Influence of Root Gap and Tack Weld on Transverse Shrinkage during Welding†

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Abstract

Welding distortion is caused by the local shrinkage produced during the welding thermal cycle. The local shrinkage can be separated into four components, namely transverse shrinkage, longitudinal shrinkage, transverse bending and longitudinal bending. In this research, the influence of the root gap on the transverse shrinkage of welded joints is closely examined from the aspect of closing or opening of the root gap with the movement of the welding torch. Since the contact phenomena between the two surfaces forming the root gap are important, an interface element is introduced to a thermal elastic-plastic FEM. The butt welding model and fillet welding model are used to study the influence of gap size and the pitch of tack welding. Once the relation between the size of the gap and the transverse shrinkage is obtained, it can be introduced to the elastic FEM using the inherent deformation to predict the welding distortion of large structures.

KEY WORDS: (Welding deformation), (Transverse shrinkage), (Root gap), (Tack welding), (Finite Element simulation)

1. Introduction

Since welding is a technology to join materials by melting them with concentrated heat, the distortion and the residual stress are produced as an inevitable consequence. The welding residual stress and the distortion are produced by the local shrinkage existing near the welding line. Strain associated with such shrinkage is called inherent strain and its integration is called inherent deformation [1-3]. The inherent deformation has four components, namely transverse shrinkage, longitudinal shrinkage, transverse bending and longitudinal bending. These inherent deformations are mostly influenced by the heat input, thickness of the plate and the material properties. However, detail of welding procedure, such as the root gap and the arrangement of tack welds may influence the local shrinkage due to the welding, especially the transverse shrinkage. Abid and Siddique [4] pointed out the importance of the tack welding for predicting the distortion and the residual stress in girth welding of a pipe-flange joint. Shibahara et al. [5] discussed the influence of the root gap and the tack welds on the welding deformation in butt welding. Deng et al. [6] discussed the influence of these factors on the distortions of structures assembled by welding.

The transverse shrinkage due to welding may be separated into two parts. One is the plastic deformation produced in the region close to the welding line. The other is the closing or opening of the root gap. The former is basically influenced by the welding heat input. The latter is influenced by the initial root gap, the arrangement of tack welding and the welding condition. It is generally said that the root gap opens with the progress of welding torch when the welding speed and the heat input are large and it closes vice versa.

In this paper, the influence of the initial root gap and the arrangement of tack welds on the transverse shrinkage in butt welded joints and fillet welded joints are investigated through serial numerical simulation using FEM.

2. Preliminary study

To examine the influence of initial root gap and the arrangement of tack welding, preliminary experiments were conducted in a shipyard. In experiments, two rectangular mild steel plates were welded by two pass welding. The full size of the tested model is 600 mm in length, 400 mm in width and the thickness of the plate is 10.5 mm as shown in Fig. 1. The groove angle is 40^{o} and the four different initial gaps were selected, namely 0 mm, 1 mm, 2 mm and 6 mm. As for the tack welding, three test models with two, three and five tack weldings were prepared. Thus experiments were performed on twelve cases. The welding conditions for these cases are presented in Table 1.

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Thermal-elastic-plastic Finite Element Analyses were also conducted to simulate the experiments. For this computation, in house code JWRIAN [7] in which element birth and contact of root surfaces are considered, was employed. Figure 2 shows one example of the computed result for Case-3 in experiment. Distributions of transverse shrinkage along welding line measured between two points 100 mm apart crossing the weld line are shown for after the third tack welding to after the welding of the second pass. It is seen from this figure that the welding joint shrinks as a result of tack welding. The transverse shrinkage after the welding of the second pass is about 1 mm and it becomes larger toward the finishing end. The shrinkages measured after the first pass are compared with the computed results in Fig.3. The transverse shrinkages are plotted against the heat input. As it is expected, the shrinkage increases with the welding heat input in both experiments and computations. Comparing experiments and computation, the measured shrinkages are generally smaller than those predicted by the computation. This is due to the fact that the measurement of the shrinkage is done before the specimen completely cooled down to the room temperature. Figure 4 shows the relation between the size of initial root gap and the heat input. The heat input increases almost linearly with the initial root gap because a larger heat input is required to fill up a large root gap.

