Effect of Root opening on Distortion of Butt-Joints in Submerged Arc Welding

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ABSTRACT

The dimensional differences in steel bridge manufacturing caused by weld deformation often occur for butt joints of thin plates. The problems of distortion, residual stresses and reduced strength of structure in and around a welded joint are of major concern in the shipbuilding industry and other similar manufacturing industries. The various distortions induced by welding process and restriction of these distortions may lead to higher residual stresses. The prediction of distortions in ship panels are of great importance from the point of view of dimensional control. In view of this, it has been investigated the effect of root opening on the transverse shrinkage, longitudinal shrinkage and angular distortions of butt joints. The experimental investigations are carried out using Submerged Arc Welding with zero mm, 1 mm and 2 mm root opening for constant heat input. The transverse and longitudinal shrinkage increase but the angular distortion decreases with increase in the root opening.

Keywords: Distortion; Root Opening; Shrinkage; SAW; Butt Joints.

1.0 INTRODUCTION

Welding is most frequently used metal jointing method and the complex problem of welding distortion; it is an obstacle that must be overcome. During the heating and cooling cycles while welding, thermal strains occur in the weld metal and the base metal regions near the weld. The strains produced during the heating are accompanied by plastic upsetting. The stresses resulting from the strains combine and react to produce internal forces, causing shrinkage of the material. Depending on the shrinkage pattern, various structural deformations such as bending, buckling and rotation take place and these deformations are referred as welding distortion [1]. Distortion is an inevitable result of welding and is an undesirable deviation in the design dimensions and shape of the component after welding. The root cause for the distortion phenomenon is the non-uniform plastic deformation around the regions of the weld and contraction of the weld metal and plasticized zones during cooling. Depending on the shape of the component welded and the location and orientation of the weld, distortion occurs in several forms [2]. During the welding cycle, complex strains occur in the weld metal and the base metal regions near the weld. As a result, residual stresses remain even after welding is completed, and distortions are produced. Correcting unacceptable weld distortion is extremely costly and in some cases impossible. In addition, excessive distortion cause mismatch of joints thus increasing the possibility the welding defects will occur. Excessive lateral distortion decreases buckling strength of structural members that are subjected to compressive loading [3]. Thus, the development of proper techniques for reducing and controlling distortion would lead to more reliable welded structures with a reduction in fabrication cost.

In arc welding processes, due to rapid heating and cooling, the work piece undergoes an uneven expansion and contraction in all the directions. This leads to distortion in different directions of the work piece. Angular distortion is one such defect that makes the work piece distort in angular directions around the weld interface. The extent of angular distortion depends on the width and depth of the fusion zone relative to plate thickness, the type of joint, the weld pass sequence, the thermo mechanical material properties and the welding process control parameters [4]. Hence, various investigations were made to study the effects of various parameters on angular distortion. Kihara and Masubuchi [5] have made an experimental investigation of how various welding process parameters, including the shape of the groove and the degree of restraint, affect the angular distortion in butt joints. Hirai and Nakamura [6] conducted an investigation to determine the values of angular changes and coefficient of rigidity for angular changes as a function of plate thickness and weight of the electrode consumed per unit length of weld. Kumose et al. [7] studied how effectively elastic prestraining could reduce the angular distortion of fillet welds in low-carbon steel. Watanabe and Satoh [8] used a combination of empirical and analytical methods to study the effects of welding conditions on the distortion in welded structures. Mandal and Parmar [9] used a statistical method of two-level full factorial techniques to develop mathematical models, and reported that welding speed had a positive effect on angular distortion for single-pass or multipass welding [10].

