# Controlling Angular Distortion in Manual Metal Arc Welding of Austenitic Stainless Steels Using Back-step Technique

**Abdul Sameea Jasim Abdul Zehra Jilabi**
*Faculty of Materials Engineering , University of Babylon*
sameeakilabi@gmail.com

## Abstract

Nowadays, austenitic stainless steels (A.S.S.) have many industrial applications in the fields of chemical and petrochemical processing, marine, medicine, water treatment, petroleum refining, food and drinks processing, nuclear power generation etc. The secret behind this wide range of applications is the fact that A.S.S. have great corrosion resistance, high strength and scale resistance at elevated temperatures, good ductility at low temperatures approached to absolute zero in addition to notable weldability. On the other hand, manual metal arc (MMA) is probably the most common process used for the welding of A.S.S. Unfortunately, MMA welding of A.S.S. could be associated with considerable distortion. Uncontrolled or excessive distortion usually increases the cost of the production process due to the high expense of rectification or replacing the weldment by a non-distorted one.

MMA welding of A.S.S. was carried out using the back-step technique with various bead lengths, and without using this technique for comparison.

Results have showed that the angular distortion was a function of the bead length in the back-step welding of A.S.S. The angular distortion decreased by (14.32%) when the back-step technique was used with a (60 mm) length for each bead, and by (41.08%) when the bead length was (40 mm). On the other hand, it increased by (25%) when the back-step technique was done with a (30 mm) length for each bead.
**Keywords**: Austenitic stainless steels, Angular distortion, Back-step welding.

## الخلاصة

يمتلك الفولاذ المقاوم للصدأ الأوستنايتي حاليا العديد من التطبيقات الصناعية في مجالات المعالجة الكيميائية والبتروكيماوية، والبحرية، والطب، ومعالجة المياه، وتكرير النفط، وتجهيز الأغذية والمشروبات، وتوليد الطاقة النووية وغيرها. ويعود السر في هذا المدى الواسع من التطبيقات الى ان الفولاذ المقاوم للصدأ الأوستنايتي يمتلك مقاومة عالية للتاكل، ومقاومة ميكانيكية ومقاومة للتقشر عاليتين في درجات الحرارة المرتفعة، ومطيلية جيدة في درجات الحرارة المنخفضة والتي تقترب من الصفر المطلق بالإضافة إلى قابلية ملحوظة للحام. وتكون طريقة القوس الكهربائي اليدوي على الأرجح هي الطريقة الأكثر شيوعاً واستخداماُ في لحام الفولاذ المقاوم للصدأ الأوستنايتي. إلا إن لحام هذا الفولاذ بطريقة القوس الكهربائي اليدوي ترافقه تشوهات كثيرة، والتشوه المفرط أو غير المسيطر عليه عادة ما يزيد من كلفة العملية الإنتاجية بسبب التكلفة العالية للمعالجة، أو ربما استبدال الملحومة بأخرى غير مشوهة عندما يصعب معالجتها.

وقد تم لحام الفولاذ المقاوم للصدأ الأوستنايتي بطريقة القوس الكهربائي اليدوي باستخدام تقنية اللحام التراجعي، وبأطوال مختلفة لدرزات اللحام، إضافة إلى لحامه بدون استخدام هذه التقنية للمقارنة.

وقد أظهرت النتائج ان التشوه الزاوي كان دالة لطول الدرزة في اللحام التراجعي للفولاذ المقاوم للصدأ الأوستنايتي، حيث انخفض التشوه الزاوي بنسبة (14.32%) عند استخدام تقنية اللحام التراجعي بطول (60 ملم) للدرزة الواحدة، و بنسبة (41.08%) عندما كان طول الدرزة (40 ملم)، في حين ارتفع بنسبة (25%) عندما نفذت تقنية اللحام التراجعي بطول (30 ملم) للدرزة الواحدة.
**كلمات المفتاحية:** الفولاذ المقاوم للصدأ الأوستنايتي ، تشويه الزاوي ، اللحام التراجعي .