To closely examine the behavior of the root gap during welding, a model with only one tack weld at the starting end of the model was analyzed. Welding condition of Case-1 in experiment is selected. Figure 5 shows the transient temperature distribution and the deformation during the welding of the 1st pass. Point A and B are located at the starting end and the finishing end. It is clearly seen that the root gap is opening toward the finishing end. The same phenomenon can be seen from

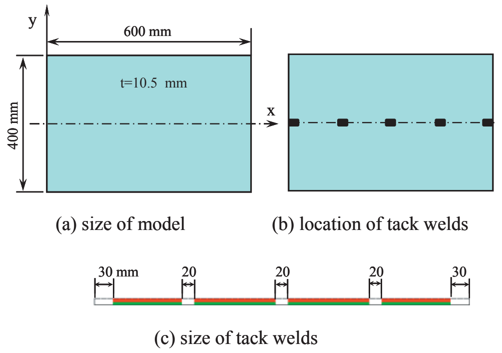

Fig. 1 Two pass welding model and tack weld arrangement.

Table 1 Welding condition in experiment.

Case No.	Gap (mm)	Tack	1st pass			2nd pass		
			Current	Voltage	Speed	Current	Voltage	Speed
1	0	2	300	32	8.84	280	32	7.96
2	0	3	310	32	14.82	280	32	7.98
3	0	5	320	34	20.83	290	34	7.69
4	1	2	310	33	9.02	283	34	6.71
5	1	3	293	34	8.86	293	35	5.75
6	1	5	276	34	15.38	273	34	5.4
7	2	2	260	35	6.5	273	34	5.34
8	2	3	290	30	6	293	31	4.96
9	2	5	267	30	5.46	273	34	5.34
10	6	2	256	34.5	4.64	283	36	4.63
11	6	3	267	36	4	300	34	4.27
12	6	5	297	34	4.13	300	34	4.2

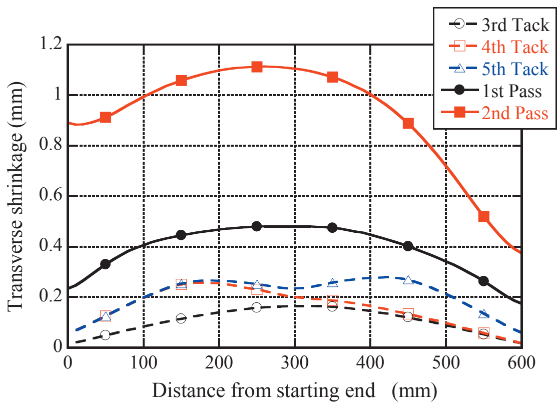

Fig. 2 Distribution of transverse shrinkage along welding line measured between two points 100 mm apart crossing weld line.

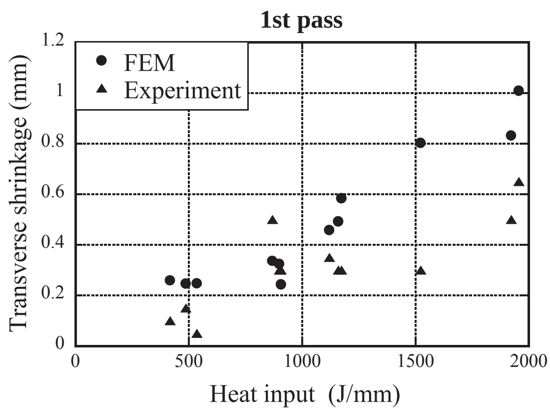

Fig. 3 Comparison of transverse shrinkage between experiments and computations.

