The Prevention of the Longitudinal Deformation on the Built-Up Beam by using Induction Heating

J. U. Park, C. H. Lee and K. H. Chang

Abstract

During the manufacture of a ship, longitudinal deformation is produced by fillet welding on the Built-Up beam used to improve the longitudinal strength of a ship. This deformation needs a correcting process separate from a manufacture process and decreases productivity and quality. This deformation is caused by welding moment, which is the value multiplied the shrinking force due to welding by the distance from the neutral axis on a cross section of Built-Up beam. This deformation can be offset by generating a moment which is the same magnitude with and is located in an opposite direction to the welding moment on web plate by induction heating. Accordingly, this study clarifies the creation mechanism of the longitudinal deformation on Built-Up beam with FEM analysis and presents the preventative method of this deformation by induction heating basing the mechanism and verifies its validity through analysis and experiments. The induction heating used here is performed by deciding its location and quantity with experiments and simple equations and by applying them to a real structure.

Key Words : Longitudinal deformation, Built-Up beam, Induction heating, Neutral axis.

1. Introduction

Built-Up(B.U) beam which is used to improve the longitudinal strengths of a ship needs about an output of 1050 EA a month in the case of building 4 ships of VLCC a year, though there is a difference among shipbuilding. This B.U beam is manufactured by fillet welding in the state that web plate is put on flange. In this process, longitudinal deformation[1] is produced by welding because the distance of welded part is long (5~22m) and the welded part is located lower than the neutral axis of B.U beam. Accordingly, the following methods are used to prevent or to correct the longitudinal deformation in shipbuilding yards. First, the corrective method to perform triangle heating on web plate. Second, the corrective method by plastic deformation with press. Third, the method to minimize the deformation in which inverse deformation is intentionally generated by laying load before welding and after welding the inverse deformation is removed after cooling the welded part completely. But these methods needs a correcting process separate from a manufacture process and especially, the inverse deformation method decreases productivity because it takes plenty of time to remove the load laid to generate the inverse deformation.

Resultingly, these problems brought up the necessity for the studies to estimate previously and to prevent the longitudinal deformation and a series of studies was done headed by Sasayama[2]. Sasayama[2] estimated the quantity of longitudinal deformation with the leg length of welding by using the theory of simple beam. Okerblom[3] presented a simple equation to estimate the quantity of longitudinal deformation by

---

J. U. Park : Department of Civil Engineering, Chosun University, Gwangju, Korea
E-mail : jupark@mail.chosun.ac.kr
C. H. Lee and ***K. H. Chang*** : Department of Civil & Environmental Engineering, Chungang University, Seoul, Korea
E-mail : changkor@cau.ac.kr

thermal elastic plastic analysis and verified the validity through experiments. Tsuji[4] got the deformed quantity produced by welding on the cross-section part of strip plate through thermal elastic plastic analysis and verified the validity by comparing the quantity with one gotten by experiments. Masubuchi[5] got last deformed quantity by one-dimensional thermal elastic plastic analysis for aluminum plate of a T type and compared it with one gotten by experiments. Akoi[6] pigeonholed the factors affecting deformation through analysis and experiment on the basis of the result of the study by Tsuji[4] and presented a simple equation. Jang [7,8] estimated the quantity of longitudinal deformation by welding through simple thermal elastic method and presented a presumed equation for the quantity of triangle heating needed to correct the deformation. But these studies attached importance to the estimation for the quantity of longitudinal deformation and the triangle heating method to correct the deformation by Jang [7,8] also decreases productivity and quality because of needing a correcting process separate from a manufacture process.

Accordingly, this study clarifies the creation mechanism of longitudinal deformation due to fillet welding and, on the basis of the mechanism, presents the method to prevent longitudinal deformation by offsetting the welding moment generating the deformation by the moment produced by induction heating on web plate. Moreover, the validity is verified by performing three-dimensional thermal elastic plastic analysis with FEM and by applying this method to real structures.

2. Longitudinal deformation and the preventive method

The creation mechanism of transient and residual longitudinal deformation which is generated by fillet welding during the manufacture of Built-Up beam is clarifies through three- dimensional thermal elastic plastic analysis with FEM. The cause productive of and the preventive method of longitudinal deformation are sought by investigating the analyzed result.

