

Method for Welding Condition Settings with Forecasted Distortion Applied for Two-wheeled Vehicle Body Preproduction by Automatic Welding Machine

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ABSTRACT

Welding experiments were conducted using test pieces in order to determine the arc current, arc voltage, and forecasted amount of distortion, which are conditions for the automatic welding process when fabricating two-wheeled vehicle bodies for preproduction. A database was created from the experimental results. Empirical formulas were derived from this database and used to calculate arc current and arc voltage. These calculation results were taken as the basis for establishing a method of forecasting heat shrink. These methods enabled the setting of processing conditions without the use of a two-wheeled vehicle body for welding tests. They further enabled the implementation of development testing using mass-production equivalents in the initial stages of development. As a result, early decisions on the design specifications for welded parts, shortening of preproduction vehicle fabrication schedules, and reduction of development costs were achieved.

1. Introduction

There is a need to determine which welding conditions can be applied during mass production in order to enable earlier determination of design specifications for welded parts on two-wheeled vehicle bodies for preproduction.

Welding processes in preproduction used to be performed manually, and settings for the processing conditions of arc current, arc voltage, and welding speed, as well as the forecasted amount of distortion due to heat shrink, depended on the experience and intuition of the worker. Because this method involves individual variations in processing condition settings, the processing conditions from preproduction could not be incorporated in mass production, which mainly employs automatic welding. The processing condition settings therefore had to be reset when the transition to mass production was made, which was inefficient.

This issue was addressed by introducing preproduction methods that include automatic welding equipment and takt time that are on a par with mass-production lines. This method becomes important in that the welding process conditions that have been set for preproduction are applied consistently to mass production.

Processing conditions for automatic welding are ordinarily set using welding tests with actual vehicle parts.

It is no simple matter to set conditions by means of a single test, however, and the consequent need for a trial-and-error approach necessitates the fabrication of numerous vehicle parts for testing as well as the expenditure of time and labor for the testing.

This research is intended to provide for greater efficiency in setting the processing conditions for automatic welding. To that end, correlations between welding process conditions and quality derived from experiments with test pieces were entered in a database, and a method was created to enable setting welding conditions and forecasting the amount of distortion from that database.

2. Two-wheeled Vehicle Body Welding Process

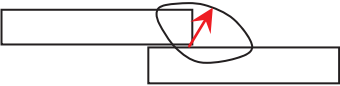
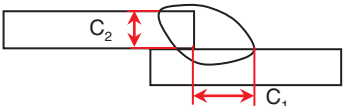
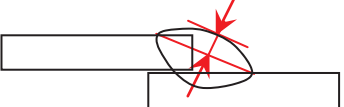
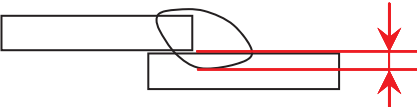
2.1. Two-wheeled Vehicle Body Welding

Figure 1 shows a two-wheeled vehicle body and the welded joints that are used. The joints in the welded parts mainly employ lap joints, T-joints, and pipe joints. These are made up of a maximum of over 200 parts. The total weld length can reach a maximum of 10 m or more.

Welding process machines mainly operate by metal active gas (MAG) welding, metal inert gas (MIG) welding, and other such forms of arc welding, which automatically feed in filler metal to the weld zone that is heated and

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Table 1 Weld quality evaluation items

Control items	Section	Explanation
Throat thickness		Minimum thickness of welding bead
Leg length		Distance from the root of joint to the toe of welding bead
Weld reinforcement		Height of the weld metal lying outside the plane containing the weld toes
Penetration		Depth of fusion into the parent metal from its surface

melted by an electric arc generated by the electrode of a tool tip known as a torch⁽¹⁾.

2.2. Weld Quality Control Items

2.2.1. Quality of welded parts

Fulfillment of the design requirements for strength is an important part of weld quality. Weld quality is evaluated by cutting across the welded part and examining the cross-section to check the quality inside the weld (Fig. 2). The areas evaluated are the leg length, throat thickness, weld reinforcement, and penetration. The quality control consists of judgment whether the requirements for these control items are fulfilled (Table 1).

2.2.2. Dimensional accuracy

It is necessary for the completed two-wheeled vehicle body to fit within the allowable dimensions given in the drawings. However, deformation occurs because of heat shrink of deposited metal (welding bead) when cooling after welding, and this affects dimensional accuracy. This makes

it necessary to forecast the amount of deformation before the welding is done⁽²⁾(Fig. 3).

2.3. Welding Process Conditions

Conditions for the welding process with two-wheeled vehicle bodies are the arc current, arc voltage, forecasted welding distortion, and welding speed.