Distortions induced by welding have been regarded as a critical issue in terms of performance, quality, and productivity. Many techniques have been developed to minimize the distortions induced by welding, such as external restraining, preheating, auxiliary side heating, heat sinking, and others. Masubuchi [11] summarized methods for reducing distortions in welded joints based on the research. He reviewed the general distortion-reduction methods in terms of weld dimensions, joint designs, welding processes, multipass welding, constraints, welding sequences, intermittent welding, and peening. Pavlovsky and Masubuchi [12] reviewed the various distortion control methods. Conrardy and Dull [13] reviewed the distortion control techniques applicable in thin ship panel structures. Park [14] developed a model to predict the thin plate panel distortion, and simulated the effect of welding sequences on the reduction of the distortions. Ohata et al. [15] introduced the preheating method to reduce the angular distortion in fillet welded aluminum thin plates, and finite element analyses to evaluate its effectiveness. Michaleris and his coworkers [Refs. 16, 17] studied the effect of thermal tensioning buckling in panel structures using tests and finite element analysis. Han [18] investigated how heat sinking and side heating affect the longitudinal cumulative plastic strain. Jung [19] developed the procedure, the so-called plasticity-based distortion analysis, which enables the investigation of the relationship between cumulative plastic strains and angular distortion in fillet welded T-joints [20].

When steel structures are welded, a localized fusion zone is generated in the weld because of the high heat input from the arc, and then non-uniform temperature distribution through heat conduction is induced. Therefore, non-uniform heat deformation and thermal stresses are included in the as-welded parts. As a result, plastic deformation is retained within the weldment and nonlinear plastic deformations and residual stresses exist after cooling of the welded joint [11, 21]. Many problems occur in the field because of dimensional differences that occur as a result of these weld deformations during manufacturing of large steel structures [22, 23]. The joint details of any welded structures have significant influence on the integrity of the structures; physical, metallurgical and mechanical discontinuities do exists in welds and may or may not deteriorate the structural fitness for the intended services [24]. The major portion of transverse shrinkage of a butt joint welded in a single pass is a result of contraction of the base metal. The base metal expands during welding. When the weld metal solidifies, the expanded base metal must shrink, and this shrinkage accounts for the major part of transverse shrinkage [25-28]. Distribution of transverse shrinkage along the weld is not uniform and depends on various factors including weld length, gaps, tack welds, welding sequences, edges preparations, welding conditions, restraint etc. The transverse shrinkage is maximum in the weld center and is minimum near the ends. The welding heat input can influence not only the value of shrinkage but also the distribution of transverse shrinkage along the weld [29]. The welding of dissimilar austenitic stainless steel and low alloy steel plate using pulsed current gas metal arc welding and Shielded Metal Arc Welding process for narrow and conventional gap butt joint of thick section were carried out, where, in Pulsed Current gas metal arc welding process heat input significantly in-hence the cumulative shrinkage and transverse shrinkage. Lower heat input gives lower cumulative deflection and transverse shrinkage-stress than higher heat input [30].

In this investigation, attempts are made to obtain the influence of root opening in butt joints on angular distortion, transverse and longitudinal shrinkages. The experiments are conducted on specimens for zero mm, 1 mm and 2 mm root opening in a single V-groove, bevel groove and double V-groove butt welded joints for designed process parameters using Submerged Arc Welding (SAW). The variation of root opening for 30° and 60° included angle and throat thickness of 5 mm and 7 mm in a single V-groove butt joints, 15o and 30o bevel angle and throat thickness of 5 mm and 7 mm in bevel-groove butt joints and 30° and 60° included angle and throat thickness of 3 mm on each side in double V-groove butt joints have been presented.

2.0 EXPERIMENTAL PROCEDURE

The commercially available mild steel used as the base material for welded specimens. Submerged Arc Welding equipment with electrode positive, the power source is basically a constant potential type is used as shown in the **Fig. 1.** The consumables include electrode wire with low manganese copper coated EL8 auto-melt grade-A in coil form of 2.5 mm diameter and aluminate-rutile type and agglomerated flux with grain size in the range of 0.25 to 2.0 mm have been used.

Unfortunately, the information available on the consumable for welding DI which will respond to isothermal heat treatment and converting ADI is still limited [24, 31]. The challenge of welding ADI therefore lies in developing welding electrodes which will compatible with ductile iron (DI) as well as respond austempering heat treatment in order to produce weld metal having microstructure similar to ADI and also to find out suitable welding conditions for crack free weld.

Successful welding of DI, which will be converted to ADI by austempering heat treatment, therefore requires understanding of interaction between the composition / microstructure of DI; filler metal composition and weld thermal cycle. This paper addresses the development of coated electrode for DI followed by suitable welding procedure to produce crack free welding and finally austempering heat treatment was performed to check the response of heat treatment applied to weld metal. Theoptical microscope (OM), scanning electron microscope (SEM), X-ray diffraction (XRD) and microhardness study were performed to characterize microstructures of the weldments (both as - welded and heat treated conditions).