2.1 Analysis model and dimensions

Fig.1 shows the shape of analysis model and 1/4 model is used considering the symmetry of B.U beam. The boundary condition for analysis is set up to symmetry condition and not to produce rigid body deformation. Under this condition, the deformation by welding is freely generated. Three-dimensional Iso-parametric solid element is used as analysis element and the temperature due to welding is taken by three-dimensional thermal conduction analysis and welding deformation is analyzed with three- thermal elastic plastic analysis using the temperature as nodal force. Also, the analysis is performed considering temperature dependence of physical constant and mechanical property of a material.

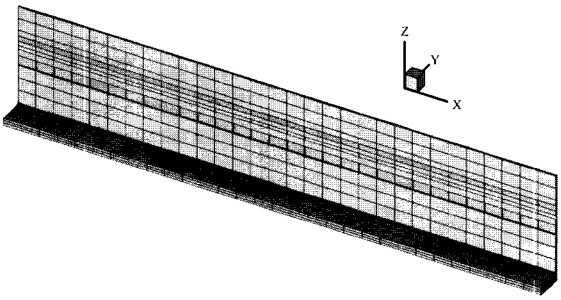

Fig. 1 Analysis Model

Fig. 2 shows a cross-section of welded part on B.U beam and the distance(Nw) from neutral axis to thermal source of welding and distance(Ni) from neutral axis to thermal source of induction are presented. Table 1 presents the dimensions of a specimen and the condition of induction heating used for analysis.

As welding condition, current is 720A, voltage 26V, speed 1,004mm/min, and leg length 5mm. The thermal quantity of input of welding for analysis is 1,121J/mm and the efficiency of heating is fixed as 0.95.

2.2 The cause and the preventive measure of longitudinal deformation

Table 1 Specimen dimension and analysis condition

Model name	Flange plate(mm)		Web plate(mm)		Length L(mm)	Heat input of Induc. (cal/mm^3·sec)	Ni(mm)
	Fw	Ft	Ww	Wt			
A1	150	18	250	11.5	3000	-	-
A2						0.640	95
A3						0.932	95
A4						0.448	95
A5		22	300			0.640	122.6

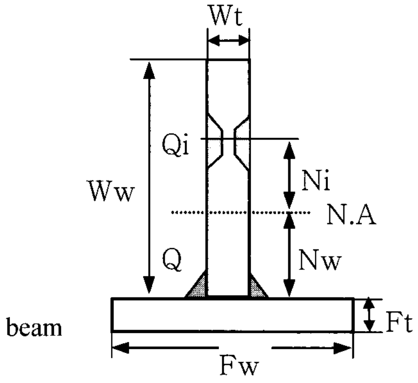

Fig. 2 Cross-section of Built-Up

Fig. 3 shows the shape of residual deformation magnified by 100 times on the basis of the results of thermal elastic plastic analysis for model A1. Fig. 4 presents transient and residual longitudinal deformation on the upper edge of web plate. During welding the deformation gets bent to lower direction because of the expansion of welded part and after finishing welding, longitudinal deformation convex to upper direction is produced because of the contraction of welded part. In the dimensions of this model, deformation is produced as maximum 3.5mm on the neutral part but in the experiment fixed the length of BU beam to 20000mm, deformation of 100mm is generated. During welding B.U beam as shown in Fig. 5, longitudinal deformation presents the shape convex to upper direction because bending moment (Mw) by welding is produced for the reason that the welded part is located Nw lower than the neutral axis of cross-section of a plate. The moment produced here is represented by multiplying the contractile power of welded part P(Qw) by the distance from the neutral axis of cross-section of a plate to thermal source (Nw). The dimensions of longitudinal deformation is produced larger as the contractile power grows larger and the distance from the neutral axis to thermal source grows longer. The longitudinal deformation produced by this welding moment can be offset by generating moment (Mi=Qi x Ni) which is the same dimensions with and is located in an opposite direction to the welding moment on the basis of the neutral axis from simple dynamic relation. In real structures, welding moment can be gotten by fixing the neutral axis of cross-section, the location of thermal source for welding, and the quantity of thermal input according to plates. Also, the other moment is generated by controlling the quantity of thermal input of induction heating source and the distance from neutral axis to induction heating source. Supposing that the thermal input is fixed, the distance from neutral axis to induction heating source is gotten with Ni=Qw x Nw / Qi and longitudinal deformation can be prevented by giving induction heating on the place.

