연 구 논 문

자동차 변속기용 정밀 부품의 용접변형 감소화에 관한 연구

정 회 윤* · 김 재 웅**,† · 윤 석 철***

*영남대학교 대학원 기계공학과
**영남대학교 기계공학부
***대구미래대 캐드캠과

A Study on the Mitigation of Welding Distortion of a Precision Component for Automobile Transmission

Hoi-Yoon Chung*, Jae-Woong Kim**,† and Seok-Chul Yun***

*Dept. of Mechanical Eng., Graduate School of Yeungnam University, Kyongsan Kyongbuk, 712-749, Korea
**School of Mechanical Eng., Yeungnam University, Kyongsan Kyongbuk, 712-749, Korea
***Dept. of CAD/CAM, Daegu-Mirae College, Kyongsan Kyongbuk, 712-716, Korea

†Corresponding author : jaekim@ynu.ac.kr
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Abstract

In recent years, a demand for precision-welding is increasing in wide industrial fields for getting a high quality welded structures. Although laser welding is commonly used for precision-welding, gas tungsten arc (GTA) welding is also attempted as a precision-welding due to the cost benefit. However, welding heat causes an uneven temperature distribution leading to welding deformation. Since it causes geometric errors and degrades product quality, welding distortion recently rises as an important issue in the field of automobile parts. To control welding deformation, it is needed to design in shapes that can maximize stiffness against deformation during welding; control the welding sequence; minimize heat input; and weld allowing reverse deformation; etc. Thus it is necessary to find the one, among such approaches, that can minimize the deformation range by mathematical analysis and understand how effective it would be when it is actually used in industrial fields. This study performs analyses by numerical calculations and experiments for the De-Tent Lever, one of transmission part that requires precision the most among automobile parts, as the subject of experiment. Decrease in welding deformation is required for this part, since there is currently a trouble in guaranteeing precision due to angular deformation by welding between boss and plate. Finally the ways to minimize welding deformation has been suggested in this study through analyses on it.

Key Words : Precision-welding, Gas tungsten arc welding (GTAW), Welding deformation, Temperature distribution, Numerical analysis.

1. Introduction

Precision welding is being increasingly used in many fields such as the automobile, aerospace, and electronic communication device industries. Although laser welding is commonly used for precision welding, precision welding is being tried by GTA welding due to the relationship between cost benefit and heat input capacity in the industrial field. GTAW is a welding method connecting parent metals by melting them using the arc which is generated between the metal and a tungsten electrode that is not melt in high temperature with inert gas shielding.

When welding any metal structure, welding deformation occurs due to uneven temperature distribution by the heat for melting. Since it degrades product quality by causing geometric discrepancies, it recently becomes one of important problems in the automobile part fields. Therefore many researches have been performed to minimize welding deformation by controlling it.

In terms of reducing the welding deformation, researches on two-pass welding with double welding head and other methods have been performed[1-2]. To control welding deformation, there are methods such as designing in a form that can maximize rigidity against deformation during welding, controlling the welding sequence, minimizing heat input capacity, and welding method permitting reverse deformation, etc[3-4]. Among them, it is necessary to figure out which method can minimize the range of deformation by numerical analysis and to understand effectiveness of manufacturing by it in actual industrial sites.

This research performs studies by numerical analysis and experiments regarding De-Tent Lever (Fig. 1), one of the transmission parts requiring the highest precision, as the experimental target. This is a part currently required to minimize welding deformation because of the problem of accuracy due to angular deformation by welding between boss and plate. For this reason, the objective of this research is to find out the method to minimize welding deformation by analysis on it. A commercial FEM analysis software is used for numerical interpretation and a 3-D finite element model was established for the numerical analysis.

2. Welding Deformation of Welded Structure

Welding deformation is inherently occurring phenomenon during welding. One of the most frequently generated deformations is angular distortion. This angular deformation is basically caused by uneven strain distribution in depth direction and by the different cooling conditions between the two parts when connecting.