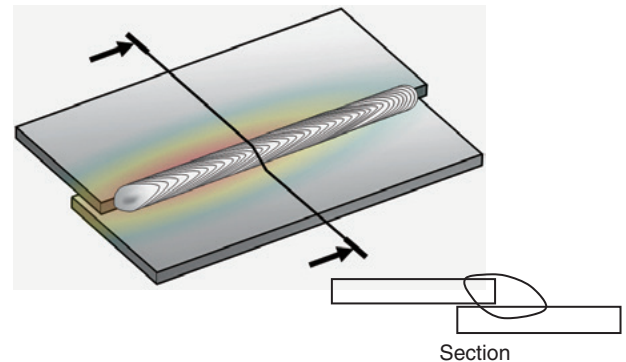


Fig. 2 Cross section of welding bead

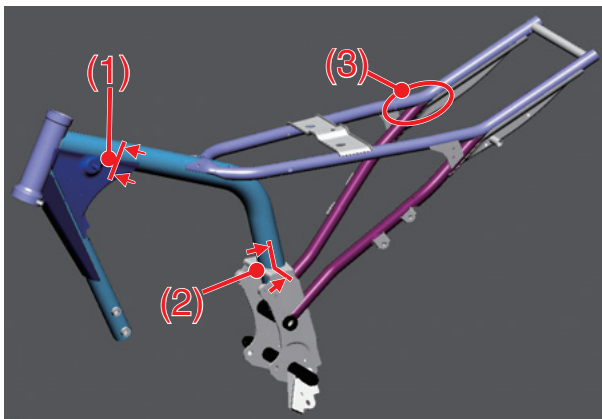
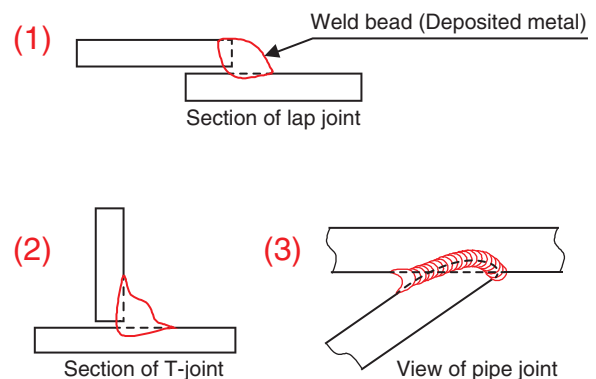


Fig. 1 Configuration of motorcycle body frame and type of welded joint



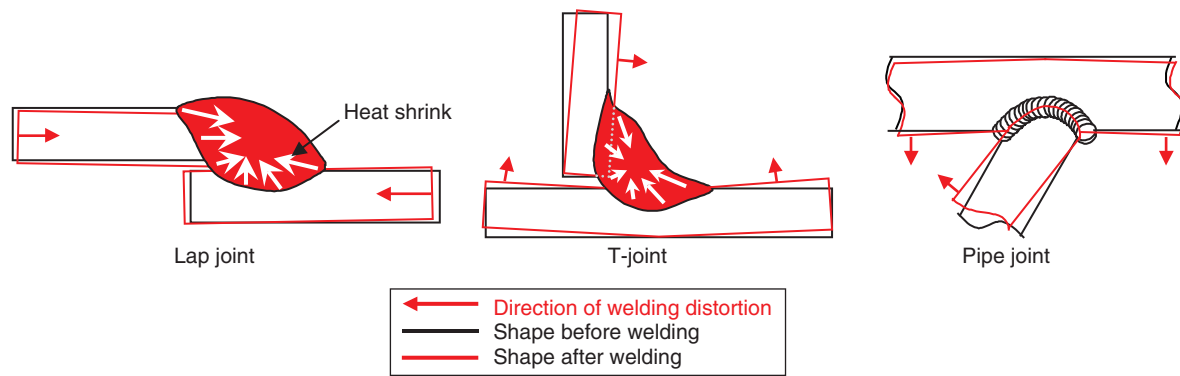


Fig. 3 Welding distortions

In the case of MIG welding and MAG welding, the arc current is used to set the filler metal feed amount and the arc voltage is used to set the amount of filler metal that is melted.

The setting of predicted welding distortion is carried out by implementing the value that includes the prospective amount of heat shrinkage to make the dimensions to be fitted within dimensional tolerance after welding.

The welding speed is the speed of welding torch movement. The welding torch is moved while filler metal is being fed in, so that a change in the speed also causes a change in the deposited metal volume. The strength of the welded joint is affected as a result, making it necessary to feed an optimal amount of filler metal for each speed range.

Those settings are to be determined to fulfill the strength requirements with the material properties, thickness and the joint shapes of the welding pieces in consideration.

3. Creation of the Database

Experiments were conducted using test pieces that recreated the shapes of welded joints used in two-wheeled vehicle bodies, and a database was created from the results.

3.1. Experiment Overview

The shapes of the welded joints, properties of the materials, and plate thicknesses classified by the model of two-wheeled vehicle body yielded 540 types of steel and 380 types of aluminum alloy welded joints. These were used in test pieces that were subjected to experiment under combinations of 17 arc current and arc voltage conditions and eight welding speed conditions. Data was collected on the welded joint deformation resulting from welding bead quality and heat shrink under each processing condition.

3.2. Experiment Conditions

Due to the necessity for considering mass producability when applying automatic welding processes to preproduction of the body, the welding speed as determined from the takt time in mass-production was set in advance.

Experiments were conducted using combinations of arc current and arc voltage conditions, as described above, based upon the set welding speed. Data on weld quality was then collected.

Pressed pieces and cast pieces are used in welded parts. When multiple parts are combined, the accumulated error can result in gaps in welded joints. Consequently, gaps were made in advance in welded joints and welding was performed (Fig. 4). The sizes of the gaps were set in view of the general tolerance of each part.

3.3. Experiment Results

To begin with, the experiments on throat thickness, leg length, penetration and weld reinforcement, which are crucial quality control items to the strength requirements, were carried out to collect the data while performing the quality evaluations. Regarding the distortions, as shown in Fig. 5, the differences in dimensions between pre- and post-welding were measured as the amount of distortions. Data on the rate of weld reinforcement was also collected as necessary to determine the deposited metal volume (Fig. 6).

