Experimental Investigations on Welding Deformation Control Methods of a Butt-Weld in a Manual Arc Welding Operation

B.N Njiraini B. W Ikua and S.M Maranga

Abstract— Welding is a joining process that has enormous applications in manufacturing and construction industry. One of the challenges faced during welding is distortion of joined metals. Since construction of some structures require welded sub-assemblies, the distortion leads to geometric inaccuracies making sub-assembly difficult and limiting automation. It also increases the cost of production due to rework involved in straightening. Researchers have proposed various mitigating factors for control of weld distortions. This paper compares two welding distortion control methods for a simplified butt weld. Distortion of the plates when the two techniques are employed is compared with normal (straight single continuous line) welding technique. Welding and distortion correction (straightening) time is taken and compared for the three procedures. The straightening method used is flame heating for a standard time for both cases. From the experiments it was seen that the procedure used can have an impact on the quality of the weld. Using the appropriate procedure can help reduce distortion, and thus save on the cost of repair.

Keywords— Butt-weld, distortion, welding,

I. Introduction

WELDING distortion occurs due to thermal gradients resulting in strains due to non uniform expansion and contraction on application of heat. During welding, the material is heated to molten state and expands while the adjacent cooler areas give resisting force or compressive force thus bulking occurs. On cooling, the heated area and the weld deposit contracts in all directions creating tensile strains that are constrained by the cold adjacent areas. If thermal tensile stresses of localized heated area increases beyond the yield stress, there occurs plastic deformation. The shrinkage leads to various forms of distortions; transverse, longitudinal angular, buckling, bowing and twisting. The nature and extent of the distortion depends on a number of factors which include intensity and rate of heat input, plate thickness, the weld design, the sequence of the welding procedure and the parent material properties [1]. Although it is difficult to eliminate deformation completely various methods have been proposed for control of deformation. Post-weld thermal management techniques have been used for control of distortion. A plastic counter-deformation method (PCMD) technique was proposed using line heating to reduce distortion. Secondary heating of heat base metal while cooling the weldment and applying restraint force on the out of plane movement of the joint by use of jigs and fixture has also been used for control of distortion with good results [2].

The validity of this method has been substantiated by a number of numerical simulations and actual measurements. Welding distortion can be controlled by reducing the amount of heat input as was shown by investigation done by varying the heat input for different materials [3]. Investigation of angular bending of butt-welded aluminum panel plate done using experimental method showed that restrained weldments has a lower distortion than a non restrained plates. [4]. The welding distortion was reduced though there was indication of fatigue cracking. Figure 1 shows restrained plate for butt welding.

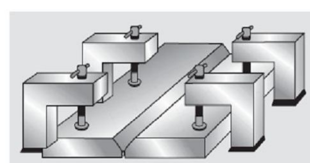

Figure 1: Clamping of plate to maintain flatness

Angular distortion is also dependant on the thickness of the plate as was shown by a relationship developed between angular changes and plate thickness for various fillet sizes and span widths [5]. Teng and Chang [1998] analysed a circumferential butt weld joining two sections of an SAE 1020 steel pipe. They concluded that the thicker walled pipes have higher tensile residual stresses compared to the thinner walled pipes. Welding distortion can be reduced by using pre-straining. An experiment was conducted by pre-straining a tee fillet joint and flange was almost straight after welding [6]. By using appropriate welding sequence, the distortion can be minimized. Figure 2 show welding sequence for butt weld. A study to investigate effect of welding sequence on panel distortion showed angular distortion reducing by using optimum sequence. Another technique used for distortion control is the use of minimum number of passes per weld [7]. While most of the applied methods for control of welding distortion yield good results, it must be observed they involve either additional time or cost for change of joint design. This requires analysis to apply the most optimum method.

B. N Njiraini. Author, Department of Mechanical Engineering, JKUAT (phone: +2540720707340; e-mail: bnjinu@yahoo.com).
S. M. Maranga, Department of Mechanical Engineering, JKUAT (e-mail: maranga@eng. jkuat.ac.ke).
B.W Ikua, School of Mechanical , Materials and Manufacturing Engineering, JKUAT (e-mail: ikua_bw@eng. jkuat.ac.ke).

Therefore a trade-off must be made between the time required for distortion control, the impact of distortion e.g precision requirements in terms of tolerances, strength of the welded joint and the cost of repair of the distortion.