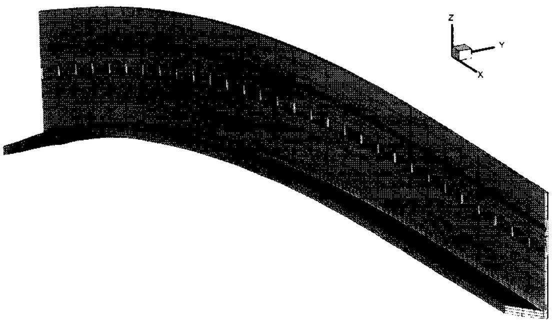

Fig.3 Shape of longitudinal deformation

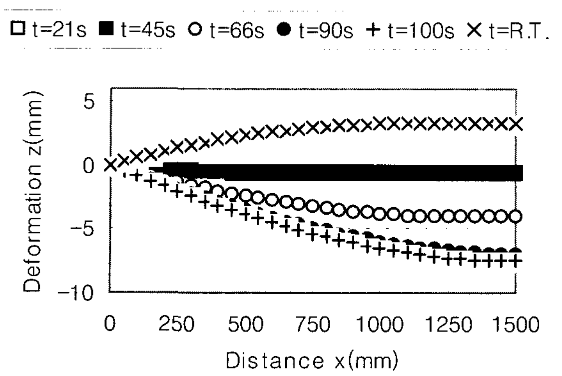

Fig. 4 Longitudinal deformation by welding(A1)

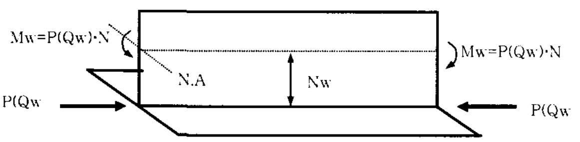

Fig. 5 Welding moment for a longitudinal deformation

3. Analysis for the properties of longitudinal deformation by induction heating

The effects of the conditions of induction heating on the preventative method of longitudinal deformation presented in Sec. 2 are verified by thermal-elastic -plastic analysis. First, by changing the input quantity of induction heating , the effects are verified. Next, by applying the result to model A5 in different dimensions, the validitys are verified.

3.1 Analysis model

Analysis is done for models A2~A4 presented in Table 1 and welding condition is the same in Sec.2. Fig .6 shows the coil shape of induction heating. The speed of induction heating equals welding speed and the real neutral depth from the cross section of induction heating are set up for 3mm and this shape is a half-oval. Though the input quantity by induction heating has to be calculated by using electric magnetic field analysis, the input heating quantity in this study is set up for 0.64cal/mm^3 · sec per a volume through thermal distribution analysis by trial and error to make the H.A.Z of the cross section of induction heating gotten by expression 700°C. Also, heating location is set up for 150mm in the direction to the edge away from fillet welding zone on web plate considering the easiness of heating.

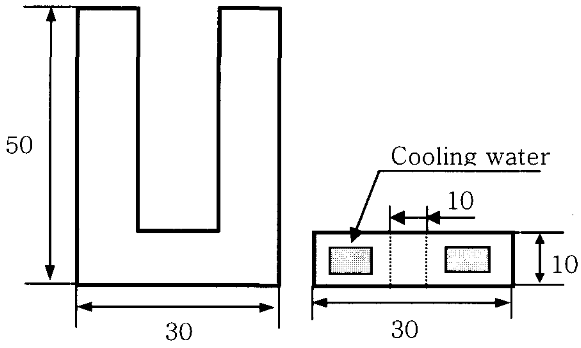

Fig. 6 Shape of induction coil (Unit : mm)

3.2 Analysis for longitudinal deformation based on induction heating

Fig. 7 figures the temperature distribution (t=90sec) produced by induction heating and welding for model A2 and Fig. 8 figures longitudinal transient/ residual deformation based on analyzed result. Judging from the result, the transient maximum deformation by induction heating is reduced to 50% as compared with one by fillet welding. However, judging from the temperature distribution and temperature history of induction heating zone and welded zone, the whole transient deformation is leaded by induction heating and residual deformation is prevented by keeping the balance of the last forces. Fig. 9 , to examine the effects of increase and decrease of input heating quantity on longitudinal deformation, figures the quantity of longitudinal deformation based on the result analyzed for both model A3 increasing the quantity of induction heating in model A2 to 30% and model A3 reducing it to 30%. Judging from the result, longitudinal deformation can be controlled by input heating quantity because residual longitudinal deformation changes pro rata with in about ±1mm according to input heating quantity.