Test pieces made of cold rolled steel plate (SPCC: JIS G 3141) with a plate thickness of 2 mm were used for experiments under four welding speed conditions and three arc current and arc voltage conditions with a high frequency of application in actual use. The results are shown below as one example.

3.3.1. Throat thickness

Figure 7 shows the relationships between arc current, arc voltage, and throat thickness at each welding speed. The results indicate that the throat thickness diminishes in proportion to the increase in welding speed. This is because the deposited metal volume diminishes. It is generally thought to be preferable to have the throat thickness be equal to or greater than the plate thickness in order to fulfill strength requirements. The experiments yielded figures equal to or greater than plate thickness under all the conditions used, so that the results fulfilled strength requirements.

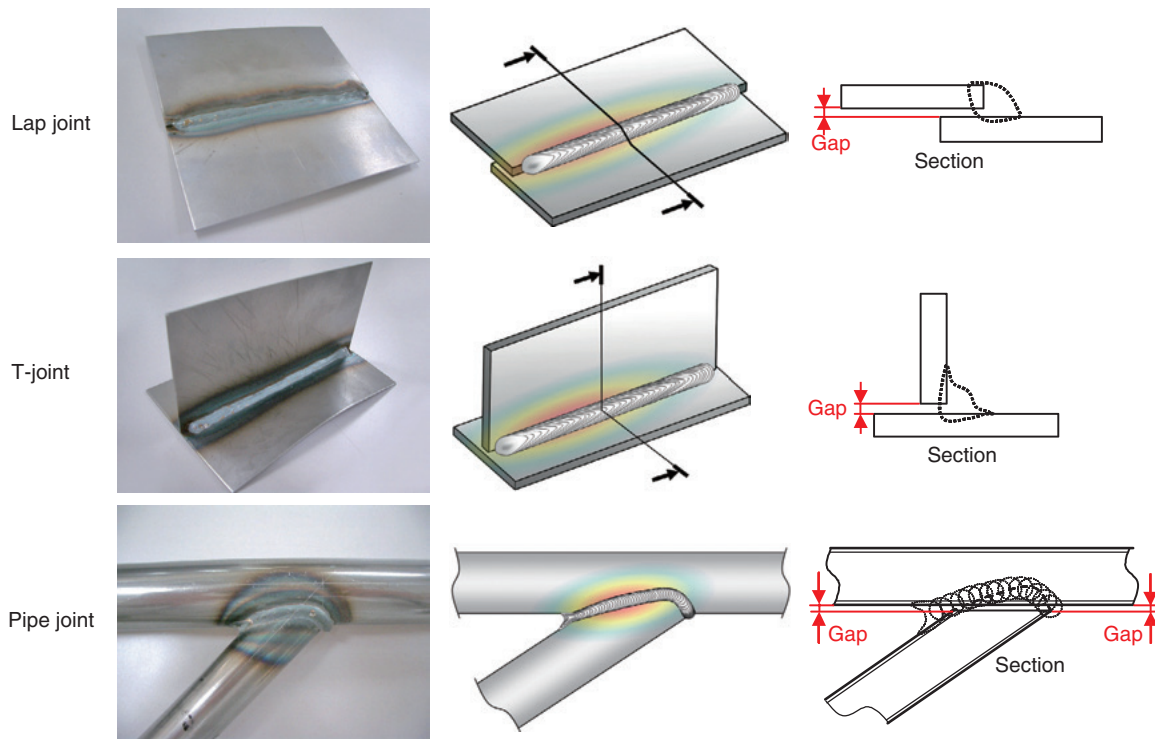


Fig. 4 Test pieces and welded joint gap settings

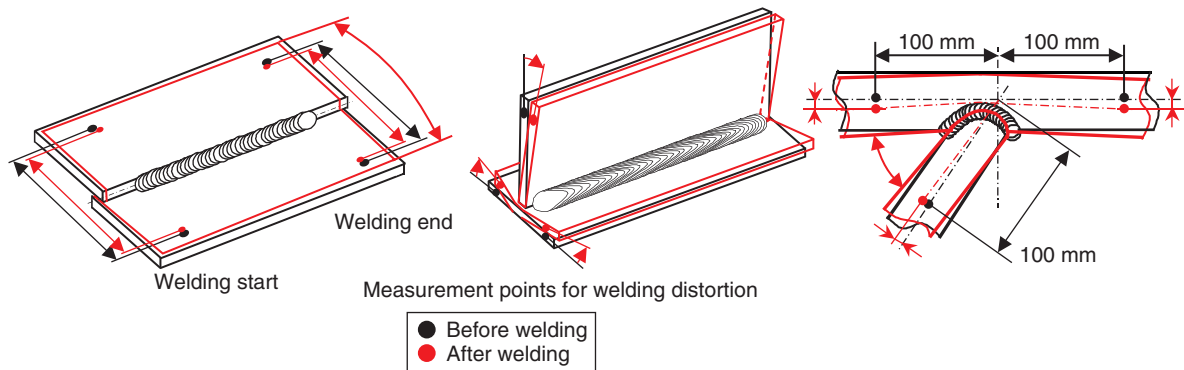


Fig. 5 Measurements of welding distortion

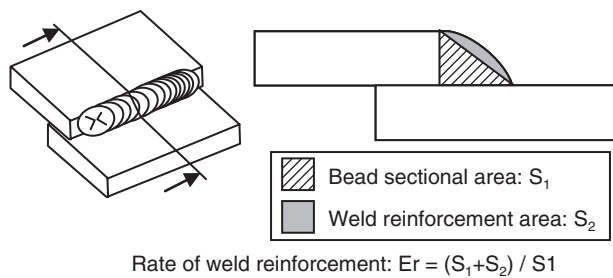


Fig. 6 Rate of weld reinforcement

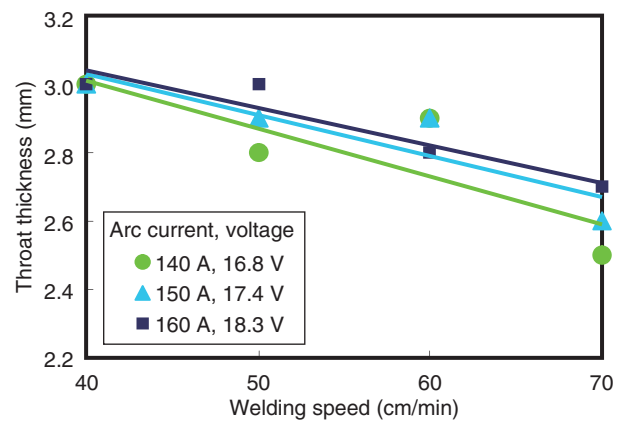


Fig. 7 Relation between welding speed and throat thickness for each arc current (SPCC, t2.0)

3.3.2. Leg length

Figure 8 shows the relationships between arc current, arc voltage, and leg length C_1 at each welding speed. It is generally thought to be preferable to have the leg length be equal to or greater than the plate thickness in order to fulfill strength requirements. The experiments yielded figures equal to or greater than plate thickness under all the conditions used, so that the results fulfilled strength requirements.