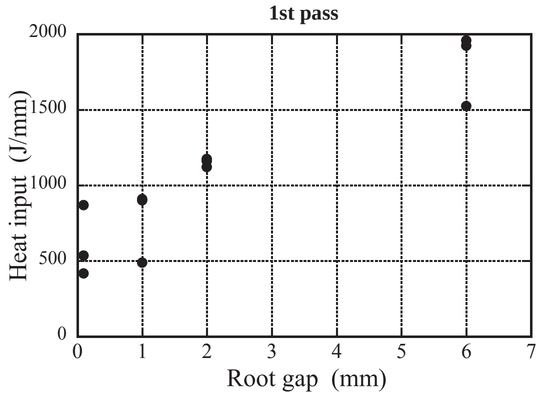

Fig. 4 Relation between initial root gap and welding heat input.

Fig. 6 which shows the shrinkage of the root gap at points A and B in Fig.5. During the welding of the first pass, the shrinkage at the finishing end B decreases. This means that the root gap is opening during the welding of the 1st pass. Once the 1st pass is completed significant shrinkage or opening of the root gap is not observed.

Using the model corresponding to Case-1, 2 and 3 in experiment the influence of tack welding arrangement is examined by computations. In these computations, the welding condition for Case-1 is used for all three cases and only the tack weld arrangements are different. Figures 7 and 8 show the distribution of shrinkage along the weld line at the root gap and that between two points 100 mm apart crossing the welding line, respectively. As it is shown by Figs. 5 or 6, the root gap has the tendency to open. The tack weld acts to prevent the opening of root gap and the shrinkage become large as a result as seen in Fig. 7. It is also seen from the figure that the dense tack weld is effective in maintaining uniform shrinkage at the root gap along the welding line. In the same way, the shrinkages between two points 100 mm apart crossing the welding line are compared in Fig. 8. Though the difference is small, the shrinkage becomes large when the interval of tack weld is small.

From these preliminary experiments and computations, the closure of the root gap with the progress of the welding torch is not observed and it is shown that the heat input increases almost linearly with the size of initial root gap and as a natural consequence that the transverse shrinkage increases when the root gap is large. It is also shown that the tack weld increases the transverse shrinkage slightly when the root gap has the tendency to open.

3. Influence of Root Gap in Welding of Butt Joint

When the heat input and the welding speed are small, it is expected that the tendency of the root gap to open is reduced or the root gap closes. In this section, two types of butt joint with relatively small heat input are selected and the influence of initial root gap on the transverse shrinkage is examined using FEM. The first model is shown in Fig. 9 together with the transient temperature distribution. The length and the width of the model are 400 mm and the thickness is 10 mm. The welding power and welding speed are assumed to be 1000 J/s and 5 mm/s, respectively. The cross-section of the model and

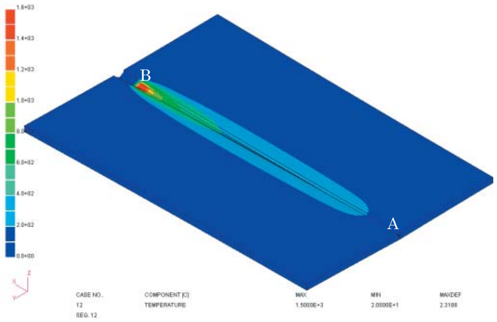

Fig. 5 Transient temperature distribution and opening deformation of root gap during welding of 1st pass.

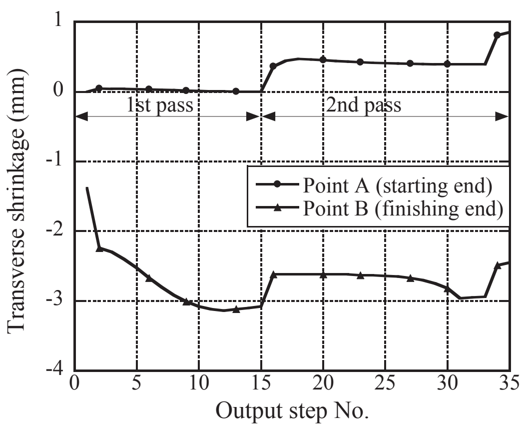

Fig. 6 Behavior of root gap at starting and finishing ends during 2 pass welding on model with open end.