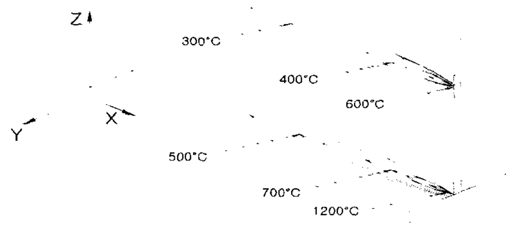

Fig. 7 Temperature distribution by weld and induction(A2)

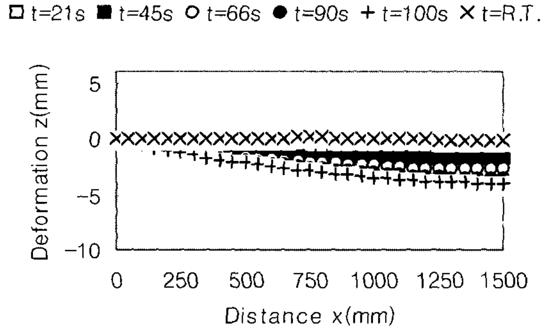

Fig. 8 Longitudinal deformation by welding and induction (A2)

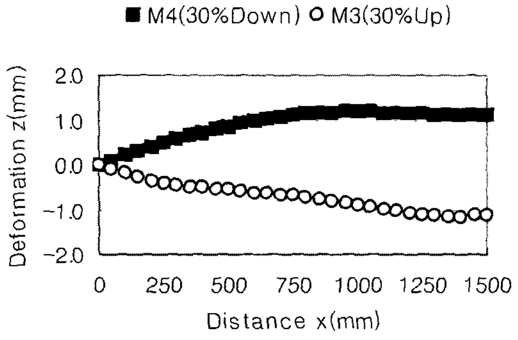

Fig. 9 Longitudinal deformation on induction heating (A3 and A4)

3.3 The investigation for the validity by analysis

To investigate the validity for the preventative method of longitudinal deformation by induction heating, analysis is performed by setting up welding condition and induction heating condition the same with Sec. 2. But the type of B.U beam A5. Because longitudinal deformation is generated by bending moment due to welding to multiply the input quantity of welding (Qw=1,121J/mm) by the distance from the neutral axis of a B.U beam to welded part (Nw=55mm), the location of induction heating must be set up to generate the induction moment which is the same dimensions with and in an opposite direction to the welding moment to offset the welding moment. Heat input of induction is calculated as follows.

$$Qw \times Nw = Qi \times Ni \quad \therefore Qi = (Ow \times Nw) / Ni \tag{1}$$

Because the distance from the neutral axis to induction heating source is 95mm in Table 1, heat input of induction is calculated to 649 J/mm by Eq. (1). This value is 20% lower than welding input used in A2. This is presumed the reason that the input condition and the sufficiency of induction is different with ones of welding. The calculation for heat input of induction by Eq. (1) can be applied to important base data to decide the output of induction machine from multi-typed induction coil. While, in this section, because the distance(Nw) from the neutral axis of the cross section of a B.U beam to welded part is 71mm, the location of induction heating is calculated to 122.6mm by Eq. (1) and this value is applied to this analysis.

Fig. 10 shows the shape of transient / residual longitudinal deformation by welding and Fig.11 shows one by induction heating which is performed according to the heat location calculated by Eq. (1) to prevent longitudinal deformation. Judging from the result, Longitudinal deformation can be prevented by applying the preliminary analysis and the heating location gotten by Eq. (1).

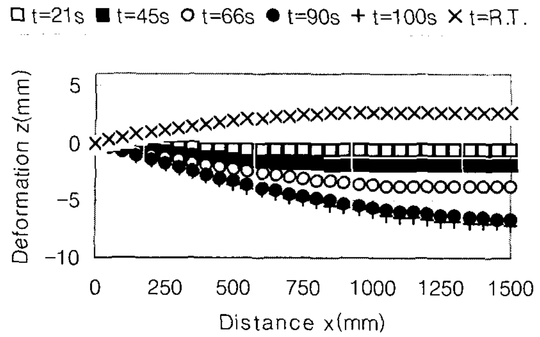

Fig. 10 Longitudinal deformation by welding(A5)

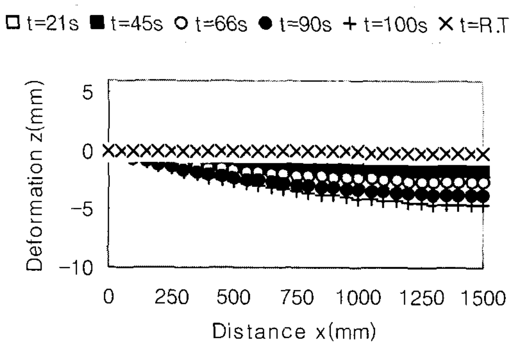

Fig. 11 Longitudinal deformation by weld and induction(A5)

4. Experiment and investigation

The preventative method of longitudinal deformation verified by numerical analysis method in Sec. 3 is verified by experiment. In the experiment, the effects of the changes in heat input and the location of induction heating on longitudinal deformation are examined and by applying the result to a real structure, the verification for the preventative method of longitudinal deformation by induction heating is examined.