3.3.3. Weld reinforcement

Figure 9 shows the relationships between arc current, arc voltage, and weld reinforcement at each welding speed. Since weld reinforcement depends on the throat thickness, the weld reinforcement diminishes as the volume of the deposit diminishes in the higher speed ranges at all arc currents. Excessive reinforcement places the weld toe under high stress, and so is not preferable. The upper limit of height is set in accordance with the joint shape, the material, and the structure.

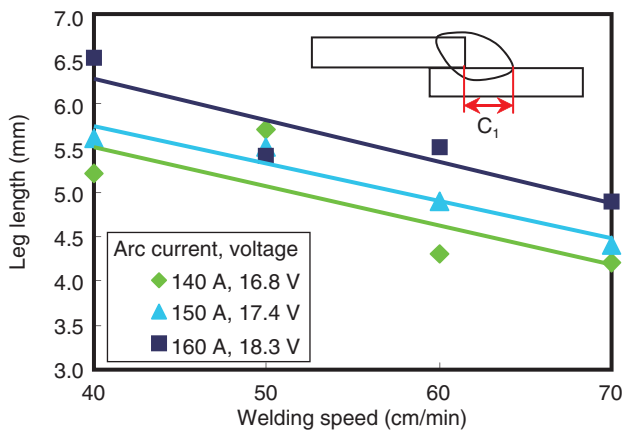


Fig. 8 Relation between welding speed and leg length for each arc current (SPCC, t2.0)

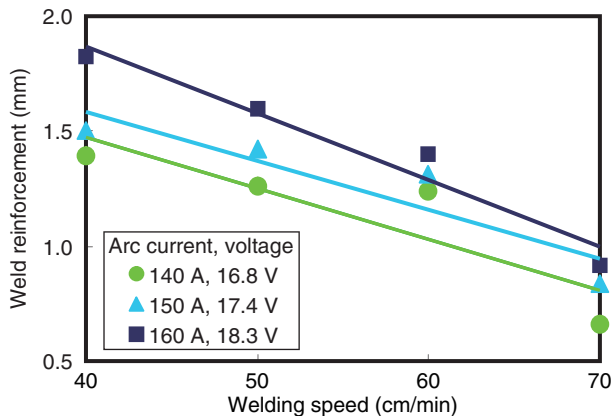


Fig. 9 Relation between welding speed and weld reinforcement for each arc current (SPCC, t2.0)

3.3.4. Penetration

Figure 10 shows the relationship with penetration at each welding speed. The results indicate that penetration was achieved in all speed ranges that were set. However, excess penetration results in deposited metal protruding from the reverse side of the plate, which can tend to cause oxidation or other such defects, and it is therefore not preferable.

3.3.5. Amount of distortion

Figure 11 shows the relationships between arc current, arc voltage, and distortion amount at each welding speed. The heat input per unit weld length increases in direct proportion to the product of arc current and arc voltage, and in inverse proportion to the welding speed. The increase in heat input also causes greater heat shrink, which is thought to result in greater distortion.