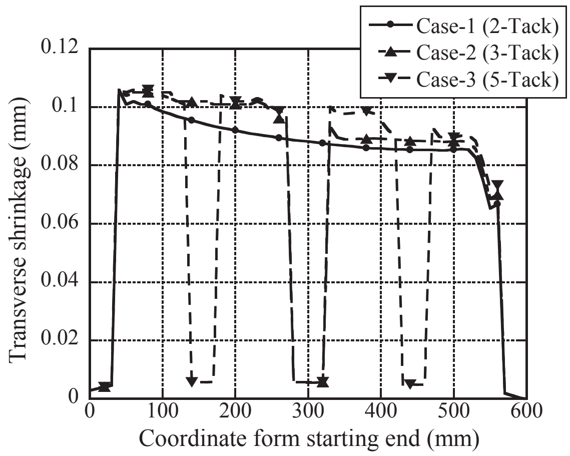

Fig. 7 Influence of tack weld on transverse shrinkage at root gap.

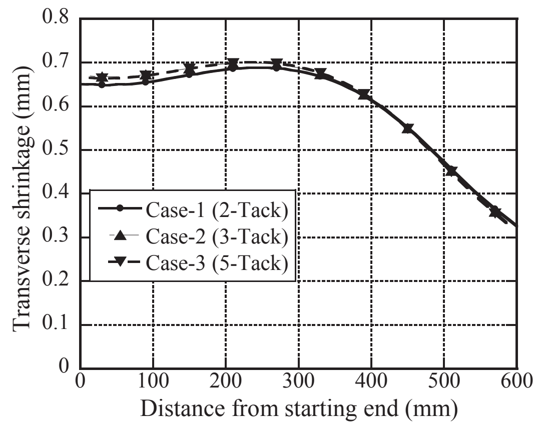

Fig. 8 Influence of tack weld on shrinkage of plate width.

the computed penetration shape are shown in Fig. 10. The groove angle is 90°. In this computation, four different values of initial root gap are assumed, namely 0.1, 0.5, 1.0 and 2.0 mm. Figure 11 shows the distribution of the Mises stress after the welding superposed on the deformed cross-section for the case in which the initial root gap is 0.5 mm. As it is seen from this figure, the root gap is completely closed after the welding. To closely examine the closure of the root gap and the shrinkage of the plate width, their distribution along the plate length are plotted in Fig. 12. The shrinkage or the closure of root gap is shown by broken lines and that of plate width is

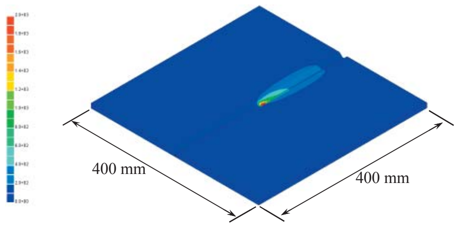

Fig. 9 Dimension of model and transient temperature distribution.

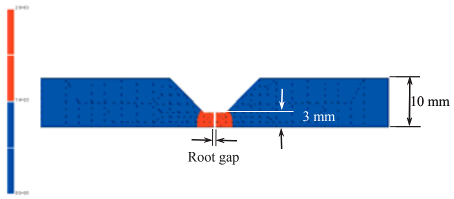

Fig. 10 Cross-section of model and penetration shape.

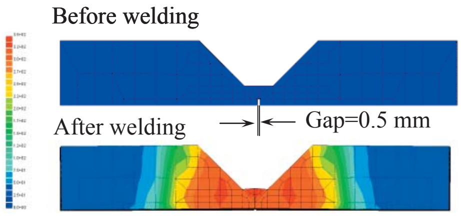

Fig. 11 Deformation of cross-section and Mises stress distribution before and after welding (initial gap=0.5 mm).

