

## Residual Stress and Deformation of Bogie Frame Steel Plate Weldment By Plasma-MAG Hybrid Welding Process

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**Abstract.** The residual stress and welding deformation were measured for the bogie frame steel plate SMA490BW butt joint welded by using the plasma-MIG hybrid welding process and the general MAG welding process respectively, as well as in different groove angle conditions. The results indicate that the plasma-MAG hybrid welding can effectively reduce the residual stress and the welding deformation compared with the classic MAG welding. With the decrease of groove angles, the residual stress and welding deformation reduced accordingly. From the angle of reducing the residual stress and the deformation, the plasma-MAG hybrid welding process should be adopted in the way of narrow groove.

### Introduction

The bogie frame is the main constructional part of weight bearing for the high-speed train. It is not only supporting the train body and every kind of components, but also transporting every kinds of loading. During the train body is manufactured the MAG welding process is mainly used for the welding of bogie frame, but as the structure of frame is complicated, the distribution density of welding line is large and the MAG welding process is possessed of itself characters, the complicated residual stress and welding deformation will be produced after welding of the frame. So there are bad influences to the bogie frame's breakage, fatigue strength, and the accuracy of shape dimension and the stability of the structure. And the residual stress is the main reason to the welding deformation and fatigue damage [1-3]. Consequently, how to effectively reduce the residual stress and the welding deformation is the main problem in the welding and producing process of the bogie frame.

The impact elements of the residual stress and welding deformation are many and complicated, which is caused by the nonuniform elastic-plastic strain during the nonuniform heating and cooling in the welding process of the frame. The welding technique, joint type, welding heat input, assembling and welding sequence, the number of plies, the restrain intensity of frock and the fit-up gap and so on directly influence on the residual stress and welding deformation of the frame [3,4].

The plasma-MAG hybrid welding is a new kind of welding technique which combines two different welding techniques, Plasma welding and MAG welding . By complementing each other's advantages of these two welding heat sources, it can improve the welding quality and welding efficiency. Compared with the classic MAG welding, the plasma-MAG hybrid welding can reduce the welding heat input, concentrate on the welding energy and reduce the HAZ size, so it is hard to produce deformation of the components and parts [5,6].

Therefore, this article respectively takes the butt weldments of SMA490BW steel for the bogie frame to investigate the different welding techniques and groove angle conditions' efforts to the residual stress and welding deformation. And it provides the experimental basic theory for the plasma-MAG hybrid welding process to be used in the frame welding.

## Test materials and methods

### Test materials

The SMA490BW steel plate (thickness of 12 mm) was selected for the test materials, and the size of test plate is 350mm\*150 mm. The welding wire chosen is CHW-55CNH solid core wire (diameter of 1.2mm). The welding protective gas is 80% Ar +20%CO<sub>2</sub> mixed gases.

### Test method

#### Welding procedure method

The MAG welding and the plasma-MAG hybrid welding, and the single v-shaped groove multilayer multichannel welding process was used respectively. The joint type is butt joint, welding's groove angle is 60° for the MAG, and the plasma - MAG hybrid welding's groove angle is 30° and 60° respectively. The blunt edge and the gap is 1 mm. During the welding process, the weldment keeps unconstrained state. The welding process parameters are listed in table 1.

Table.1 Welding process parameters

welding process	wroove angle /°	weld pass	plasma current /A	plasma voltage /V	MIG current /A	MIG voltage /V	welding speed /cm·min <sup>-1</sup>	plasma gas flow /L·min <sup>-1</sup>
Plasma-MAG	30	1	180	27.2	190-200	20.6	60	6
		2	100	23	260-270	27.7	40	3
	60	1	120	24.6	180-190	19.4	60	5
		2~3	80	22	255-260	26.3	35	3
MAG	60	1	/	/	110-115	20.5	20	/
		2~3	/	/	265-270	28.1	30	/

### Residual stress measurement

Residual stress measurement reference CB3395-92 using the blind hole method. The position of the stress measuring point is shown in figure 1, weld residual stress along the direction of weld direction is the longitudinal residual stress, expressed with sigma x, weld residual stress of perpendicular to the direction is the transverse residual stress, with sigma y said. The distance between the residual stress test point is not less than 30 mm.