3.3.6. Rate of weld reinforcement

Figure 12 shows the relationships between arc current, arc voltage, and rate of weld reinforcement at each welding

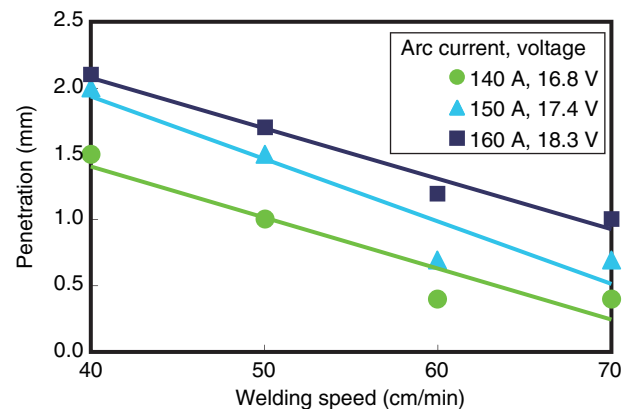


Fig. 10 Relation between welding speed and penetration for each arc current (SPCC, t2.0)

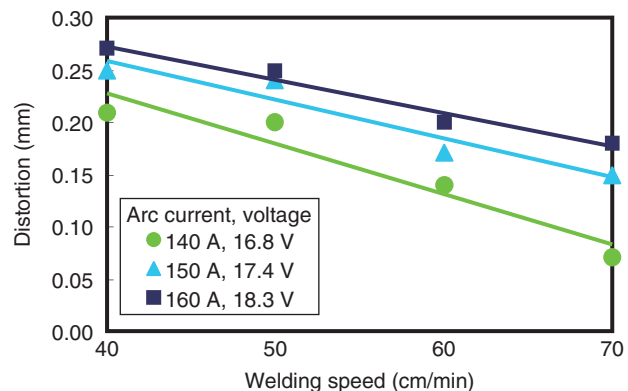


Fig. 11 Relation between welding speed and distortion for each arc current (SPCC, t2.0)

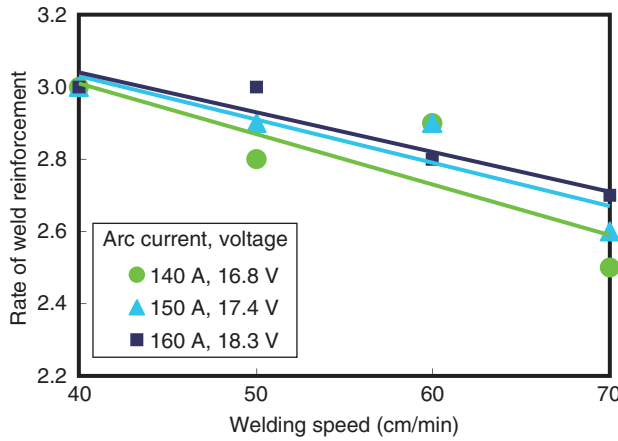


Fig. 12 Relation between welding speed and rate of weld reinforcement for each arc current (SPCC, t2.0)

speed. The rate of weld reinforcement is dependent on weld reinforcement, and the weld reinforcement diminishes with the reduction in the volume of the deposit in the higher speed ranges. The deposited metal volume can be found from the results in accordance with the welding speed, arc current, and arc voltage.

4. Derivation of Welding Conditions

The welding conditions of arc current and arc voltage are calculated by the following procedure:

1. Determine the deposited metal volume that satisfies the strength requirement suited to welding speed and plate thickness.
2. Determine the filler metal feed amount (hereafter expressed as the wire feed speed) from the deposited metal volume.
3. Convert the wire feed speed into arc current and arc voltage.

4.1. Determination of Deposited Metal Volume

Figure 13 shows typical dimensions for a welding bead section.

The deposited metal volume D is the volume of metal to be deposited per unit time. It is expressed as the product of the total bead sectional area and the welding speed. The total bead sectional area is expressed as the product of the bead sectional area S_1 and the rate of weld reinforcement

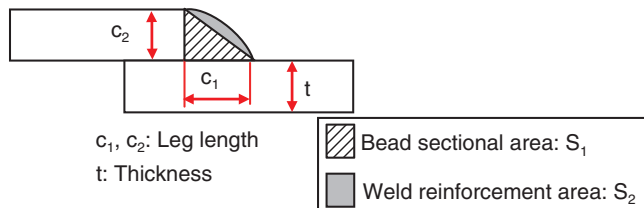


Fig. 13 Theoretical section of welding bead shape

E_r . The deposited metal volume D is expressed by Eq. (1)⁽³⁾. In general, a value of 1.15 is assigned as the rate of weld reinforcement and the leg length necessary for strength is made equal to the plate thickness.

$$D = (S_1 + S_2) v = E_r \cdot S_1 \cdot v$$

$$S_1 = \frac{(c_1 \cdot c_2)}{2} \quad (1)$$

$$E_r = \frac{S_1 + S_2}{S_1}$$

c_1, c_2 : Leg length

The experimental results in Section 3, however, indicate that the rate of weld reinforcement E_r and the leg length c_1 and c_2 vary with the welding speed v . The leg length c_1 is equal to or greater than the plate thickness. Using Eq. (1), therefore, the regression formula for each plate thickness is determined from the experimental data obtained in the practical use range, and the rate of weld reinforcement E_r' and the leg length c_1' and c_2' that depend on the welding speed are calculated. The joint gap G was then added to c_2' to derive Eq. (2), which determines the deposited metal volume D' (Fig. 14).

$$D' = E_r' \frac{c_1'(c_2' + G)}{2} v \quad (2)$$

The terms here are:

$$E_r' = -a_1 v + b_1$$

$$c_1' = -a_2 v + b_2$$

$$c_2' = -a_3 v + b_3$$

Figure 15 shows the results from calculation for each plate thickness using Eq. (2). This confirms that the figures come out close to the experimental results for deposited metal volume.