Fig. 1 - Submerged Arc Welding equipment used in the fabrication

Table 1 : Edge preparations in V-groove butt joints

Sl. No.	Throat thickness (mm)	Included angle (deg.)	Root opening (mm)
1	5	30	0
2	5	30	1
3	5	30	2
4	5	60	0
5	5	60	1
6	5	60	2
7	7	30	0
8	7	30	1
9	7	30	2
10	7	60	0
11	7	60	1
12	7	60	2

Table 2 : Edge preparations in bevel-groove butt joints

Sl. No.	Throat thickness (mm)	Bevel angle (deg.)	Root opening (mm)
1	5	15	0
2	5	15	1
3	5	15	2
4	5	30	0
5	5	30	1
6	5	30	2
7	7	15	0
8	7	15	1
9	7	15	2
10	7	30	0
11	7	30	1
12	7	30	2

Table 3 : Edge preparations in double V-groove butt joints

Sl. No.	Throat thickness on each side (mm)	Included angle (deg.)	Root opening (mm)
1	3	30	0
2	3	30	1
3	3	30	2
4	3	60	0
5	3	60	1
6	3	60	2

The specimens for single V-groove are prepared for 30° and 60° included angle, 5-mm and 7-mm throat thickness by varying root opening. The bevel groove specimens are prepared for 15° and 30° bevel angle and 5 mm and 7 mm throat thickness by varying root opening. The double V-groove specimens are prepared for 30° and 60° included angle and 3-mm throat thickness on each side for different root opening. The root opening of zero mm, 1 mm and 2 mm in single V-groove, double V-groove and bevel groove butt joints are used in the edge preparations. The plates are tack welded at the ends to keep them intact in the position using manual metal arc welding for butt joints. The specimens are then measured for initial evenness before welding. The flux is heated in an electric oven to the temperature of 300°C to remove moisture content and then used for welding specimens. The specimens are welded in single pass by using submerged arc welding process. The thirty specimens are prepared as per the edge preparations as given in the **Table 1, 2** and **3**. The single V-groove, bevel-groove and double V-groove butt joints are shown in the **Fig. 2, 3** and **4**. The process parameters used are 350 Amp current, 22V voltage, 6 m/min wire feed rate, 0.25 m/min welding speed and 20 mm electrode extension in the welding process to prepare butt joints.

The angular distortion is measured using sine bar principle with the help of 3D Coordinate Measuring Machine. The specimen is placed on the flat surface of the measuring machine and fixed with one half of the specimen on flat surface of the measuring machine and measured the other half of the specimen for maximum height of deflection. The net distortion values before and after welding are obtained. The angular distortion is then found.