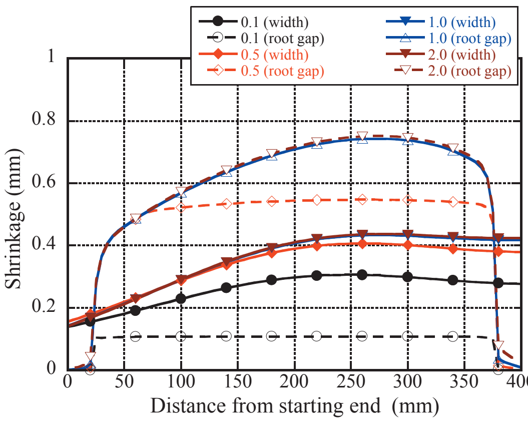

Fig. 12 Influence of initial root gap on distribution of shrinkage of root gap and plate width in welding direction.

shown by solid lines. When the initial root gap is smaller than 0.5 mm, the closure of the root gap is limited by the value of the initial gap. When the initial gap is larger than 0.5 mm, the root surfaces do not reach the contact and no difference is observed between the cases with different initial root gap. As for the shrinkage of the plate width shown by solid lines, the difference produced by the initial root gap is small compared to that at the root surfaces. These computed results are summarized as a relation between the initial root gap and the shrinkages in Fig. 13. The shrinkage between root surfaces is almost equal to the size of the initial root gap when the initial root gap is smaller than 0.5 mm in which the root surfaces are in contact after welding. This is reflected to the shrinkage of the plate width. However the influence is reduced by the stiffness of the plate and its order is 0.1 mm.

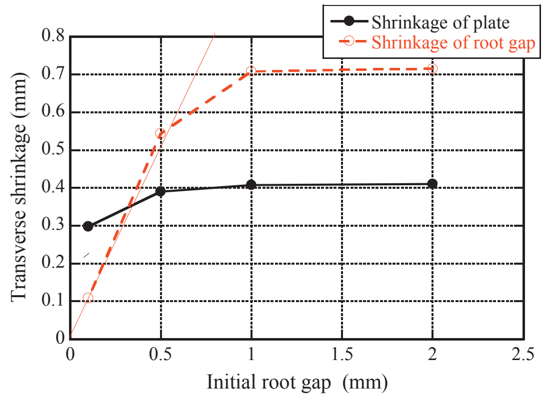

Fig. 13 Influence of initial root gap on shrinkage of root gap and plate width at center section.

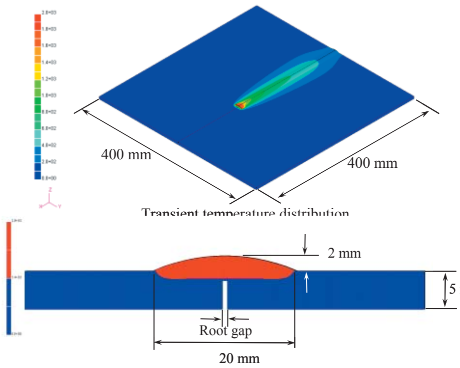

Fig. 14 Transient temperature distribution and penetration shape.

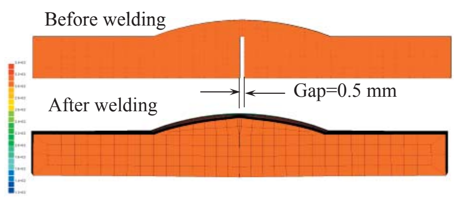

Fig. 15 Deformation of cross-section before and after welding (initial gap=0.5 mm).