## Introduction

Non-magnetic Austenitic Stainless Steels (A.S.S.) generally have the greatest resistance to corrosion of all types of the stainless steels. They also have the highest strength and scale resistance at elevated temperatures, and can retain ductility at low temperatures approached to absolute zero. A.S.S. are usually more weldable than the other types of the stainless steels, and their welds are generally tough, ductile and capable to withstand stresses without failure ( Khanna, 1980 ). Accordingly, A.S.S. have many industrial applications in the aviation industry (engine parts), chemical and food processing (heat exchangers and tanks), housewares (utensils of cooking), the transportation industry (railway coaches and trailers) and more.

Manual Metal Arc (MMA) is possibly the most common process used for welding of austenitic stainless steels. The main advantage of this process is flexibility. Manual metal arc welding of austenitic stainless steels could be associated with *distortion* in weld zone and Heat Affected Zone (HAZ). Distortion can be defined as a temporary or permanent change in the shape or dimensions of the welded parts due to welding heat.

During the welding process, when a weld is deposited, the parent metal (the metal to be welded) is heated, therefore, it expands (non-uniform expansion). If this expansion is restrained, deformation will occur. After the welding, the parent metal plus the weld will contract. If this contraction is restrained, internal stresses are created. If these stresses result in movement, distortion occurs, else, they are left as residual stresses. Non uniform expansion and contraction of the weld and the adjacent parent metal which takes place throughout the heating and cooling cycles of welding processes causes distortion of the weldment (AL-Dhamin, 1998; Sacks, 1981; Khanna, 1980).

Distortion in weldments occur by three dimensional changes which take place during welding: longitudinal shrinkage which occurs parallel to the weld centerline, transverse shrinkage which occurs perpendicular to the weld centerline and angular change which consists of rotation around the weld centerline (Al-Dhamin, 1998). There are four metal properties that affect welding distortion. The higher distortion occurs with the higher coefficient of thermal expansion, lower thermal conductivity, higher yield strength and lower modulus of elasticity of the material ( Dunovic, 2002; Sacks, 1981).

When compared with plain carbon steels, A.S.S. have a thermal conductivity of about 50% lower, and a thermal expansion of about 50% higher ( Khanna, 1980 ). Therefore, A.S.S. are usually more susceptible to distortion than plain carbon steels.

The shrinkage or contraction cannot be avoided, however, it can be controlled. There are several practical ways for controlling distortion caused by contraction, some of them can be applied before welding such as off-setting, preheating, pre-bending, contra-heating, during welding such as back-step welding, welding sequence, forced cooling and after welding such as peening, stress relief… (AL-Dhamin, 1998; Sacks, 1981; Khanna, 1980). The back-step technique is recommended to control angular distortion-the most effective distortion- in A.S.S. welded plates ( Karadeniz *et.al.*, 2013; Khanna, 1980).

The back-step welding technique consists of depositing individual beads, each bead ends at the beginning of the previous one, i.e. the beads are deposited in the opposite direction of the welding progress. This technique is commonly used to control distortion during welding by reducing the contraction forces. The expansion will be less and less with each deposited bead due to the restraints of the previous welds. So, the back-step welding technique helps to prevent the stress accumulation ( Sacks, 1981).

Although there are a few researches ( Karadeniz *et.al.*, 2013; Tseng and Chou, 2013; Tseng and Chou, 2003) that have dealt with angular distortion in austenitic stainless steel weldments, so far, there has not been any research to study controlling angular distortion in austenitic stainless steels using the back-step welding technique for improving the performance and decreasing the costs.

# Experimental Work

## 1. Parent Metal

Table (1) shows the chemical composition of the parent metal in addition to the shape and dimensions of the raw material section according to AMS 5524/5507 standard specifications.