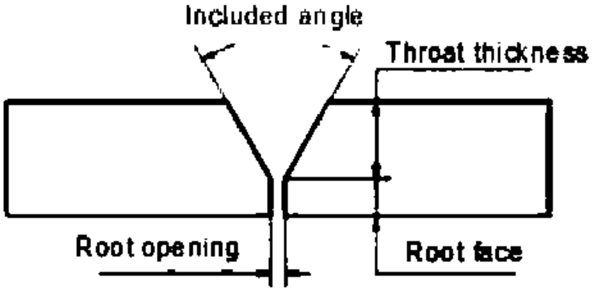

Fig. 2 - Single V-groove butt joint

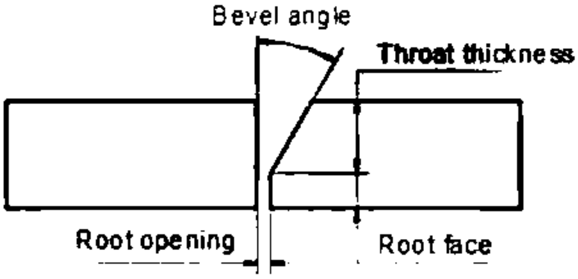

Fig. 3: Bevel-groove butt joint

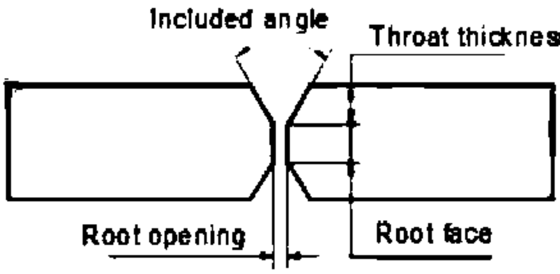

Fig. 4 : Double V-groove butt joint

The transverse and longitudinal shrinkages are measured at different locations of the specimen. Peak values of Transverse shrinkage perpendicular to the weld line and longitudinal shrinkages along the weld line are measured using digital vernier calipers and dial gauge before and after welding. The peak values of transverse and longitudinal shrinkages are at the center of the specimen [29]. Shrinkages measured at the center of specimens are the difference of the values recorded before and after welding. The effect of angular change on transverse shrinkage is taken into account during calculation of transverse shrinkage.

3.0 RESULTS AND DISCUSSIONS

The variation in angular distortion, transverse and longitudinal shrinkage with root opening are discussed for different groove angles and throat thickness with constsnt heat input in single V-groove, bevel groove and double V-groove butt joints in submerged arc welding.

3.1 Angular distortion

The angular distortion is induced by transverse cumulative plastic strain, which is distributed non-uniformly through the thickness of a plate [19]. The peak values of angular distortion of specimens with root opening for 30° and 60° included angle and throat thickness of 5 mm in single V-groove butt joints are as shown in the **Fig. 5**. It can be observed from the figure that, the angular distortion decreases with increase in the root opening for both included angles. When the root opening is increased, the distortion is reduced due to the deeper penetration of the weld nugget into the thickness of the joint and which changes transverse shrinkage along the thickness of the specimen [4]. The transverse shrinkage along the thickness of the specimen towards the bottom increases which leads to decrease in the angular distortion. The similar trend has been observed in the welded specimens of throat thickness 7 mm for 30° and 60° included angle in case of single V-groove butt joints as shown in the **Fig. 6**, which confirms that, the angular distortion decreases as increase in the root opening.

The variation of peak values of angular distortion of specimens with root opening for 15° and 30° bevel angle and throat thickness of 5 mm and 7 mm in bevel-groove butt joints are as shown in the **Fig. 7** and **8**. It shows that, the angular distortion decreases with increase in the root opening similar to single V-groove butt joints.

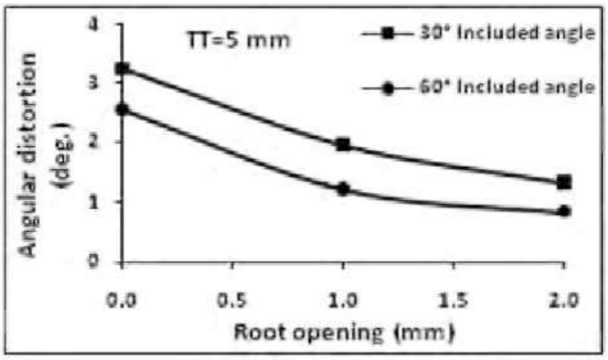

Fig. 5 - Variation of angular distortion with root opening for 5 mm Throat Thickness (TT) in single V-groove butt joints

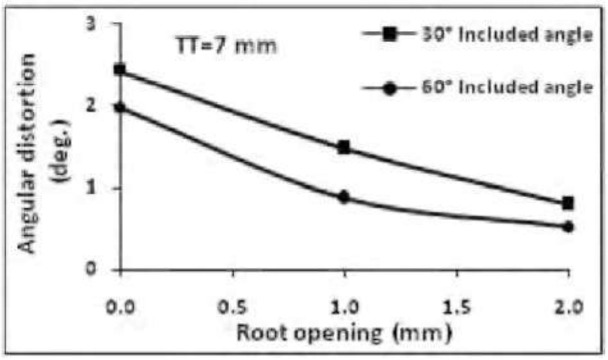

Fig. 6 - Variation of angular distortion with root opening for 7 mm Throat Thickness (TT) in single V-groove butt joints