4.1 Specimen dimension and experimental condition

Table 2 presents the dimensions of specimens and the experimental condition. Welding condition and induction coil in experiment is the same with ones in the analysis in Sec. 3. However, the condition of induction heating is varied according to experiment condition. Longitudinal deformation is measured on the upper edge of web plate when both welded part and induction heated part become room temperature.

4.2 The effects of the temperature of induction on heating

To examine the effects of the temperature by induction heating on longitudinal deformation, the

Table 2 Specimen dimension and experimental conditions

Model name	Flange plate(mm)		Web plate(mm)		Length L(mm)	Temperature (°C)	Ni(mm)
	Fw	Ft	Ww	Wt			
E1	150	18	450	11.5	20,600	390	200
E2						430	
E3						470	
E4						430	145
E5			300				165
E6							205
E7							225
E8		22	500		20,200	430	240
E9		18	450		20,600	430	225

location of induction heating is set up for 200mm away from the neutral axis consistently and the temperature of induction heating is varied gradually from E1(390°C) to E3(470°C). The heating temperatures in here are the values measured with an infrared temperature measuring instrument on the location of 100mm away from coil after induction heating.

Fig. 12 figures the quantity of longitudinal deformation during welding varying the temperature of induction heating. As the temperature gets higher, the quantity of longitudinal deformation gets less. That's because the moment by induction heating increases.

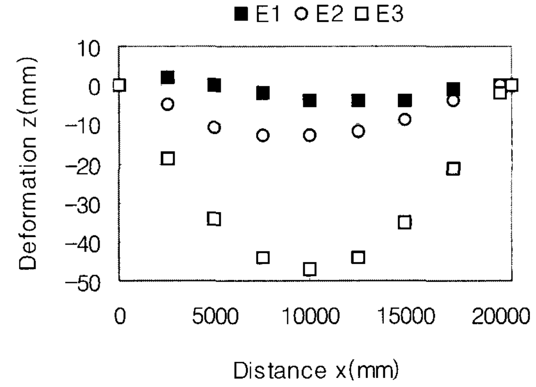

Fig. 12 Longitudinal deformation on heating temperature

4.3 The Effects of the Location of Induction Heating on Longitudinal Deformation

To examine longitudinal deformation, the temperature of induction heating is set up for 430°C (the temperature on the location of 100mm away from coil) consistently and the distant (Ni) from neutral axis to induction heating source is varied from E4(145mm) to E7(225mm).

Fig. 13 figures the quantity of longitudinal deformation based on the location of induction heating. The longitudinal deformation is produced least with ± 10mm ion E7. While, as the distant from neutral axis to the source gets shorter, deformation convex upward is produced to maximum 50mm. This is because as the distant from neutral axis to induction heating source gets shorter, the moment by induction heating gets less than one by welding.

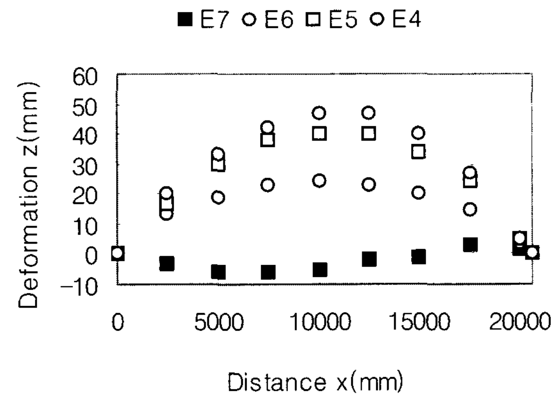

Fig. 13 Longitudinal deformation on location of induction heating

4.4 The Verification for the Validity by Experiment

Because judging from numerical analysis in Sec. 3 and the result of experiment in Sec.4, longitudinal deformation can be controlled with both the temperature and the location of induction heating, the validity is examined by applying the result to a real structure. The used models are E8 and E9 in Table 2 and the heating temperature and the location is calculated by Eq. (1) and the experiment in Sec. 4.2 and 4.3.