II. TYPE OF DISTORTIONS

Distortion can be categorized into six main types, longitudinal shrinkage, transverse shrinkage, angular distortion, bowing and dishing, buckling, and twisting. Fig 2 shows the various forms of distortion.

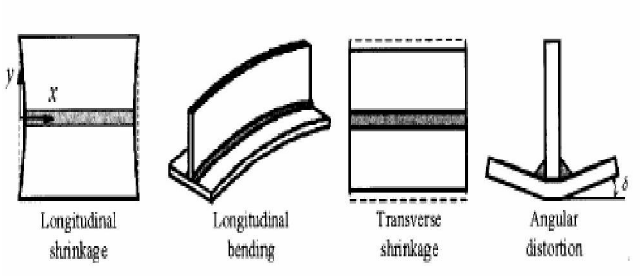

Figure 2: Types of distortions

Longitudinal shrinkage leads to shortening of the member along the principal axis of the welded joint. Transverse shrinkage stresses leads to a shortening of the member across the toes of the welded joint. Angular distortion weld zone transverse shrinkage stresses not in the plane of the neutral axis leading to rotation of one member with respect to an adjacent member. Bowing and dishing distortion is when the weld centre is not coincident with the neutral axis of the section so that longitudinal shrinkage in the welds bends the section into a curved shape. Buckling is similar to bowing and dishing but more pronounced localized deformations as seen on larger structures or thinner or less restrained sections. Twisting is seen in slender structures with shear deformation at welded joints. Box sections with fabricated beams and columns can twist.

III. DISTORTION CONTROL METHODS

There are many techniques which are applied for reducing welding deformation. All the techniques applied try to achieve a set of three objectives;

a. Reduction of the volume of the plastically strained zone and the values of the plastic strains during the heating stage.

b. Compensate for the plastic shortening produced during the heating stage by introducing plastic elongation during the cooling stage or after the weld has been completed.

c. Compensation of the welding deformation by preweld misalignment and using
larger parts, taking into account welding deformations.

The first principle can be achieved by regulation of the thermal action and mechanically. The measures are:

- Preheating
- Reduction of the size and number of welds
- Reduction of the net heat input per unit length of the weld
- Introduction of additional heat sinks
- Welding of the pre-stretched parts

The second principle is reduction of the residual plastic deformation volume achieved during heating period. The measures are:

- Successive forging treatment
- High-temperature tempering
- Successive rolling treatment

Third group of mitigation techniques involves;

- Pre-alignment taking into consideration estimated deformations
- Symmetrical joint arrangement (X-groove preparation, double-fillet weld)

The mitigating factors used depend on a number of factors e.g the type of joint, its accessibility, the plate thickness, cost associated with correction of distortion. Its is important to use the correct method without compromise of quality and design strength. A trade off must be made to between the distortion tolerances acceptable and the cost of control.

IV. EXPERIMENTAL PROCEDURE

The experiment was carried to investigate angular distortion of butt welded plates using manual metal arc welding. The material used in experiment was mild steel plate 200 x 150 x 6mm. Figure 6 shows the joint preparation. A double vee of 45° angle joint was prepared using a milling machine. Parameters for the welding condition used were set as shown in Table 1. The welding rods used were ASTM A6. The welding was carried out in a room temperature of about 28° C. Distortion was measured using a vernier height gauge and dial test indicator (DTI) and time was taken using a stop watch. Measurements were performed at several points at the surface of the plate before and after welding. The measurements were done on both sides left and right sides of the welded plate. The locations of deflection measurements are shown in Figure 4

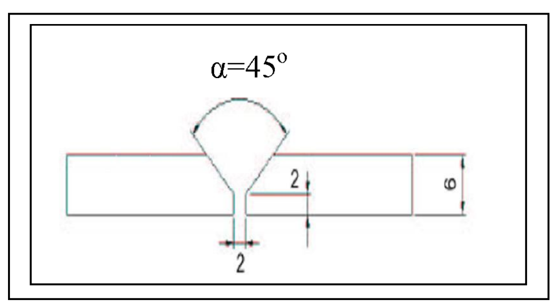

Figure 3: Double vee butt joint

Table 1: Welding type and parameters

Current polarity	AC
Current (A)	300
Voltage (V)	30

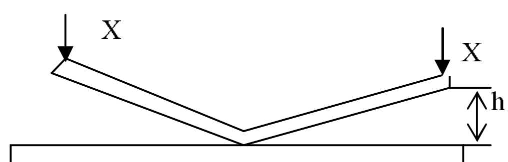

Figure 4: Experimental set up for distortion measurement

Case 1: Normal manual arc welding

Unrestrained plate were welded together. The weld joint was first tack welded at both ends of the plate.