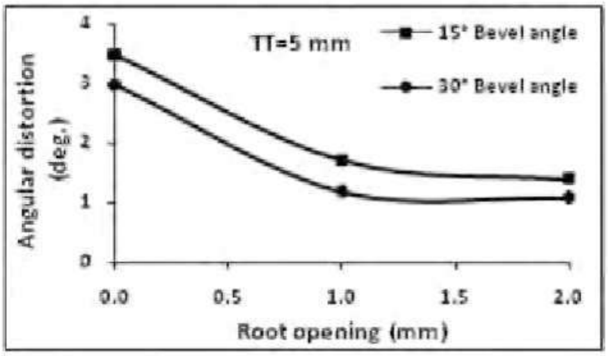

Fig. 7 - Variation of angular distortion with root opening for 5 mm Throat Thickness (TT) in bevel -groove butt joints

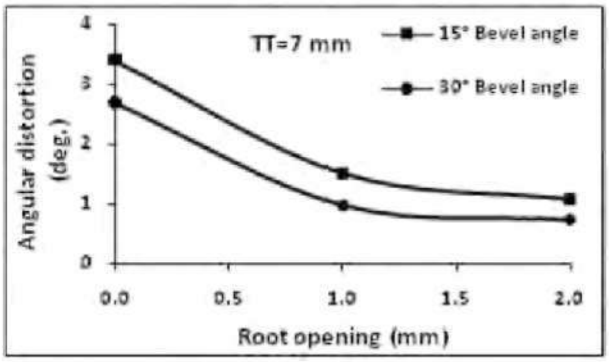

Fig. 8 - Variation of angular distortion with root opening for 7 mm Throat Thickness (TT) in bevel -groove butt joints

In double V-groove butt joints, the angular distortion of specimens with root opening for 30° and 60° included angle is shown in the **Fig. 9**. This shows that, the angular distortions in double V-groove butt joints are not significant and there is a small change with increase in the root opening. This is due to the angular distortion induced by welding on one side is almost balanced by the welding on the other side.

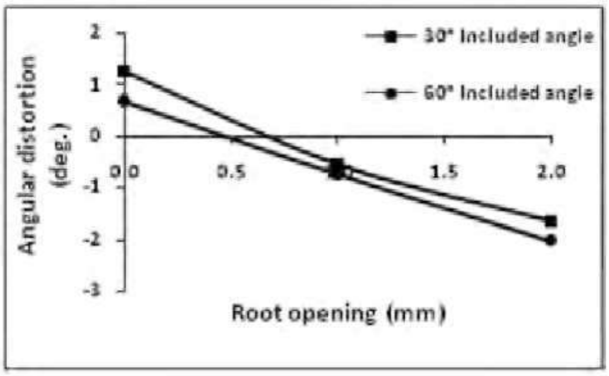

Fig. 9 - Variation of angular distortion with root opening in double V-groove butt joints

The angular distortion observed in specimens with 30° groove angle is higher values than the specimens with 60° groove angle in single V-groove butt joints. Similarly the angular distortion observed in specimens with 15° groove angle is higher values than the specimens with 30° groove angle in bevel-groove butt joints. With respect to throat thickness, the angular distortion found higher values in specimens of 5 mm throat thickness when compared with specimens of 7 mm throat thickness. For larger value of groove angle and throat thickness, the distortion is smaller; this is due to the fact that, the deeper penetration of the weld metal into the thickness of the joint [4].

3.2 Transverse Shrinkage

The maximum transverse shrinkage of specimens increases with increase in the root opening for 30° and 60° included angle and throat thickness of 5 mm in single V-groove butt joints as shown in the **Fig. 10.** The increase in the transverse shrinkage with increase in root opening is due to the increase in the groove area with the greater volume of weld metal which would contract more on solidifying, therefore resulting in greater dimensional shrinkage of the weld metal [28]. The similar trend has been observed in the welded joints of throat thickness 7 mm in single V-groove butt joints as shown in the **Fig. 11** confirming the transverse shrinkage increases with increase in the root opening.