Fig. 1 is a photograph of De-tent Lever that is chosen as the experimental target for welding experiments. It consists of boss and plate as described above. For this part, tolerance limit between boss and plate is 1.444°, in which the tolerance means the angular value between the axis of boss and the plate as shown in Fig. 2. Converting this angular allowance to the value of Z-directional displacement (displacement in the direction of thickness of plate), it becomes 0.25mm at the round edge of plate. For the convenience in geometric measurement, this displacement tolerance is chosen as an evaluation value for the experiment and analysis.

The material of plate is SPHC and autogeneous GTA welding is applied. The conditions of the welding test are shown in Table 1, and the welding is performed in a real manufacturing site. The welding power supply of 350 DA welder (rated current: 350A) was used.

Welding experiments were performed in practical sites in such a way that the measurements

Fig. 1 Photograph of De-Tent Lever

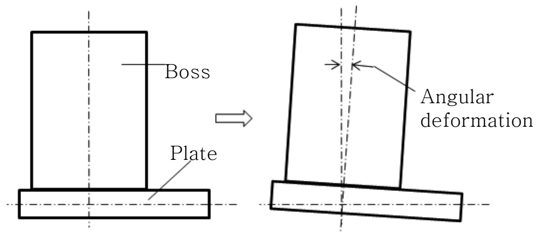


Fig. 2 Schematic diagram of angular deformation

Table 1 Welding condition for experiment

Welding power	1200W
Welding speed	6.7mm/s

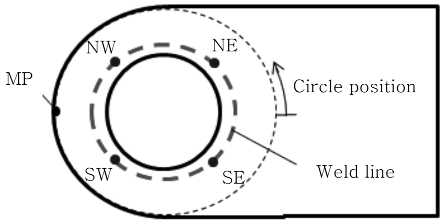


Fig. 3 The start points of welding, measuring point (MP) and calculated displacement position (along the circle position) of the plate part in the model

Table 2 Measured deformation displacement

Welding start position	Deformation displacement (mm)
Northwest	0.322
Northeast	0.248
Southwest	0.243
Southeast	0.226

were done changing the welding start points of NW (Northwest), NE (Northeast), SW (Southwest), and SE (Southeast) to comply with main materials. In terms of measurement method, it was done by measuring the displacement in the direction of thickness at the left edge point (MP) on the perimeter portion of the plate region as shown in Fig. 3. Measured displacements after welding experiment are presented in Table 2.

3. Numerical Analysis of Welding Deformation

3.1 Numerical Analysis Modeling

For numerical analysis, it was basically necessary to choose welding process parameters such as welding power and its efficiency, and welding speed. And heat source model correspond to the GTA, boundary and constrained conditions, and material properties are also needed.[5)] In the analysis, material properties are assigned as those of carbon steel C15 because of its similarity to SPHC, which include Young's modulus, specific heat, and thermal conductivity as shown in Figs. 4. The density of metal is $7.89e^3$ kg/m^3 and 0.3 of Poisson's ratio is used in the calculations. A commercial FEM analysis software is used as the analysis program and modeling works are performed as follows.

The real plate shape of De-tent Lever is very complicated one so it is difficult to make numerical model and mesh generation. Thus a simplified shape of the plate shown in Fig. 5(a) is made as a numerical model. However