**Table 1: Chemical composition and material section of the parent metal.**

| Parent metal | Spec. symbol | Material section (mm) (as annealed) | Chemical composition (wt %) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | Mn | Si | Cr | Ni | Mo | P | S | Fe |
| Austenitic stainless steel | 316LP | Plate (20*120) | 0.03 max | 2.0 max | 0.75 max | 16.0-18.0 | 10.0-14.0 | 2.0-3.0 | 0.045 max | 0.03 max | Balance |

## 2. The electrode Used

Table (2) shows specifications and size of the electrode used as a filler metal according to the American Welding Society (AWS) ( ESAB, 2001).

**Table 2: Electrode specifications and size.**

| Electrode | Electrode size/diameter (mm) | Electrode type | Wire metal type | Typical all weld metal composition (wt %) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | C | Mn | Si | Cr | Ni | Mo | Fe |
| E316L-16 | 3.2 | Acid-rutile | Austenitic stainless steel | 0.03 | 0.8 | 0.7 | 18.5 | 12.0 | 2.8 | Balance |

## 3. Weld Joint Preparation

Figure (1) shows the dimensions of the pieces being welded and the weld joint design (Single-V) according to the AWS ( ASM, 1971).

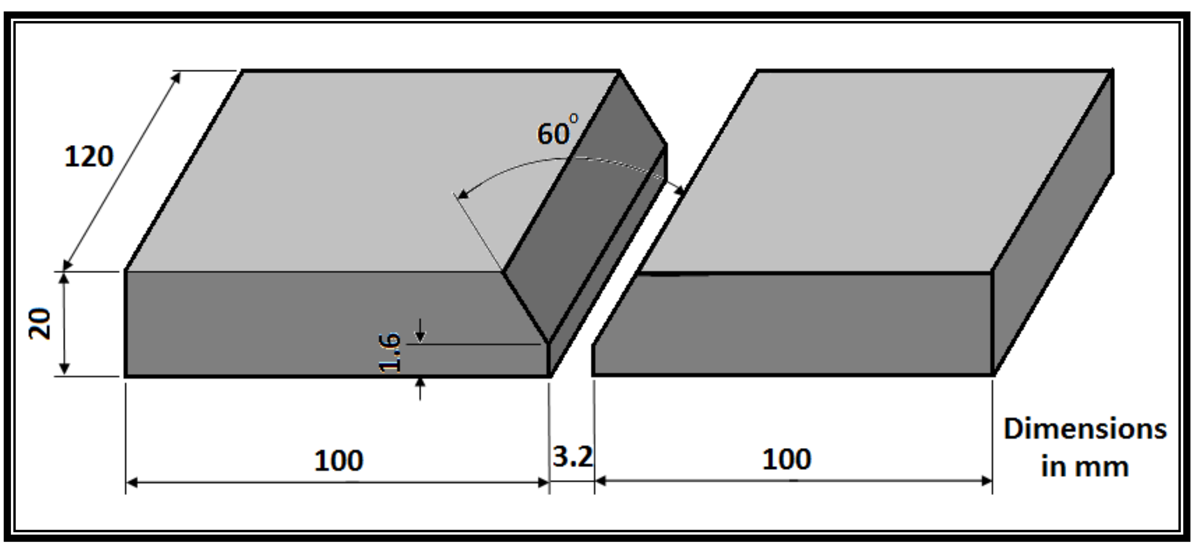


**Figure 1: Weld joint design.**

Figure (2) shows a photograph of the weld joint before welding.