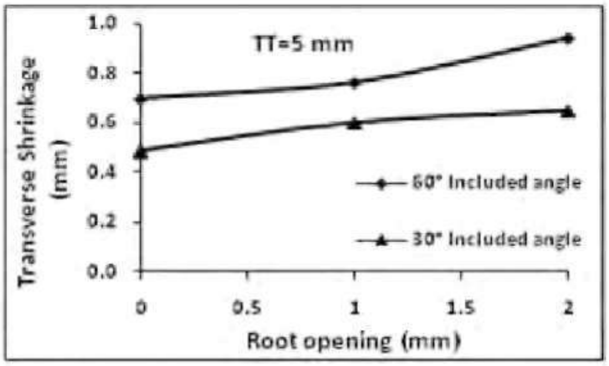

Fig. 10 - Variation of transverse shrinkage with root opening for 5 mm Throat Thickness (TT) in single V-groove butt joints

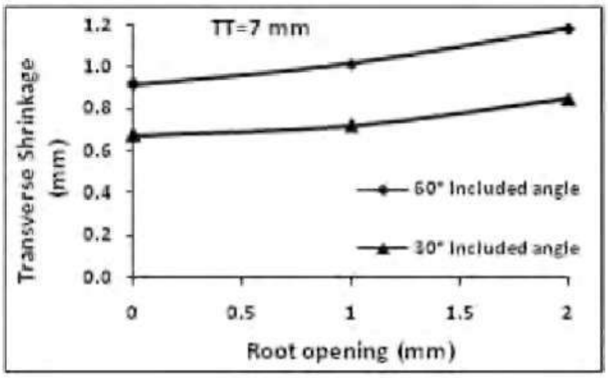

Fig. 11 - Variation of transverse shrinkage with root opening for 7 mm Throat Thickness (TT) in single V-groove butt joints

As in the case of single V-groove butt joints, the peak values transverse shrinkage of specimens with root opening for 15° and 30° bevel angle and throat thickness of 5 mm and 7 mm in bevel groove butt joints are as shown in the **Fig. 12** and **13**, where the transverse shrinkage increases with increase in the root opening similar to single V-groove butt joints.

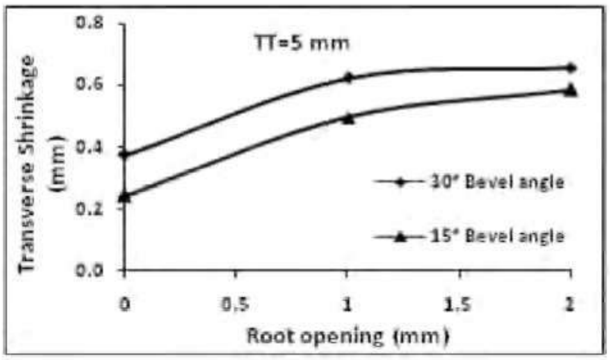

Fig 12 - Variation of transverse shrinkage with root opening for 5 mm Throat Thickness (TT) in bevel groove butt joints

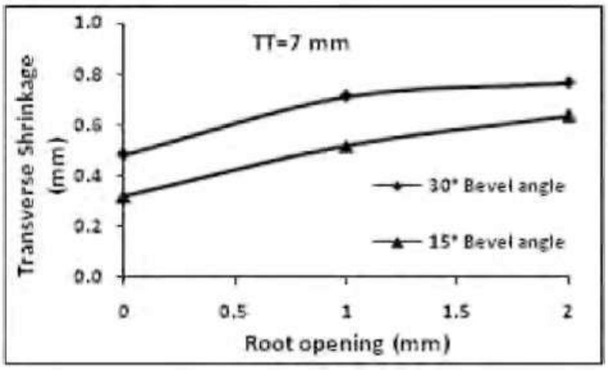

Fig. 13 - Variation of transverse shrinkage with root opening for 7 mm Throat Thickness (TT) in bevel groove butt joints

Variation of maximum transverse shrinkage of specimens with root opening for 30° and 60° included angle in double V-groove butt joints are plotted as shown in the **Fig. 14**. It is found that, the transverse shrinkage increases with increase in the root opening since it is welded on both sides which would lead to higher heat input.