4.2. Determination of the Wire Feed Speed from the Deposited Metal Volume

The filler metal feed speed (hereafter wire feed speed)

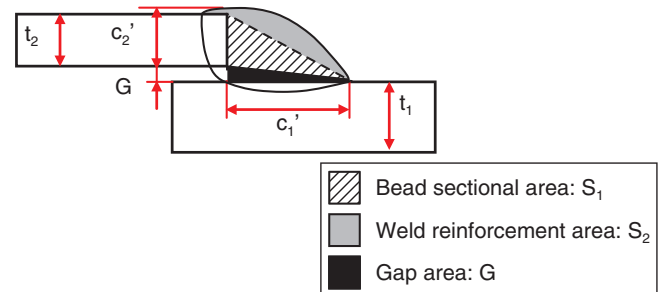


Fig. 14 Actual section of welding bead shape

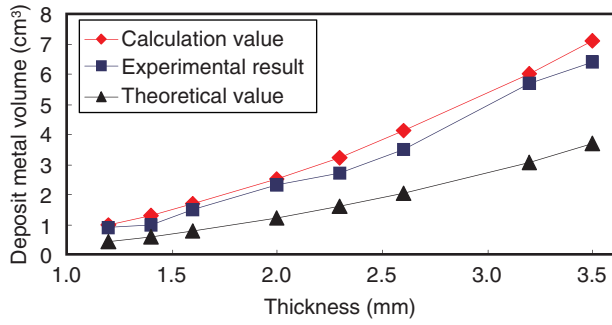


Fig. 15 Relation between deposited metal volume and thickness

W required per unit weld length is determined from the calculation results described above. The wire feed speed W is generally expressed by Eq. (3)⁽³⁾.

$$W = \frac{D}{\pi(d/2)^2} \quad (3)$$

d : Filler metal diameter

4.3. Conversion of Wire Feed Speed to Arc Current and Arc Voltage

Figure 16 shows the measurement results for the wire feed speed and arc current, and Fig. 17 the measurements

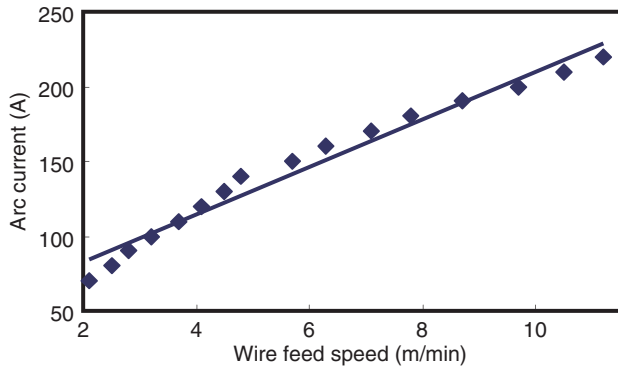


Fig. 16 Relation between wire feed speed and arc current

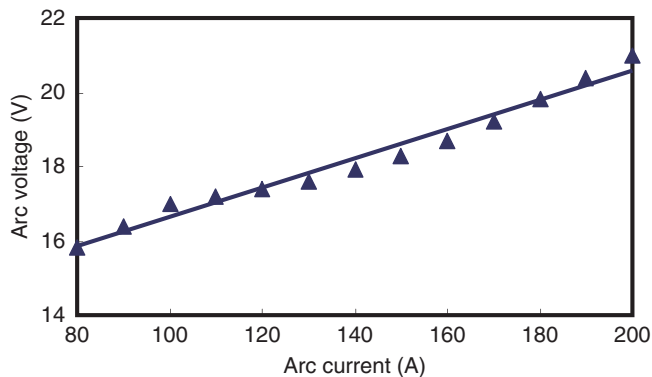


Fig. 17 Relation between arc current and voltage

results for arc current and arc voltage. The regression formula was determined from the database of actual wire feed speed measurements for each arc current condition in the experiment in Section 3.

$$I = a_4 W - b_4 \quad (4)$$

The arc voltage V was determined from the database of actual arc current measurements using the regression formula.

$$V = a_5 I - b_5 \quad (5)$$

The arc current and arc voltage are then calculated in a similar manner by material and welded joint shape.

5. Derivation of a Formula for Forecasted Distortion Amount

Calculation of the amount of distortion is performed by the following procedure:

1. Calculate the heat input.
2. Calculate the bead shrinkage of the welding start portion and the welding end portion.
3. Calculate the change in angle.

5.1. Calculation of Heat Input

The heat input Q (J/cm) per unit weld length can be determined from the arc current, arc voltage, and welding speed.

The heat input Q is generally expressed by Eq. (6)⁽¹⁾.

$$Q = \frac{I \cdot V}{v} \quad (6)$$

I : Arc current

V : Arc voltage

v : Welding speed

5.2. Calculation of Bead Shrinkage

The heat input Q obtained above is taken as the basis for determining a regression formula for welding bead shrinkage from the database of actual measurements of welding start portions and welding end portions.

$$\varepsilon_{st} = a_6 Q + b_6 \quad (7)$$

$$\varepsilon_{ed} = a_7 Q + b_7 \quad (8)$$

ε_{st} : Shrinkage of welding start portion

ε_{ed} : Shrinkage of welding end portion

5.3. Calculation of the Change of Angle

The temperature of the parent metal rises during the passage of time from the start of welding to the end of welding. The penetration therefore increases, and the

difference in the shrinkage at the two ends causes a change in the angle (Fig. 18). The change in angle θ that occurs per unit weld length can be determined using Eq. (9).

$$\theta = 2 \frac{\tan^{-1}[(\varepsilon_{ed} - \varepsilon_{st})/2]}{L} \quad (9)$$

L : Weld length (mm)

The above calculation results are used for the forecasted amount setting of the welding jig.