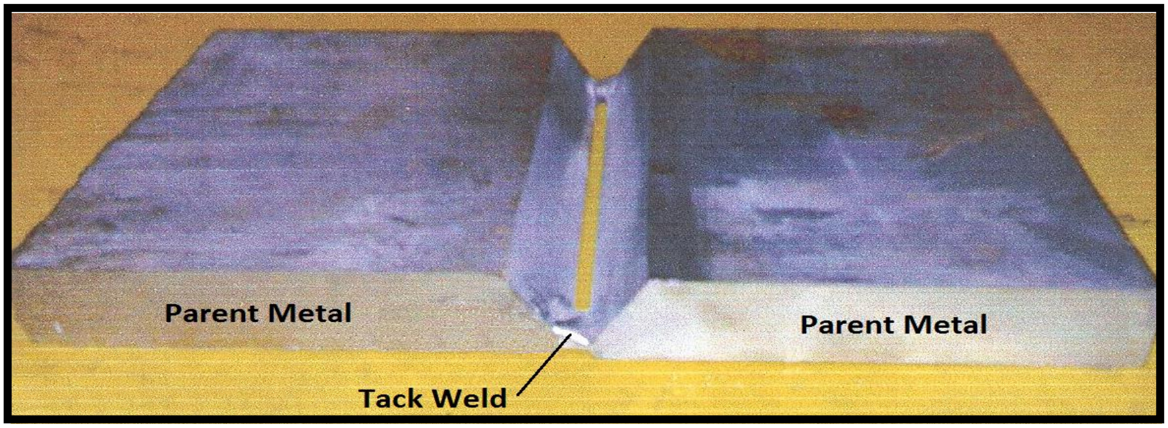


**Figure 2: Weld joint.**

## 4. Joints Welding

The process used to weld the joints was MMA, and the welding conditions were as shown in Table (3) below. The welding process was carried out on a welding bench without preheating and/or post-heating the joints. The value of the welding current was set depending on the electrode type, size and welding position according to the AWS [ESAB, 2001]. Figure (3) shows the details of the welds that have been done firstly, along the weld centerline (120 mm) without using the back-step welding technique, followed by using this technique with lengths of (60, 40, 30 mm) for each bead, i.e. carrying out the welding process with (two, three, four) beads for each pass respectively.

**Table 3: Welding conditions.**

| Position | Current type | Current value | Passes | Room temperature |
|---|---|---|---|---|
| Flat | DC+ | 95A | 12 | 25 C° |

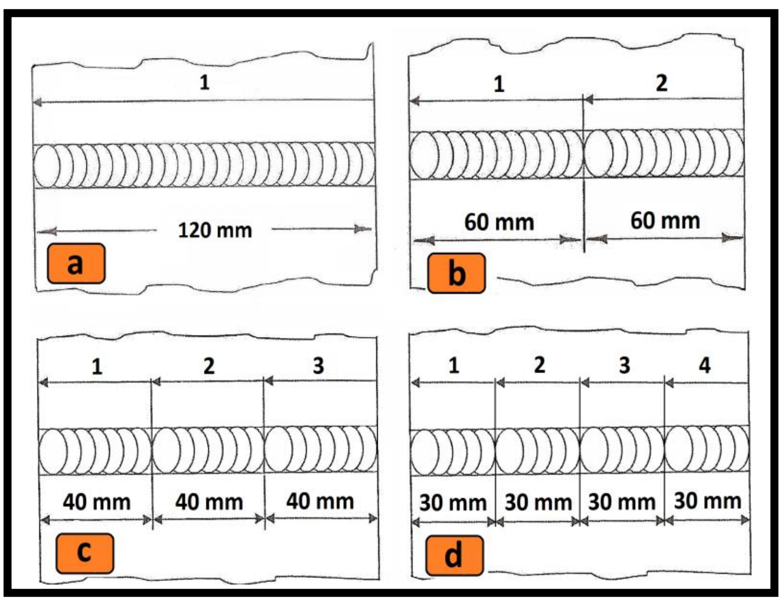


**Figure 3: Details of the welds.**

## 5. Distortion Measuring

Distortion was measured by using a 3D co-ordinates measuring device (CX-652.854–MITUTOYO MFG. CO. LTD TOKYO JAPAN) .The measuring depends on a probe contacts the point to be measured. The measurement appears on a dial gauge with accuracy of (0.01mm). The distortion measuring process was carried out in The Quality Control labs of the State Company of Automotive and Equipment Industries/ Alexandria.

## Results and Discussion

The single-V butt joint was selected because it is the most common design of the weld joints, and suitable for the parent metal thickness used in this study, as well as its edge preparation is one of the easiest to implement [Khanna, 1980].