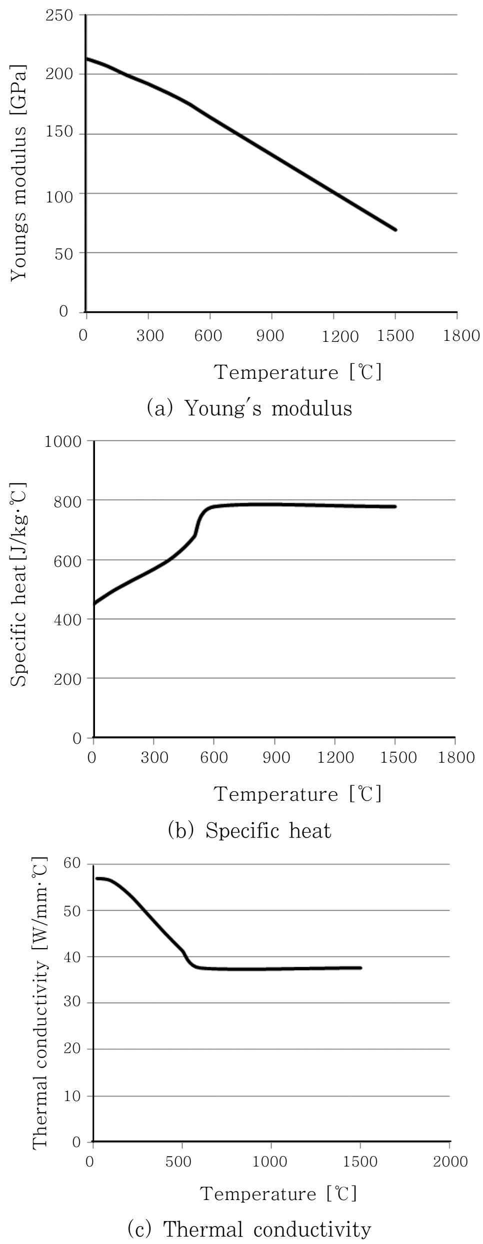
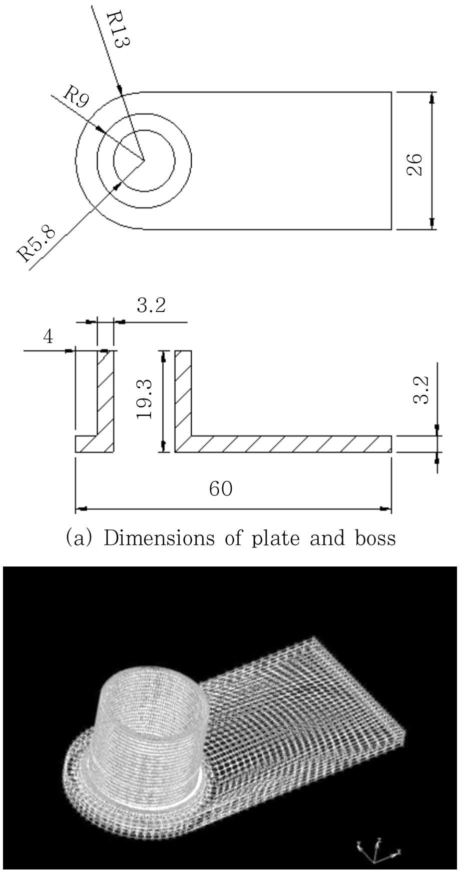


Fig. 4 Material properties for analysis



(a) Dimensions of plate and boss

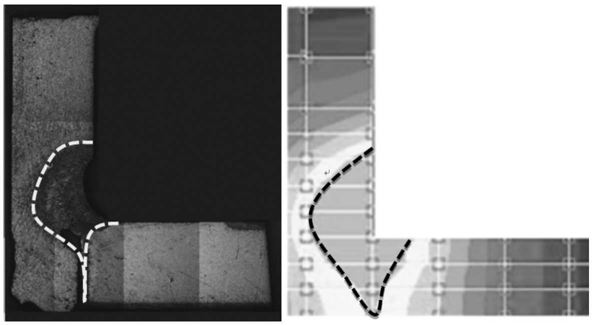
(b) Numerical full-model

Fig. 5 Numerical model for De-tent Lever

the shape of boss is so simple that real measurement is reflected to the numerical model. Finally a full-model was completed as shown in Fig. 5(b), and it is used for the numerical analysis. In terms of the number of final factors, the material point consisted of 24,192 nodes[6].

3.2 Heat Source Modeling

While we found numerical analyzability of the experiment through numerical analysis, the heat source modeling was also performed to confirm how the heat source efficiency complied to the actual one in this experiment. Based on the Goldak model[3,4,7], numerical analyses were performed through various methods to match the welding efficiency to the actual one. Comparing the estimated values for cross-section of fusion zone area from the experiment and numerical analysis as shown in Fig. 6, the incident case



(a) experiment (b) calculation

Fig. 6 Comparison of fusion zone areas of experiment and numerical analysis

could be obtained when the efficiency of the actual welding power is 67.7%. Thus, this efficiency was chosen as a factor of the final heat source model[3,4,8].