6. Verification of Practicability and Results of Application

The two-wheeled vehicle body is fabricated using an automatic welding machine (robot welding) with arc current and arc voltage set by the formula shown in Section 4 as well as a welding jig that incorporates the forecasted welding distortion calculated by the formula shown in Section 5. The weld quality and dimensional accuracy of the body were then verified (Fig. 19).

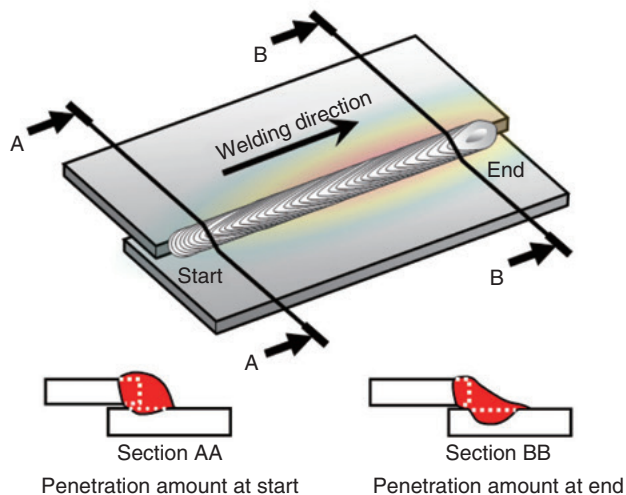
6.1. Verification Results

Weld Quality

Figure 20 shows the results from comparison of the deposited metal volume values relative to plate thickness as calculated and as actually measured. The two were in close correlation.

Dimensional Accuracy

Figure 21 shows the dimensional datum point and dimensional measurement points including the engine mounting points and suspension system attachment points.



Amount of shrinkage increases with increasing penetration into base metal

Fig. 18 Angle change due to welding distortion

Figure 22 shows the results for dimensional accuracy. The horizontal axis shows the distance of each measurement point from the dimensional datum point. The vertical axis shows the rate of dimensional error in the X, Y, and Z directions of each measured

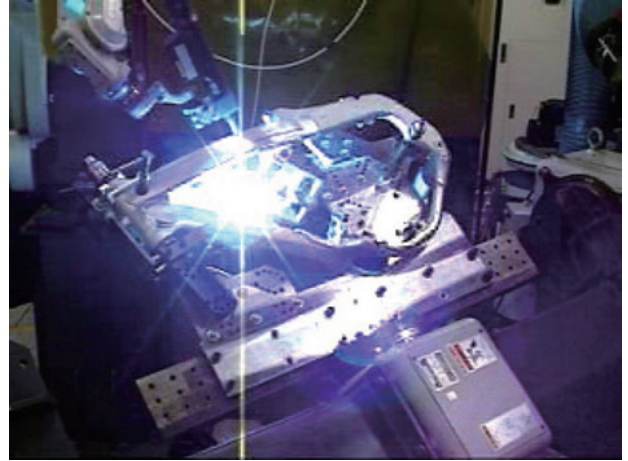


Fig. 19 Automatic welding machine

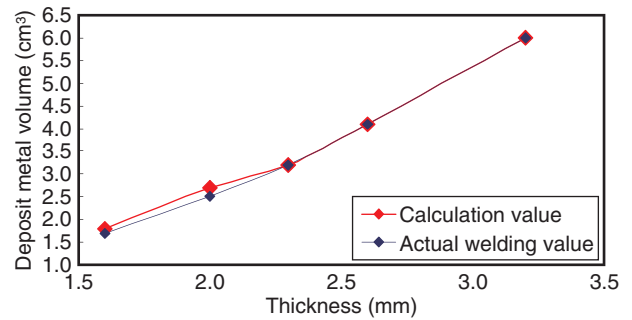
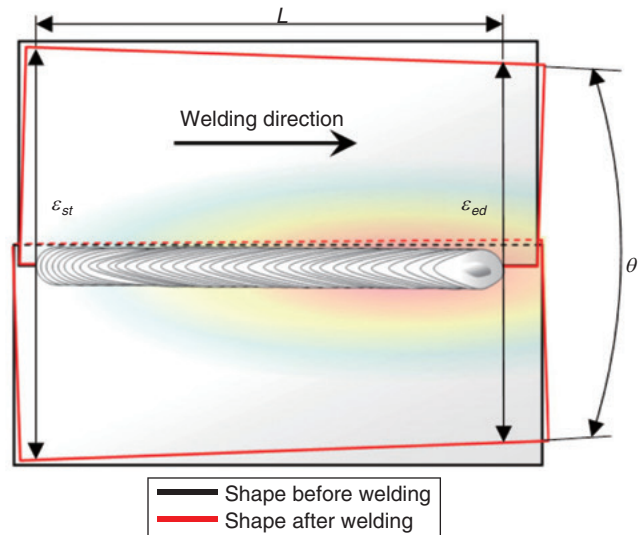


Fig. 20 Verification of calculation results



dimension as a percentage of the design tolerance. The dimensional error rate stayed at 50% or under for all the measurement points, indicating that stable accuracy had been achieved.