The measurements showed that there is no significant longitudinal distortion in the weldments because the weldments rigidity is high (relatively high thickness) and the length of the weld joints is small (120 mm), while the longitudinal distortion occurs only in the light metal strips and can be neglected in the small weldments [(TC), 1997].

The transverse distortion has not exceeded (0.08 mm) because of the following cares taken into account in this study:(WTIA, 2007; Sacks, 1981)

1. Using proper tack welds.
2. Reducing root opening and bevel angle as much as possible.

Table (4) shows the angular distortion at the measuring points which were marked on the bottom surface of the weldments as shown in Figure (4). The measurements are for one side of each weldment due to the symmetry of the angular distortion on both sides of the weld center, because the shape of the weld joint (single-V) used is symmetrical.

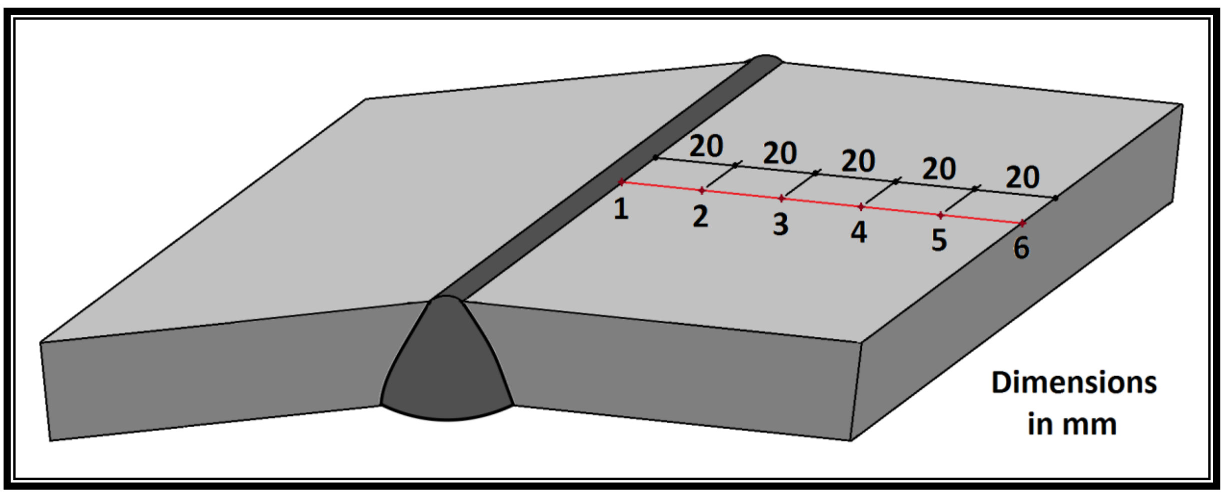


**Figure 4: Location of the measuring points.**

**Table 4: Angular distortion.**

| Weld No. | Weld details | Angular distortion at the measuring points marked on the bottom surface of the weldments (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Without using the back-step welding technique | 0 | 1.22 | 2.71 | 4.29 | 5.85 | 7.40 |
| 2 | Using the back-step technique with a 60 mm length for each bead | 0 | 1.02 | 2.30 | 3.65 | 5.00 | 6.34 |
| 3 | Using the back-step technique with a 40 mm length for each bead | 0 | 0.80 | 1.71 | 2.59 | 3.48 | 4.36 |
| 4 | Using the back-step technique with a 30 mm length for each bead | 0 | 1.32 | 3.30 | 5.23 | 7.14 | 9.25 |

It is clearly noted from Table (4) that the angular distortion is the most effective and significant in the A.S.S. welds. So, the study undertook controlling this type of distortion, especially as it is a common problem in industries (Sacks, 1981).

The amount of the angular distortion was (7.4 mm) when the welding process was implemented along the weld centerline without using the back-step technique because the weld joint required the deposition of (15) weld passes to be filled but from one side. This great number of the passes caused the accumulation of the shrinkage of each pass on the shrinkages of the previous passes, because there were no shrinkage forces in the opposite side (AL-Dhamin, 1998).

