A Study on the compensation margin on butt welding joint of Large Steel plates during Shipbuilding construction.

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Abstract. This paper examines the characteristics of butt welding joint shrinkage for shipbuilding and marine structures main plate. The shrinkage strain of butt welding joint which is caused by the process of heat input and cooling, results in the difference between dimensions of the actual parent metal and the dimensions of design. This, in turn, leads to poor quality in the production of ship blocks and reworking through period of correction brings about impediment on improvement of productivity. Through experiments on butt welding joint’s shrinkage strain on large structures main plate, the deformation of welding residual stress in the form of I, Y, V was obtained. In addition, the results of experiments indicate that there is limited range of shrinkage in the range of 1 ~ 2 mm in 11t ~ 21.5t thickness and the effect of heat transfer of weld appears to be limited within 1000mm based on one side of seam line so there was limited impact of weight of parent metal on the shrinkage. Finally, it has been learned that Shrinkage margin needs to be applied differently based on groove phenomenon in the design phase in order to minimize shrinkage.

1. Introduction
Main plates of hull and off-shore structure are welded by butt welding method and it is quite normal procedure that the 2nd welding shall be performed on the opposite side after cooling and turning over the 1st welding side. During this heating and cooling cycles while welding repeatedly, residual stress occur.

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in a welded butt joint and this stress react to produce internal forces, causing shrinkage or length
deficiency of main plates in comparison with designed dimension as shown on preceding research data
[1]-[3]. The shrinkage around welded joint is one of major concern in the shipbuilding industry and an
obstacle that must be overcome to meet the relevant quality standard and production schedule.

In order to avoid butt welding shrinkage effect, Shipyards have been applying 10mm~20 mm of four
(4) direction margins or two (2) direction margins at the end of plates and cutting in accordance with
actual designed dimension after finishing butt welding. This is one of quality control methods in
shipbuilding industry. This paper shows the values of welding shrinkage which were measured around
butt welding joint during actual shipbuilding construction and shows how we can control its residual
stress and effect on the dimension of main plates assembled by butt weld, applying reasonable margin at
design stage, not depending on their experience.

2. Theoretical Analysis of Welding Shrinkage

Atoms being vibrated by getting thermal heat expansion energy act as if they have a larger radius.
Therefore, the average distance between atoms and the overall dimensions of material are increased.
Such dimensional changes of material, namely the length change ($\Delta L$) per unit length can be
represented by a linear thermal expansion coefficient ($\alpha$) as below equation (1).

$$\alpha = \frac{L_f - L_0}{L_0(T_f - T_0)} = \frac{\Delta L}{L_0 \Delta T}$$

(1)

Also, when an isotropic material is heated slowly and evenly, material is equally expanded without any
occurrence of residual stress. However, if the material is suppressed to prevent its swelling, its
dimensional change does not occur, on the other hand its thermal stress is generated. This thermal stress
having thermal expansion coefficient ($\alpha$), the modulus of elasticity ($E$) and thermal change ($\Delta T$) has the
same as below equation (2) [4].

$$\sigma_{\text{thermal}} = \alpha E \Delta T$$

(2)

Welding heat input given from the outside. That is to say, electrical heat energy (J) which Arc generates
per unit length (cm) of welding can be represented by Arc voltage (V), Welding current (A) and
Welding speed ($\text{cm/min}$) as below formula (3) [5].

$$J = \frac{60ET}{v} \text{ (joule/cm)}$$

(3)

Welding deformation and welding residual stress represent an effect opposite to each other that when
less restraint is given to welding metal, welding residual stress is rather small, but the welding
deformation is large. While if welding restraint is greatly increased to the extent of preventing the free
contraction of welding metal, the welding deformation is decreased, but the welding residual stress is
increased [4]. The main formulas are the equation (4) and (7) as below.

Figure 1. Compressive strength and tensile strength
Strain  \[ \delta = \frac{l'}{l} = \frac{l}{l_1} \cdot \alpha \cdot (t_2 - t_1) \]  (4)

Strain rate  \[ \epsilon = \alpha \cdot (t_2 - t_1) \]  (5)

Thermal stress  \[ \sigma = E \cdot \alpha \cdot (t_2 - t_1) \]  (6)

Tension  \[ P = A E \cdot \alpha \cdot (t_2 - t_1) \]  (7)

\( \alpha \) is thermal expansion coefficient and as for mild steel, \( \alpha \) is 11.45 \( \cdot 10^{-6} \) [4].

The way of control of welding deformation is to rate the status of shrinkage and to compensate it by design margin. But, in the workplace, the experienced data is much more utilized rather than theoretical analysis and experimental results of data.