4. Results of Numerical Analysis on Welding Deformation

4.1 Welding Deformation for Different Welding Start Points

By using the numerical model developed, we analyzed firstly the phenomenon that deformation could be reduced with different welding start points. The start points are designated in Fig. 3, and the welding direction is counter clockwise. As can be seen in Table 2, the deformation of plate was affected by the welding start position. In the case of NW start, the displacement is greater than the tolerance limit (0.25 mm). Even the displacement slightly smaller than the tolerance limit for NE start, it can't be guaranteed safely. For confirming the numerical model, analyses were performed by setting the welding start points as NW (Northwest), NE (Northeast), SW (Southwest), and SE (Southeast) as shown in Fig. 3.

A typical distribution of deformation displacement is represented in Fig. 7, in which the largest deformation is formed in the round edge of the plate. Calculation results with different start points are shown in Fig. 8, in which the largest deformation arises in the NW start condition

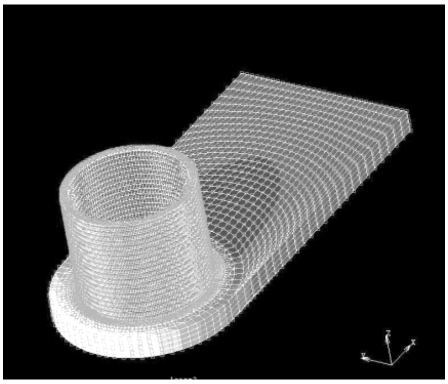


Fig. 7 Distribution of calculated deformations (Model color : bright - larger deformation, dark - smaller deformation)

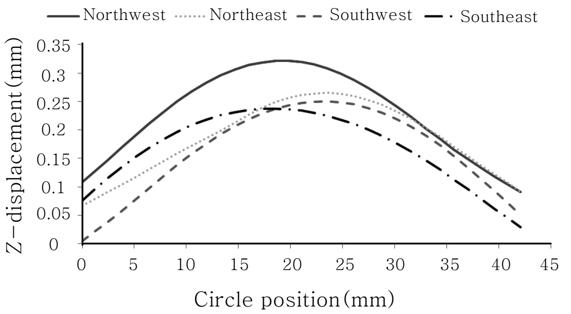


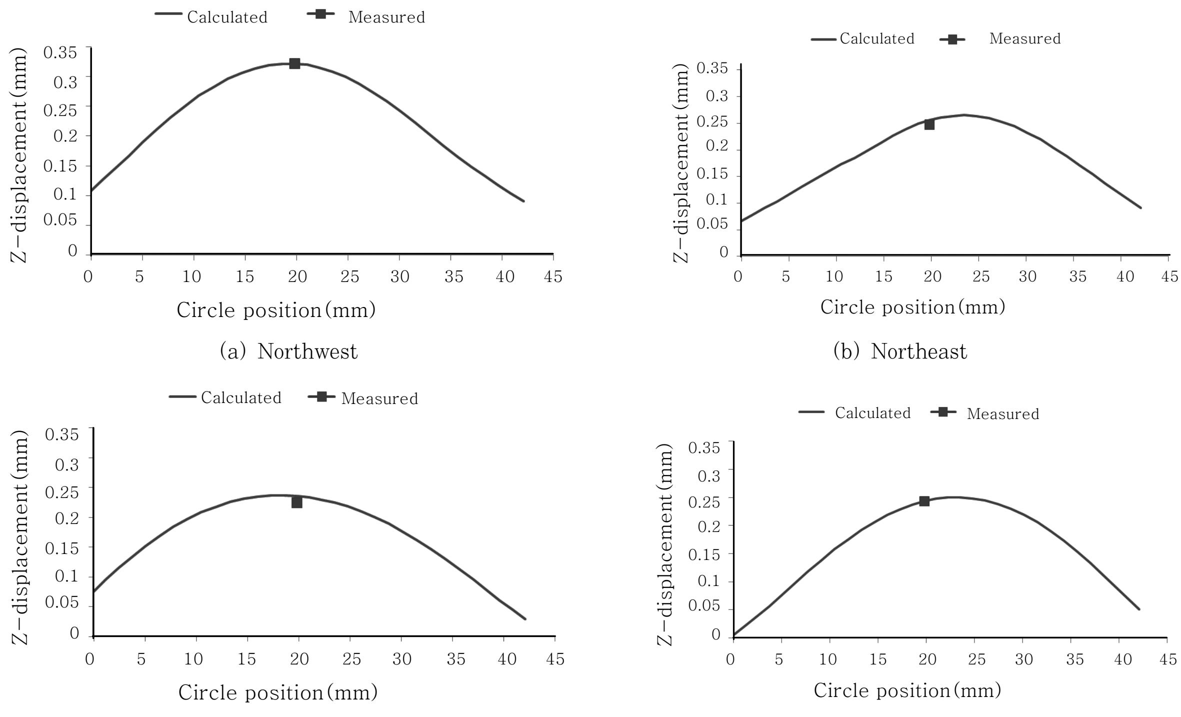
Fig. 8 Calculation results of deformation according to welding start point