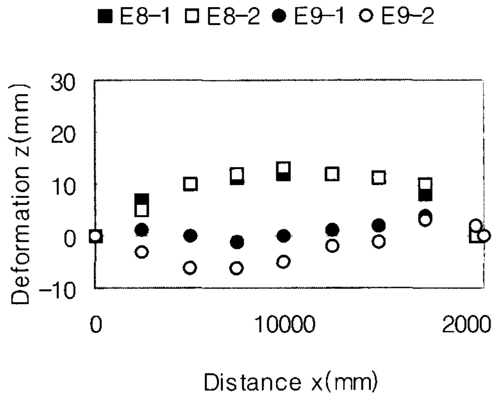

Fig. 14 Longitudinal deformation (E8 and E9)

Fig. 14 figures longitudinal deformation gotten by experimenting a plate two times. Judging from the result of experiment, longitudinal deformation is produced within ±10mm on the distant of a B.U beam of 20,000mm. This means the fact that though the dimensions of a B.U beam changes, longitudinal deformation can be prevented by controlling the temperature and the location of induction heating gotten by Eq. (1) and experiment.

5. Conclusion

This study presents the new method to prevent longitudinal deformation by fillet welding during the manufacture of Built-Up beam with the induction heating, in which because the process to correct the longitudinal deformation is performed simultaneously with fillet welding, productivity and quality can be pretty improved. Accordingly, the present study clarifies the creation mechanism of the longitudinal deformation and the effect of the condition of induction heating on the deformation with experiment and analysis. The results are as follows,

1. Judging from the result by 3D thermal elastic plastic analysis using FEM, the longitudinal deformation is produced by welding moment(Mw), which can be expressed as the multiply of the shrinking force(Qw) in welded part by the distance(Nw) from the neutral axis on a cross section of Built-Up beam to welding source. Also, The magnitude of the longitudinal deformation gets larger as the shrinking force gets larger and the distance from the neutral axis to welding source gets longer.

2. This longitudinal deformation by welding moment can be offset by generating the induction moment(Mi) which is the same magnitude with the welding moment and is located in an opposite direction to the welding moment. Then, the induction moment(Mi) is generated by controlling the heat input of induction and the distance(Ni) from the neutral axis to the induction heating.

3. Judging from the experiments on the effects of the changes in heat input and the location of induction heating on the longitudinal deformation, as the temperature of induction heat gets higher and the distance from the neutral axis to induction source gets longer, the longitudinal deformation gets less.

4. By applying the temperature and the location of induction heat gotten by the numerical analysis and the experiments to real structures, the following fact is clarified. Though the magnitude of structure vary, the longitudinal deformation can be prevented by controlling the temperature and the location of induction heating gotten by the expressions and the simple equation (Eq.(1)).

References

1. Y. C. Kim, K. H. Chang and K. Horikawa : Production mechanism for out-of-plane deformation in fillet welding and investigation of generality, *Journal of the Japanese Welding Society*, Vol. 17, No. 2 (1999), pp. 294-300
2. Y. Sasayama, K. Masubuchi and S. Moriguchi : Longitudinal deformation of a long beam due to fillet welding, *Welding Journal*, Vol. 34, No. 12 (1955), pp. 518s-530s
3. N. O. Okerblom : The calculations of deformations of welded metal structures, *Her Majesty's Stationery Office*, (1958)
4. I. Tsuji and K. Yamaguchi : Distortion and shrinkage stresses in edge welding of beams, *Journal of the Western Society of Naval Architects of Japan*, Vol. 42, No. 7 (1967) (in Japanese)
5. K. Masubichi and V. J. Papazoglou : Analysis and control of distortion in welded aluminum structures, *SNAME Transaction*, Vol. 86, (1978)
6. H. Aoki, K. Nagai, H. Kuwajima and M. Watanabe : Estimation of welding deformations for actual plate girgers, *Journal of the Japanese Welding Society*, Vol. 50, No. 10 (1981) (in Japanese)
7. C. D. Jang and S. I. Seo : Basic studies for the automatic fabrication of welded built-up beams, *Journal of Ship Production*, Vol. 11, No. 2 (1995), pp. 111-116
8. C. D. Jang. and S. I. Seo : On the prediction of deformation of welded built-up beams, *Journal of the Society of Naval Architects of Korea*, Vol. 31, No. 3 (1994), pp. 145-153