3. Experiment

The shrinkage measurements were carried out on the plates welded in a butt joint using submerged arc welding, during actual shipbuilding construction, at D shipyard in S. Korea. Welding parameters are in the WPS (Welding Procedure Specification) as shown on Table 1. and the dimension of the plates and welding condition including ambient temperatures are shown in Table 2. Groove shapes of the plates are shown on Figure 2.

| Process | D.t.(mm) | Type & Pd. | Amperage(A) | Voltage(V) | Speed (cm/min) | Thickness |
|---------|----------|------------|-------------|------------|----------------|-----------|
| SAW     | 4.0~ 4.8 | DCRP       | 800~ 1050   | 28~ 38     | 27~ 45         | 11\(\leq T < 15\) |
|         |          |            | 900~ 1150   | 28~ 38     | 25~ 35         | 15\(\leq T < 18\) |
|         |          |            | 1000~ 1200  | 29~ 40     | 22~ 30         | 13\(\leq T < 22\) |
|         |          |            | 1100~ 1250  | 30~ 40     | 20~ 27         | 22\(\leq T < 27\) |

| Kind    | Welding conditions | Remark |
|---------|--------------------|--------|
| Size(L * B) | 21.6 M * 2.5 ~ 3 M |        |
| Thickness(t) | 11 ~ 21.5 | Figure 2 |
| Welding Materials | WIRE: H-14(∅4.8) FLUX:S707T |        |
| Workplace temperature | 18 ~ 34°C |        |
| Welding positions | Below |        |
3.1 Preparation

Shrinkage measurement was conducted under the following conditions. Run on and run off tab pieces were provided with same edge details as those of the plates before the plates were assembled and tack welded as a normal welding procedure in the shipbuilding industry.

1) Plate thickness : 11mm~21.5mm 
2) Plate Length: 15m~21.6m 
3) Plate Width: 2.5m~3.5m 
4) Steel grade: A, AH, AH36 (Discrepancy between steel grades is not considered) 
5) Number of block: 12 blocks 
6) Number of butt welding joint: 41 EA

3.2 Measurement

Specially ordered marking device was used for the marking of 150 mm off line from the welding line as shown on Figure 3. These 150 mm off line parallel to the welding line was drawn on the plates using the marking device before welding. The length of joint gap was included into 150 mm off marking line and to get the reliability and easy reading its display, Digital Vernier Caliper was used to measure the distance between these lines before and after welding as shown on Figure 3.

![Image of Figure 3](image-url)

**Figure 3.** 150mm off marking and measuring tools

After tack welding, 300 mm between two parallel lines were confirmed by Digital Vernier Caliper (150mm + 150mm=300mm). No any arrest devices were used to make the free end of plates during welding. After finishing the first welding side, it takes 2.5~3.0 hours for cooling and the plates were turned over for the second welding and the transverse shrinkage was measured in 3 hours after the second welding considering cooling time as shown on Figure 4.
4. Experiment results and Discussion

1) The measurement result was obtained from the difference between these 300 mm (150mm+150mm) off lines on the plates and half of this value can be taken as the shrinkage of each individual plate. Measurement results are as shown on Table 3.

| Block no. | Thickness | Grooves | Measurement(mm) Before welding | After welding | Average Shrinkage |
|-----------|-----------|---------|-------------------------------|--------------|------------------|
| 22XX-538  | 11.0~20.0 | I       | 300                           | 298.8        | 1.2 mm           |
| 51XX-243  | 20.5~21.5 | Y       | 300                           | 298.4        | 1.6 mm           |
| 11XX-122  | 14.0~16.0 | V       | 300                           | 298.7        | 1.3 mm           |

2) As a first step, tack welding was carried out and it took about 2.5~3.0 hours for cooling after finishing the first welding and the plates were turned over for the second welding on opposite side. During these twice welding processes, heating and cooling cycles were occurred on the plates. It is assumed that the degree of shrinkage measured by this experiment may differ from the predicted result by the theoretical analysis because of plastic deformation which caused by high heating on the plates during welding.

3) Temperature of welding point just after welding was measured by infrared thermometer during natural air cooling and the result. As it is shown on Figure 5, temperature of welding point is cooled down within 5 minute rapidly and then cooled down gently. Because of the Max capacity of infrared thermometer, it was measured from 650 °C so the temperature of welding point right after welding is predicted about 1300~1500 °C.
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5. Conclusion
The main conclusions, derived from the measurement of transverse shrinkage and investigation in the butt welded joint between two plates during actual shipbuilding construction, are as follows.

The Shrinkage value of Y-Groove is slightly bigger than I-Groove because of the higher welding heat input so the value of compensation to control the dimension of plates shall be applied differently in accordance with groove shape.

In case of I-Groove welding, for the same thickness, the amounts of transverse shrinkages were measured from 1.0 mm ~1.5 mm variously and these results are the same as for the plate thickness of 11.0 mm~20.0 mm. This could be due to no good straightness of the plate edge making no zero joint gaps between two plates. At the welding point of no zero joint gaps, the higher welding heat is inputted during welding and the more shrinkage is occurred vs.

The degree of transverse shrinkage of I, Y and V-Groove welding on the plates thickness of 11.0 mm~21.5 mm, measured almost equally being limited within 1.0 mm~2.0 mm and the effect of heat transfer by welding is limited within 1,000 mm off from the welding line and welding residual stress is occurred due to high cooling velocity. This result suggests that an effect on shrinkage by self-weight of plates is very small.

6. Postscript
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