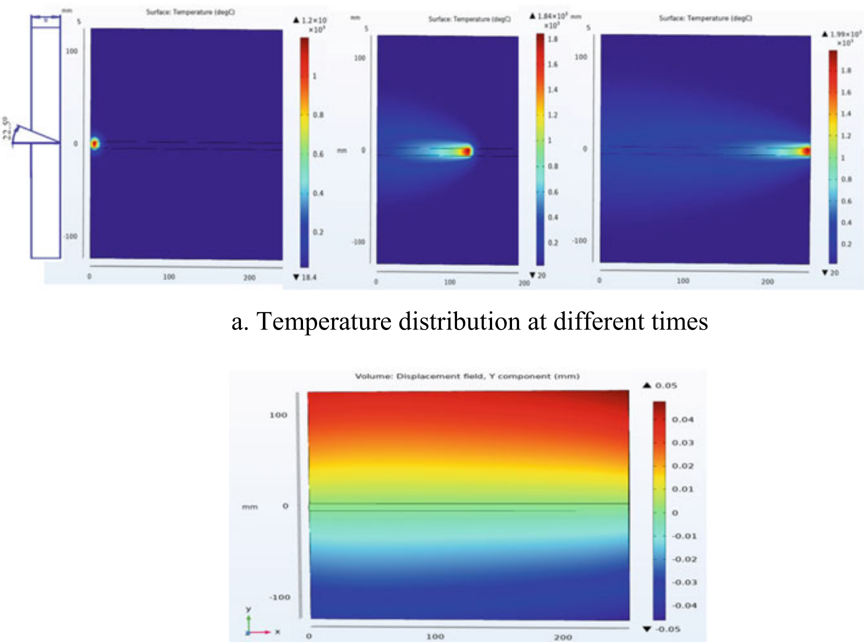
Fig. 2 Results of single V-groove butt joint for case 2

3.2 The Transverse Shrinkage in Bevel Groove Butt Joint

Similarly, 12 cases with different groove angles and root opening are performed for bevel-groove butt joint given in Table 2. Figure 3 depicts the temperature distribution in the workpiece and the transverse shrinkage of the weld using case 3 in Table 2. A stable welding temperature is obtained in the middle of the weld about 1840 °C, while the maximum transverse shrinkage is achieved at 0.05 mm on each side. The simulated transverse shrinkage of other weld joints with different root opening and groove angle is also summarized in Table 2. Results show that the transverse shrinkage increases with increasing chamfer angle and root opening. Theses transverse shrinkages are slightly smaller comparing to the results of the single V-groove joint. It may be due to the smaller volume of the molten metal of bevel-groove joint leading to the smaller shrinkage results in a smaller transverse shrinkage. Thus the type of joint also affects the transverse shrinkage of the weld.

Table 2 Heat source size and simulated transverse shrinkages for bevel-groove butt joints

No.	Groove angle	Root opening	Heat source size				Transverse shrinkage (mm)
	β (deg)	α (mm)	b (mm)	C (mm)	a_1 (mm)	a_2 (mm)	
1	0	0	8.9	7.5	4.9	11.5	0.07
2	15	0	8.88	7.46	4.88	11.4	0.07
3	22.5	0	8.99	7.53	4.94	11.5	0.1
4	30	0	9.03	7.58	4.96	11.6	0.2
5	0	1	8.88	7.46	4.88	11.3	0.19
6	15	1	8.93	7.5	4.91	11.5	0.2
7	22.5	1	9.02	7.58	4.96	11.6	0.24
8	30	1	8.93	7.51	4.99	11.7	0.26
9	0	2	8.88	7.46	4.88	11.3	0.28
10	15	2	9.01	7.56	4.95	11.5	0.31
11	22.5	2	9.06	7.62	4.95	11.6	0.36
12	30	2	9.14	7.68	5.02	11.7	0.47