The second model examined is a partial penetration welding with I-groove shown in Fig. 14. In this figure, transient temperature distribution and the computed penetration shape are shown. The size of the plate is 400 mm in length and width. The thickness of the plate is 5 mm. The welding power and the welding speed are assumed to be 1500 J/s and 5 mm/s, respectively. In this computation, three different values of initial root gap are assumed, namely 0.1, 0.5, and 2.0 mm. Figure 15 shows the cross-section of the model at the center before and after the welding. In this case the initial root gap is 0.5 mm and it is closed after the welding. The computed results are plotted in the same manner as in the previous butt joint mode. Figure 16 shows that the shrinkage between root surfaces is almost equal to the size of the initial root gap when the initial root gap is smaller than 0.5 mm in which the root surfaces are in contact after welding. Comparing the shrinkage of the plate width between cases with 0.1 mm gap and 2.0 mm gap, the difference is about 0.15 mm. The influence of the initial root gap on the shrinkage at the center section is summarized in Fig. 17. In this case also, the initial root gap directly influences the shrinkage at the root gap when the initial gap is small. Its influence on the shrinkage of the plate width becomes relatively small.

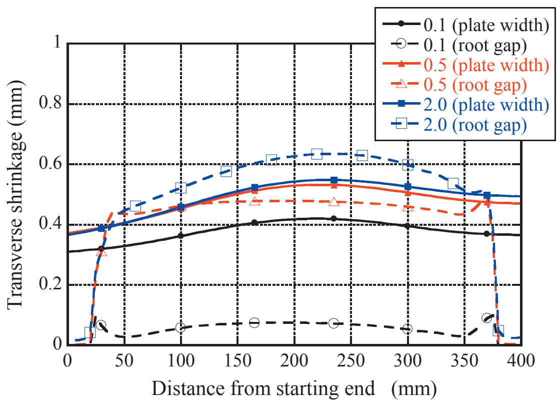

Fig. 16 Influence of initial root gap on distribution of shrinkage of root gap and plate width in welding direction.

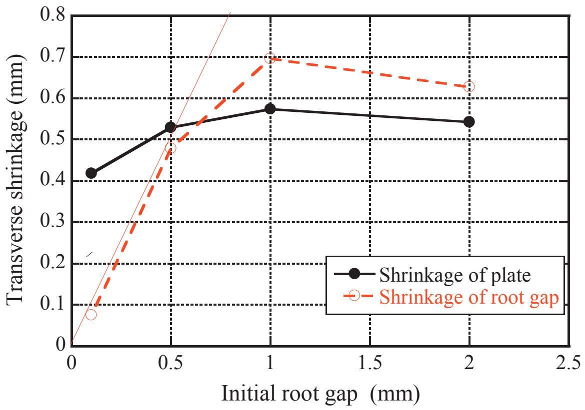

Fig. 17 Influence of initial root gap on shrinkage of root gap and plate width at center section.

4. Influence of Root Gap in Welding of Fillet Joint

As far as the cases we examined, influence of the initial root gap on the transverse shrinkage of butt joint is about the order of 0.1 mm. This may change when the joint is fillet joint. Figure 18 shows the fillet joint model studied. The length and the width of the model are 300 mm and 300 mm. The thickness of the flange and web plates is 10 mm. The size of the initial gap is changed from 0.1 mm to 0.7 mm. The welding current, voltage and speed assumed in FEA are 225 A, 24 V and 6.5 mm/sec. The heat input efficiency is assumed to be 70 %. Figure 19 shows the deformation of cross-section and Mises stress distribution before and after welding of the 1st pass (initial gap=0.5 mm). As seen from the figure, the root gap closes after the 1st pass welding. Figure 20 shows the influence of initial root gap on distribution of

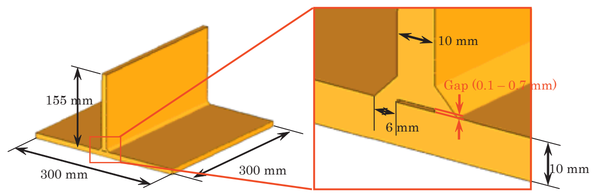

Fig. 18 Fillet weld joint model with initial root gap.