Case II: Back step welding procedure

Welding was done using back step welding procedure. Figure 5 shows the sequence of back step welding sequence. The plates were tack welded together and the operator used back step welding technique. The distortion was recorded after the weld had cooled.

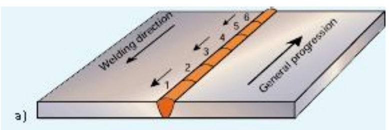

Figure 5: Back step welding procedure

Case III: Welding done in two runs at an interval of 10 minutes.

The plates were tack-welded together and then two runs of weld were made to completely fill the butt weld. The time between the welds was varied between 10 and 60 minutes and distortion observed.

V. RESULTS AND DISCUSSIONS

Case I- Normal welding procedure

When welding was done in a single continuous line average displacement was 2.2 mm at the edge of the plate. There was also observed shrinkage at the middle of the plate. Figure 6 and 7 show the displacement curve and the photograph of the welded plates respectively.

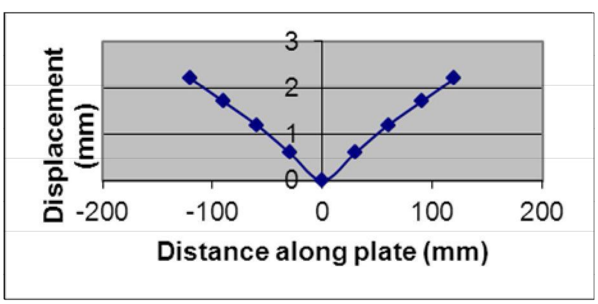

Figure 6: Displacement when plates were welded in a single continuous line.

Figure7: Distortion of the welded plate

Case II-Back step welding procedure

When back step welding was done the average displacement was 1.88 mm at the edge of the plate. Figure 8 shows the displacement curve for back step welding. Using back step welding reduced the distortion as the displacement reduced. The procedure facilitates some form of preheat since the temperature gradient is not as high as when one welds from one side to the other.

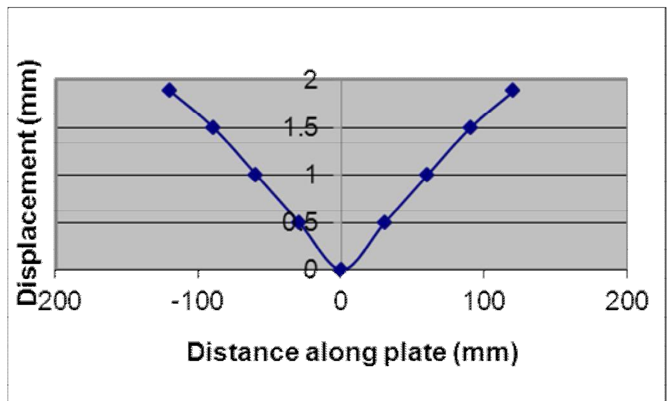

Figure 8: Distortion in back step welding

Case III: Effect of time between successive welds between runs

This showed that distortion increases generally when more than one run is made, however distortion reduces when there is delay between two successive runs. Figure 9 shows distortion when two weld runs are done at intervals of 20 minutes. Figure 10 depicts the effect of time between the successive weld runs. The average displacement was 1.78mm. The experiment showed that for welds that require several runs, time between these runs influence the amount of distortion. It can be seen that distortion decrease with increase of time between successive runs. This can be explained by the lost of heat when the run is delayed.