6.2. Effectiveness of Application to Developed Models

It was judged from the above verification results that this method could be applied to model development, and a preproduction two-wheeled vehicle body was fabricated. One effect of this was to eliminate the

necessity for the process of setting conditions by means of welding tests using two-wheeled vehicle parts. This eliminated the two days' time and labor for establishing conditions and enabled an approximately 40% reduction in preproduction costs (average value after database application) (Fig. 23). This also enabled implementation of two-wheeled vehicle body endurance tests and other such activities using mass-production equivalents in the initial stages of development, which contributed to earlier determination of design specifications.

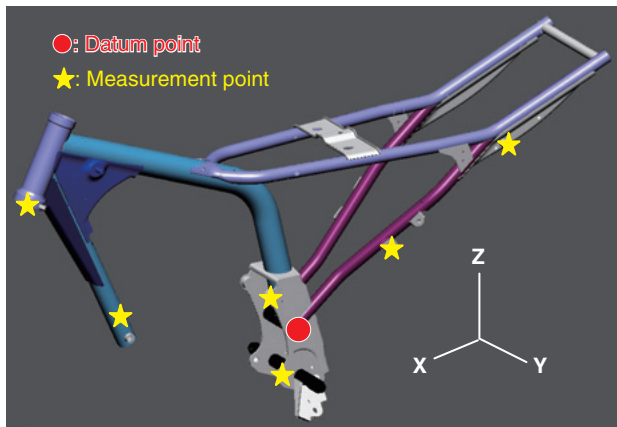


Fig. 21 Measurement points

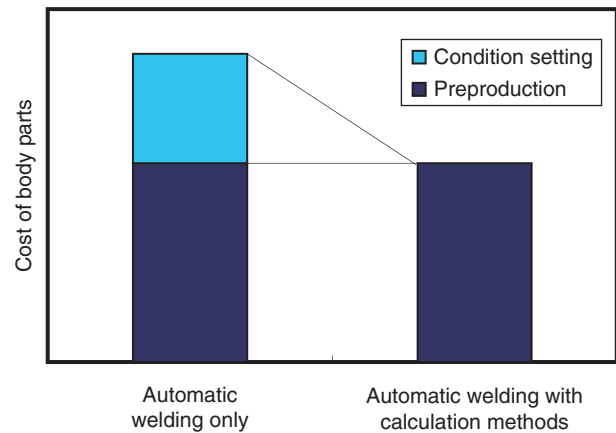


Fig. 23 Cost reduction of body parts

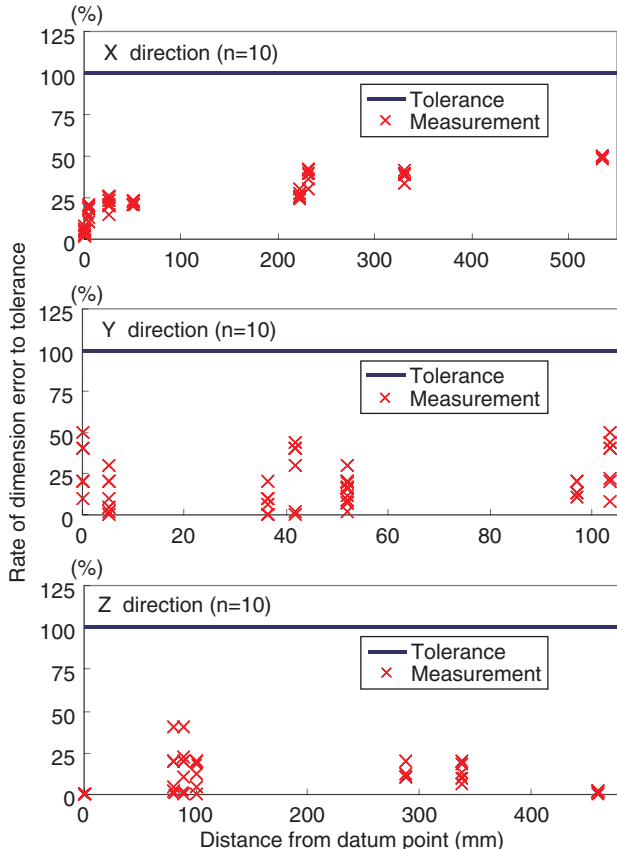


Fig. 22 Results of dimensional accuracy verification

7. Conclusion

In order to achieve efficient setting of welding process conditions for automatic welding machines used in fabricating preproduction two-wheeled vehicle bodies, experiments were conducted using test pieces, and those results were entered in a database. This database was used to create methods for setting the processing conditions of arc current, arc voltage, and welding speed, as well as to forecast the amount of heat shrink. The following results were obtained:

- (1) The necessity for the step of setting process conditions by means of welding tests using two-wheeled vehicle parts was eliminated, enabling reduction in preproduction time and labor and costs.
- (2) The highly accurate setting of processing conditions enabled stabilization of welding quality and dimensional accuracy.

The above enabled implementation of development testing using mass-production equivalents in the initial stages of development, contributing also to the earlier determination of design specifications for welded parts.

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