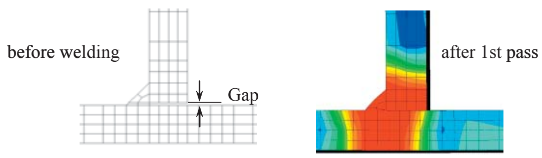

Fig. 19 Deformation of cross-section and Mises stress distribution before and after welding (initial gap=0.5 mm).

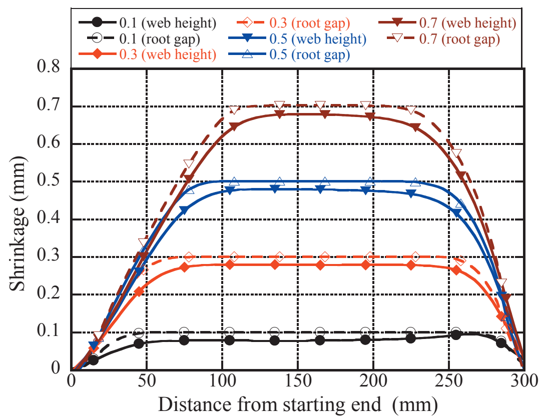

Fig. 20 Influence of initial root gap on distribution of shrinkage of root gap and web height in welding direction after 1st pass welding.

shrinkage of root gap and web height in welding direction after 1st pass welding. In this case, the root gap closes in all cases with initial root gap varying from 0.1 mm to 0.7 mm. The web height shrinks almost the same amount as the initial root gap. The relation between the initial root gap and the shrinkage of the web height is summarized in Fig. 21. The joint shrinks almost the same amount as the initial root gap by the 1st pass welding. Once the root gap is closed, the joint does not show significant shrinkage after the 2nd pass welding. Comparing with the cases of butt welding, influence of initial root gap on the shrinkage of the joint is large in case of fillet welding and the shrinkage is almost the same as the initial root gap. This difference comes from the fact that the stiffness of the flange of the fillet joint is small compared to that of the plate in butt joint. Therefore the root gap in the fillet welding must be carefully controlled to maintain geometrical accuracy of welded components and structures.

5. Conclusions

To minimize the transverse shrinkage produced by welding, the most influential factor is the heat input. For further improvement of geometrical accuracy of the welded structures, the influence of minor factors, such as the initial root gap and the arrangement of tack welds, is studied through numerical simulation and the following conclusions are drawn.

(1) The root gap in butt welding has the tendency to open in the cases studied in preliminary experiments and computations. This tendency becomes large when the heat input and the welding speed are large.

(2) When the root gap opens in butt welding, the transverse shrinkage increases slightly as the interval of tack welding becomes small.

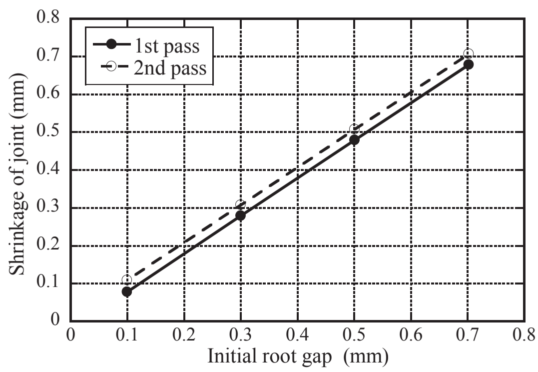

Fig. 21 Relation between size of initial root gap and shrinkage of web height at center section after 1st and 2nd pass welding.

(3) When the heat input and welding speed is small, the root gap has the tendency to closes. In such cases, the size of the initial gap influences the shrinkage of the plate width when the initial root gap is small so that the root surfaces become in contact during welding.

(4) In case of fillet joint, root gap has strong tendency to close and the initial root gap is directly reflected to the shrinkage of the joint because the stiffness of the flange plate is small. The root gap in fillet welding must be carefully controlled to maintain geometrical accuracy of welded components and structures.

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