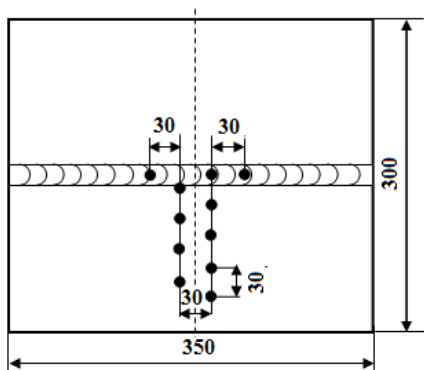


Fig. 1 The location of residual stress measuring point



Fig. 2 The scene of residual stress measurement

When it is measured, a resistance strain gage which model is BE120-2CA-K is pasted on the position to be measured, the sensitive coefficient is 2.16. The CCZ-1 test drilling equipment is adopted to drill a blind hole with diameter of 2 mm and 2 mm deep. According to the released strains obtained through YJ-25 type strain gauge, the residual stress of the position is calculated by

means of elastic theory. The scene of residual stress measurement is shown in figure 2.

### Welding deformation measurement

Using Hexagon three-dimensional coordinate measuring machine, the welding residual deformation was precisely measured based on triggering and scanning technology. Welding deformation test points are shown in figure 3.

When the deformation measured, the weldment was firstly fixed on the worktable, and then the one side of the weldment was tightly pressed, the other side of the weldment appeared a free state. Selected zero position as a benchmark, the three-dimensional space coordinates of each measuring point of the welding pieces were measured, and then according to the corresponding coordinate values of the two points, the angular deformation was calculated by the pythagore'an theorem. The scene of welding deformation measurement is shown in figure 4.

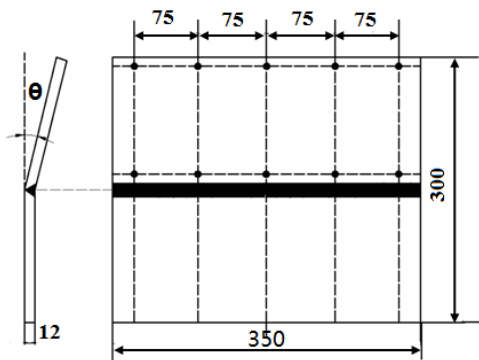


Fig. 3 The location of welding deformation measuring point

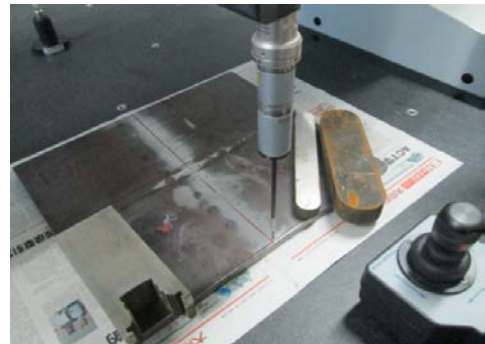


Fig. 4 The scene of welding deformation measurement

## The test results and analysis

### Residual stress

Welding residual stress distribution is shown in figure 5. Can be seen from figure 5, both MAG welding and plasma-MAG hybrid welding, longitudinal residual stress  $\sigma_x$  of the weld seam and its nearby regions are in tensile stress state, the stress value is close to or achieves the yield limit of SMA490BW steel. With the increase of distance from the weld centerline,  $\sigma_x$  gradually change from tensile residual stress to compression residual stress. Compared with the longitudinal residual stress  $\sigma_x$ , transverse residual stress  $\sigma_y$  is in lower stress levels.