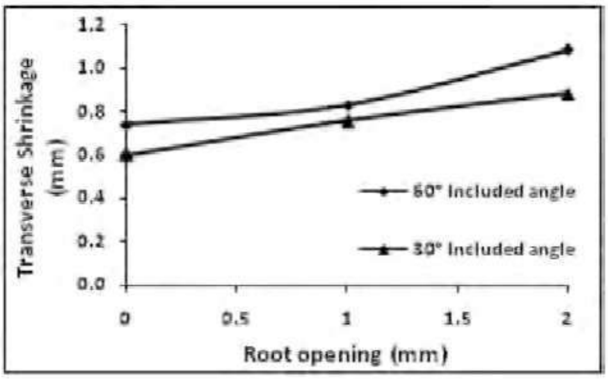

Fig. 14 - Variation of transverse shrinkage with root opening in double V-groove butt joints

3.3 Longitudinal Shrinkages

The variation of maximum longitudinal shrinkage of specimens with root opening for 30° and 60° included angle for 5 mm throat thickness in case of single V-groove butt joints are shown in the **Fig. 15**. There is a little increase in the longitudinal shrinkage with increase in the root opening. The reason for little change with the very small increase in root opening is the large restraint provided by the surrounding base plate [29]. The increase in longitudinal shrinkage is less than that of transverse shrinkage. This is due to the fact that, the restraint forces from the base material in longitudinal directions are more than that in the transverse directions. The similar trend has been observed in the welded specimens of throat thickness 7 mm in case of single V-groove butt welded joints as shown in the **Fig. 16** confirming that, the longitudinal shrinkage increases with increase in the root opening.

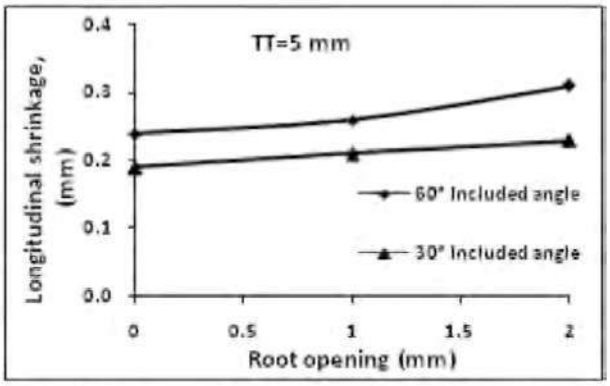

Fig. 15 - Variation of longitudinal shrinkage with root opening for 5-mm Throat Thickness (TT) in single V-groove butt joints

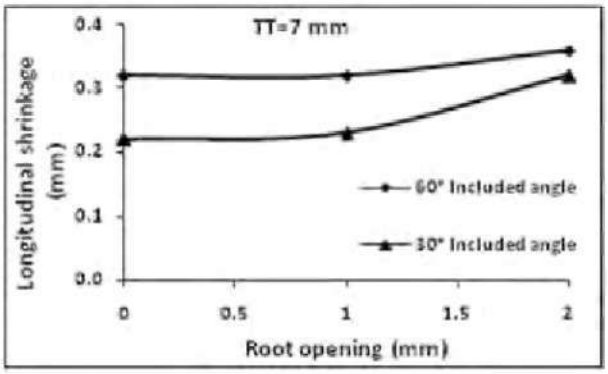

Fig. 16 - Variation of longitudinal shrinkage with root opening for 7-mm Throat Thickness (TT) in single V-groove butt joints

The variation of maximum longitudinal shrinkage of specimens with root opening for 15° and 30° included angle for 5 mm and 7 mm throat thickness in case of bevel groove butt joints are plotted as shown in the **Fig. 17** and **Fig. 18** in which there is an increase in the longitudinal shrinkage with increase in the root opening but increase is very small.