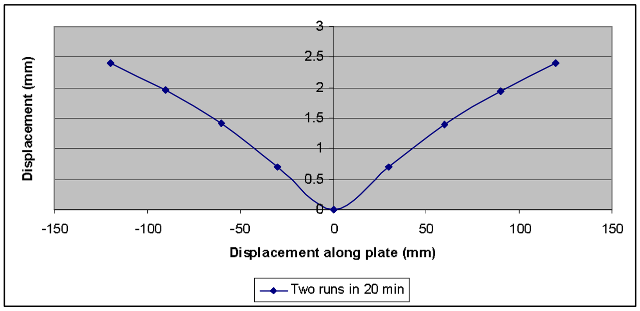

Figure 9: Distortion when for 20 min delay between successive welds runs

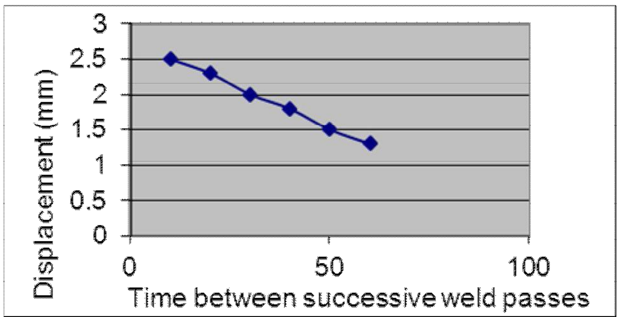

Figure 10: Displacement versus time between successive weld runs

Figure 11 shows the distortion curves for the three cases. Angular distortion was more when welding was done in two runs while distortion was minimal when back step welding was applied. In choosing the best technique the rate of distortion and time taken for the procedure should be considered. While there was remarkable difference in distortion for normal welding against the two, the later methods produced almost similar result. It is important to note that welding in two runs and delaying the second run in 10 minutes consumes time. From the analysis of the extent of distortion and time taken for straightening its can be seen that back step welding is more efficient and should be applied where situation allow.

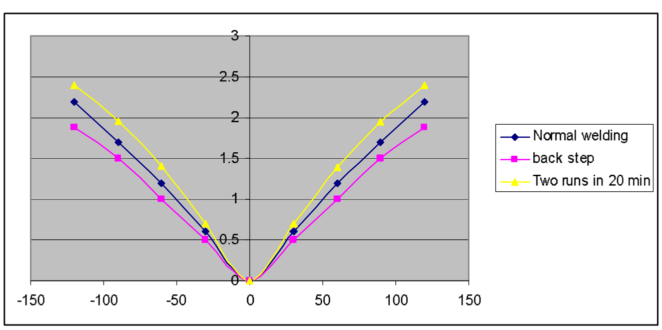

Figure 11: Displacement curves for welding control methods

Correction of weld distortions

Time for repair and correction of the three welding techniques were recorded. The correction technique used was flame heating of the welded assembly to a specified time. Figure 12 shows the time curve required for correction for the three considered situation.

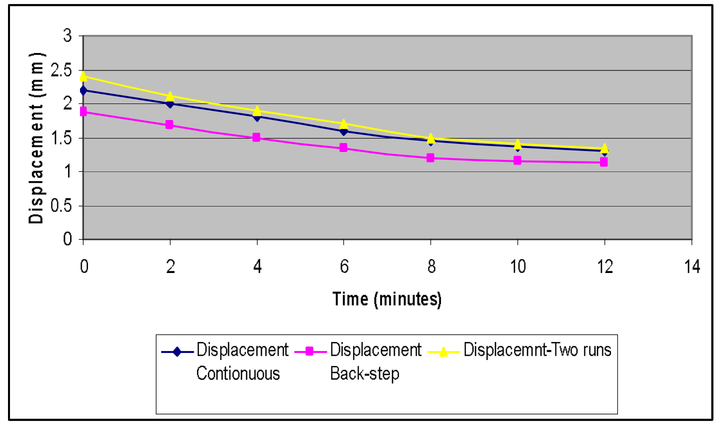

Figure 12: Time for distortion correction using flame heating technique

VI. Conclusion

The study showed that the choice of welding procedure has an impact of the nature and extent of the welding distortion. Distortion was more pronounced when two weld runs was done and least when back step procedure was used. For making the choice welding procedure, time for the three cases was observed and time for weld distortion correction. It was observed that correction of distortion where more than two runs are used, more time is required to bring the plates to flatness. The procedure is costly as it requires a skilled welder for flame heating and the cost of gas. For a simple joint it is recommended that the welder uses back step welding to avoid higher distortion. Further research is required since manual arc welding does not produce a uniform weld and the welding speed varies along the run.

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