a. Temperature distribution at different times

b. Transverse shrinkages

Fig. 3 Results of bevel-groove butt joint for case 2

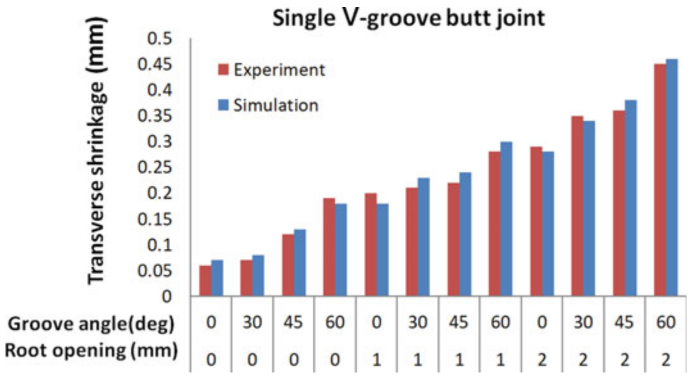


Fig. 4 Simulation and experiment transverse shrinkage of single V-groove butt joint

3.3 Comparison of Simulated and Experimental Results

To evaluate the reliability of the simulation results as well as simulation method, the simulated transverse shrinkage of both welded joints is compared to the experimental transverse shrinkage under the same conditions which has been published in references [3, 4]. Figures 4 and 5 show a comparison of simulation and experiment transverse shrinkage of single V and bevel-groove butt joints, respectively. A good agreement of simulation and experimental results is found in both Figures. As observed, the simulation shrinkages agree well with the experimental shrinkages in tend and value. A clear comparison with percentage error of simulated and experimental transverse shrinkage for each case is also shown in Table 3. Results show that although the error between simulation and experimental results still exists, the error value is within the allowable range except for cases 1 and 2 for both welding joint. From all results, the simulation method used in this study has high reliability. It can be applied to simulate not only shrinkage of butt joints, but also to other welding processes, other welding joints for determining welding stress and deformation as well.

4 Conclusions

Comsol software has been successfully used to determine the transverse shrinkage of single V and bevel-groove butt joints under various angle and root opening. Simulation results display that the transverse shrinkage increases with an increase in the groove angle and root opening for both welded joints. Simulated transverse shrinkage is compared to experimental transverse shrinkage in references [3, 4]. The simulated

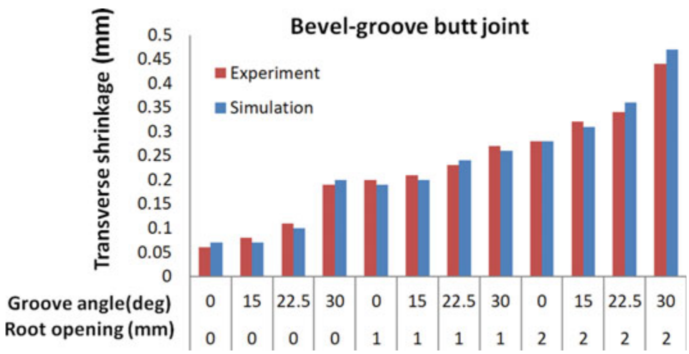


Fig. 5 Simulation and experiment transverse shrinkage of bevel-groove butt joint

results agree well with the experimental results. It can be said that presented simulation method is a reliable tool to quickly determine the shrinkage of the welded joint, thereby reducing the cost and time of experiments.

Table 3 Comparison of simulation and experiment transverse shrinkage

Transverse shrinkages/No.		1	2	3	4	5	6	7	8	9	10	11	12
Single V-groove joint	Simulation (mm)	0.07	0.08	0.13	0.18	0.18	0.23	0.24	0.3	0.28	0.34	0.38	0.46
	Experiment (mm)	0.06	0.07	0.12	0.19	0.2	0.21	0.22	0.28	0.29	0.35	0.36	0.45
	Error (%)	16.7	14.3	8.3	5.3	10.0	9.5	9.1	7.1	3.4	2.9	5.6	2.2
Bevel-groove joint	Simulation (mm)	0.07	0.07	0.1	0.2	0.19	0.2	0.24	0.26	0.28	0.31	0.36	0.47
	Experiment (mm)	0.06	0.08	0.11	0.19	0.2	0.21	0.23	0.27	0.28	0.32	0.34	0.44
	Error (%)	16.7	12.5	9.1	5.3	5.0	4.8	4.3	3.7	0.0	3.1	5.9	6.8

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