Figure (5) shows the distribution of the angular distortion along the distance from the weld center, while Figure (6) exhibits the effect of using the back-step welding technique on angular distortion in the A.S.S. welds.

It is clearly observed from Table (4) and Figures (5 and 6) that the amount of angular distortion is a function of the bead length in the back-step welding. The angular distortion decreased by (14.32%) when the back-step technique was used with a (60 mm) length for each bead, i.e. when each pass was deposited with two beads only. Furthermore, it decreased by (41.08%) when the bead length was (40 mm) using three beads for each pass. On the other hand, the angular distortion increased by (25%) when the back-step technique was carried out with a (30 mm) length for each bead, i.e. when each pass was deposited with four beads.

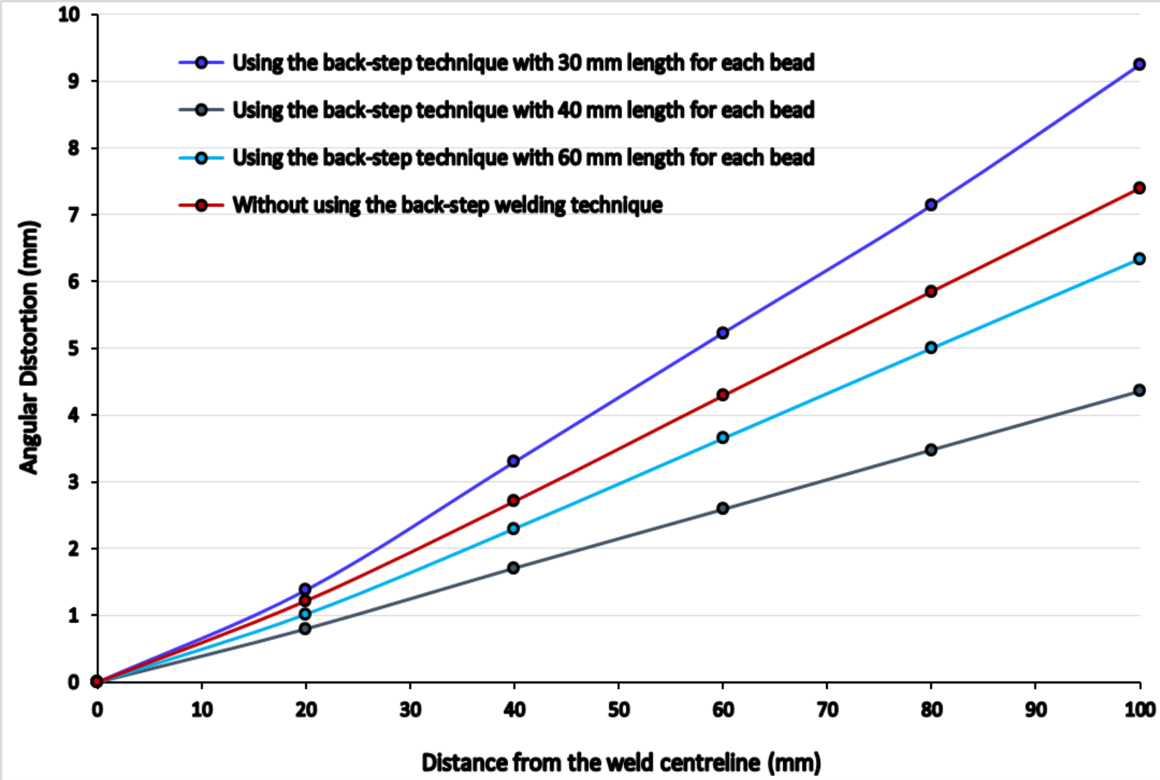


**Figure 5: Distribution of the angular distortion in the A.S.S. welds.**

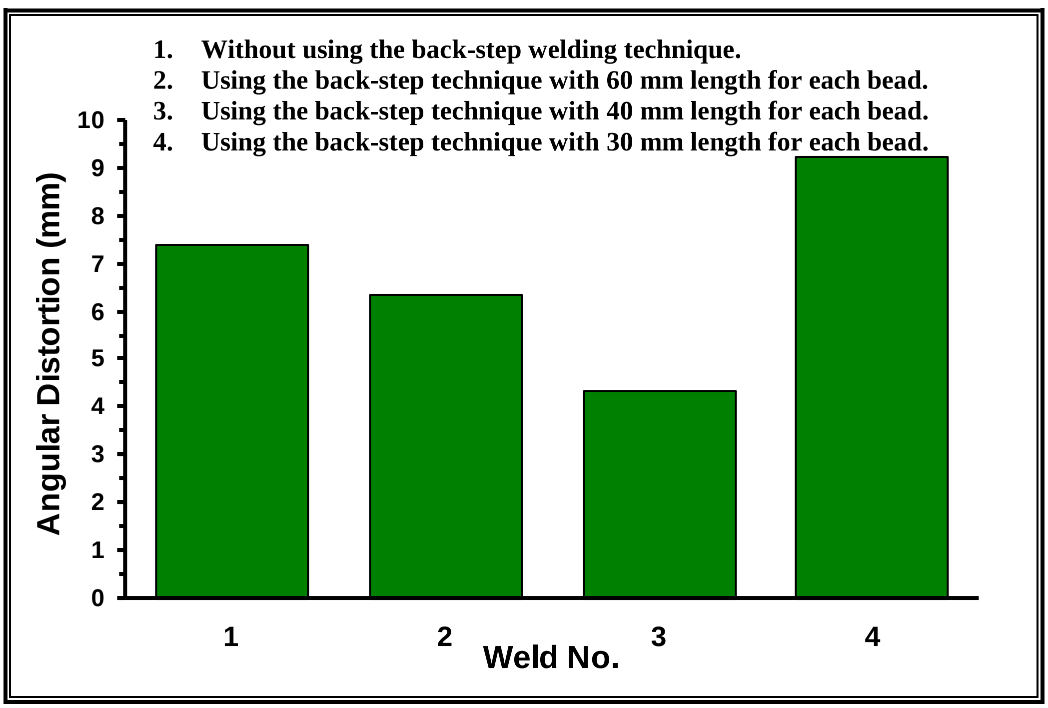


**Figure 6: Effect of using the back-step welding technique on angular distortion in the A.S.S. welds.**

When each pass was deposited with two beads only, the amount of angular distortion decreased slightly. This is because the time required for the end of the second bead to reach the beginning of the first bead was long enough to find that the first bead has almost shrunk. Therefore, the expansion of the second bead is not restrained much by the contraction of the first bead, but by the little remaining contraction only. It is well known that the time period depends on the length of the weld bead.

The angular distortion decreased much more when each pass was deposited with three beads because the time needed for the end of the second bead to reach the beginning of the first bead and the end of the third bead to reach the beginning of the second bead was shorter than that of the previous case. So, the second bead, e.g. would find the first bead either still shrinking or at the beginning of its shrinkage causing the expansion of the second bead to be significantly restrained by the contraction of the first bead, and so on for the third bead with the second one.

On the other hand, the amount of angular distortion notably increased when each pass was deposited with four beads. This is because the time required for the end of the second bead to reach the beginning of the first bead e.g. was short enough for the second bead to find that the first bead is still expanding. Therefore, the expansion of the second bead would accumulate on that of the first one. The expansion would be less and less with each deposited bead due to the restraints of the previous welds. Thus, the back-step welding technique helps to prevent the stress accumulation (Sacks, 1981).

## Conclusions

1. Manual metal arc welding of austenitic stainless steels is associated with a relatively high angular distortion distributed along the distance from the weld centerline.
2. The back-step welding is an effective technique for controlling angular distortion during manual metal arc welding of austenitic stainless steels.
3. The amount of angular distortion is a function of the bead length in the back-step welding of austenitic stainless steels.

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