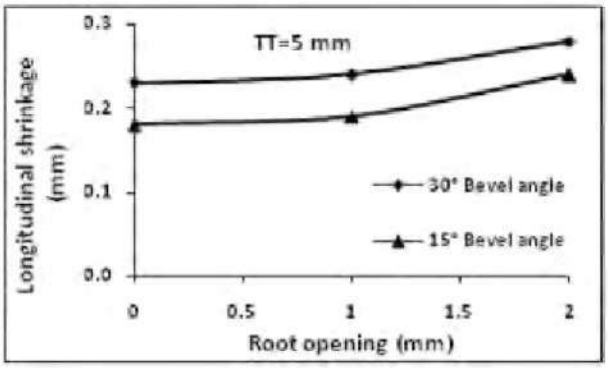

Fig. 17 - Variation of longitudinal shrinkage with root opening for 5-mm Throat Thickness (TT) in bevel groove butt joints

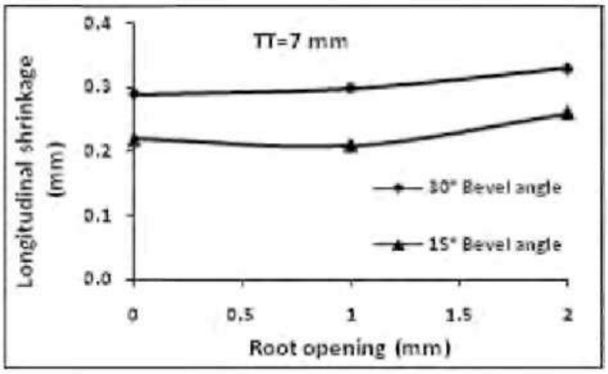

Fig. 18 - Variation of longitudinal shrinkage with root opening for 7-mm Throat Thickness (TT) in bevel groove butt joints

Variation of maximum longitudinal shrinkage of a specimen with root opening for 30° and 60° included angle in double V-groove butt joints are plotted as shown in the **Fig. 19**. Similar trends have been observed in double V-groove butt joints as in the case of single V-groove and bevel groove butt joints. It is found that, the longitudinal shrinkage increases with increase in the root opening.

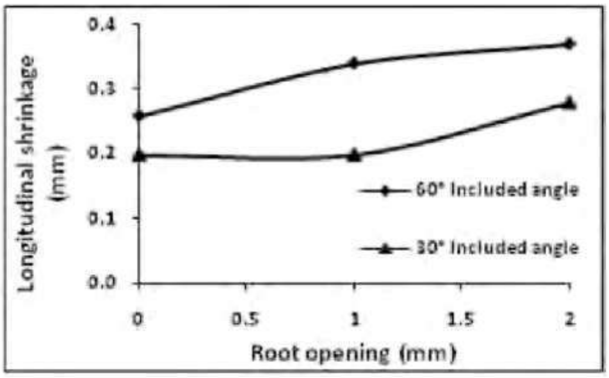

Fig. 19 - Variation of longitudinal shrinkage with root opening in double V- groove butt joints

The transverse and longitudinal shrinkages in specimens with 30° groove angle is observed lower values than the specimens with 60° groove angle in single V-groove butt joints. Similarly the transverse and longitudinal shrinkages in specimens with 15° groove angle were observed lower values than the specimens with 30° groove angle in bevel-groove butt joints. With respect to throat thickness, the transverse and longitudinal shrinkages found higher values in specimens of 7 mm throat thickness when compared with specimens of 5 mm throat thickness. For larger included angle and larger throat thickness, the greater volume of weld metal will contract more on solidifying, therefore resulting in greater dimensional transverse and longitudinal shrinkage [28].

4.0 CONCLUSIONS

The results obtained by experimental investigations will be of great useful to the designers to account for the angular distortion, transverse shrinkage and longitudinal shrinkage taking place during fabrication of thin plates. The angular distortion decreases with increase in the root opening due to the deeper penetration of the weld into the thickness of the joint in single V-groove butt welded joints for different included angle and throat thickness. Similar trend is observed in bevel groove butt welded joints. The variation of angular distortion is very small and not significant in double V-groove butt welded joints since it is welded on both sides. The least angular distortion is obtained for 2 mm root opening. The transverse and longitudinal shrinkages increase with increase in the root opening due to the greater volume of weld metal contract more on solidifying resulting in greater shrinkage in single V-groove, double V-groove and bevel groove butt joints. The variation of transverse shrinkage is found to be significant but there is a little variation in longitudinal shrinkage due to the large restraint provided by the surrounding base plate. The least transverse and longitudinal shrinkages are observed in the specimens for zero mm root opening.

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