and smallest in the SE start condition as the same with the experimental results. Comparisons of each calculation with the experiment according to start point were represented in Fig. 9, in which the calculated results coincide well with the experimental ones.

The reasons of different deformation according to start points included cooling time and pre-cooling area. In the case of NW, it passes through a narrow area toward a wide area. Since the initial starting point is located on the narrow area, the welded part cools quickly, and then large deformation results. In contrast, in the case of SE, it starts from a wide area and passes toward a narrow area. Thus, since welding heat is applied to the wide area first and it takes a long time to be cooled, there is relatively smaller deformation.

4.2 Deformation Reduction Suggestion by Controlling Cooling Condition

Although the deformation reduction method by positioning the welding start point results



(a) Northwest (b) Northeast

(c) Southeast (d) Southwest

Fig. 9 Comparison of analysis data with measured values in a definite reduction effect, deformations are still serious. To resolve this problem, controlling the cooling condition is proposed. As a practical method to change the cooling condition, it is suggested that emission of welding heat absorbed in the plate can be promoted through the welding jig. For example, a certain surface of the parent material may contact with the high heat conductive material jig or with the water-cooling jig.

In this analysis, behaviors of welding deformation were investigated by modeling the way of promoting heat emission on the bottom of the parent material and fixing the temperature of the bottom side to room temperature. Considering such conditions, from the start to the end of welding, the temperature of bottom side was fixed to room temperature. In addition, in terms of welding start locations, the cases of NW, NE, SW, and SE were applied for the analysis.

Numerical analysis results are represented in Fig. 10, in which the welding deformations were reduced definitely. Deformation reduction of 26.7% was accomplished in the case of NW start welding and 12.7% in SE start welding. The reason of deformation reduction is considered as follows. When keeping the temperature of the bottom side of the parent material low, rigidity on the bottom-side region increases and the standing capability corresponding to the contractile force caused by welding heat in the upper portion of the plate is improved. As a result, reduction in welding deformation can be expected.

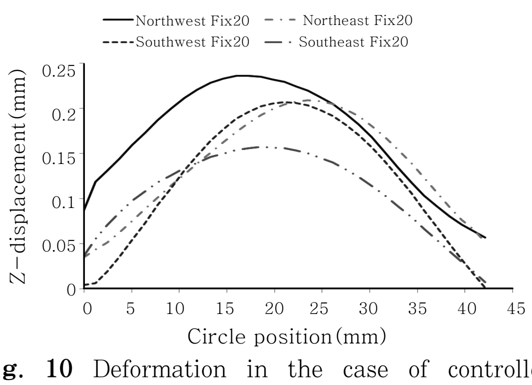


Fig. 10 Deformation in the case of controlled cooling proposed

5. Concluding Remarks

Numerical and experimental analyses on welding deformation for a precision part were performed in this study. From the analysis results, the concluding remarks are as follows;

1) By simplified geometric modeling of an automobile part and modeling the heat input of welding arc, 3-dimensional numerical analysis model was constructed.

2) The numerical analysis model was verified by comparing the shape of cross-section of fusion zone with actual one, and the welding efficiency was confirmed as about 67.7% through the repeated calculations.

3) Analyses were performed in terms of welding start points, and it is revealed that the welding start point has an influence on welding deformation. Among the 4 start points, the smallest deformation can be obtained for the case of SE point.

4) Finally, in this study, cooling condition was suggested as one of important control variable to reducing welding deformation. From the analysis, in the case of fixing the bottom-side to room temperature, it is found that welding deformation remarkably decreased.

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