Compared with the traditional MAG welding, under the conditions of the same welding process, the longitudinal residual stress  $\sigma_x$  and transverse residual stress  $\sigma_y$  are all down to a certain extent by using the plasma-MAG hybrid welding, and among them the  $\sigma_x$  reduce about 7.5% at the weld seam and 18.1% at the near seam area. The main reason for residual stress decline with plasma-MAG hybrid welding is the heat energy of plasma-MAG hybrid welding is more concentrated than traditional MAG welding, heating range is shrink, and welding speed is rapid, welding heat input is reduced, so as to reduce high temperature thermoplastic area to reduce residual stress.

Using plasma-MAG hybrid welding method and at the same time the other welding process conditions unchanged, with reduction of the weld groove angle, the welding residual stress also reduced accordingly. Compared with the commonly used  $60^\circ$  groove angle, the  $\sigma_x$  of weld area reduces 6.7%, and the near seam regions the  $\sigma_x$  declines 19.6% when the angle of  $30^\circ$  groove is selected. Obviously, the groove angle is smaller, the weld beads and filler metals are less, and the welding heat input is more reduced, so that the residual stress of joint is reduced.

Compared with the traditional MAG welding, choosing plasma-MAG hybrid welding process, or reducing the weld groove angle, can all reduce the residual stress of near weld seam regions and weld seam area, in the nearly seam area the effect of residual stress decrease is more obvious.

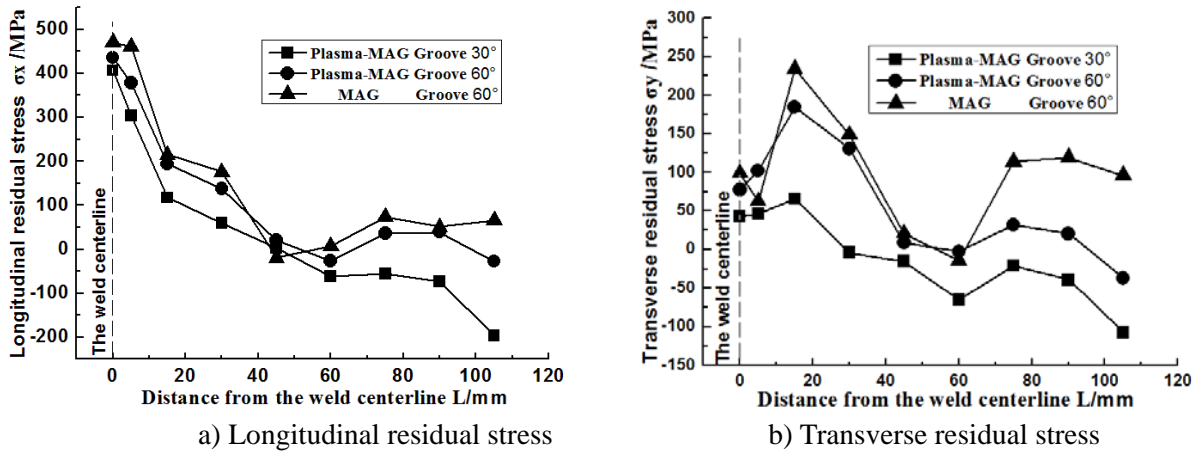


Fig. 5 The residual stress distribution of weldments

### The welding deformation

The results of welding deformation measurement are shown in figure 6. In the same groove angle with 60°, the angular distortion of plasma-MAG welding is smaller than MAG welding, the average angular distortion  $\theta$  reduced from 3.14° to 2.69°, decrease about 14.3%. Plasma-MAG welding deformation is smaller than MAG welding, the main reason is the welding heat input is relatively small.

With the welding method of plasma-MAG welding, the groove reduced from 60° to 30°, the average angular distortion  $\theta$  reduced from 2.69° to 2.50°, reduced 7.1%. Welding groove angle is small, the filler metal and weld cross-sectional area is small, the contraction deformation is little after cooling. In addition, the narrower the groove angle, the lower the difference from top to bottom of the weld section, the smaller the bending deformation of weldment.

In the case of other welding conditions unchanged, with the plasma-MAG hybrid welding and narrow groove welding technology the welding deformation can effectively reduce. Compared with the effect of reducing the deformation by reducing groove angle, the effect of using plasma-MAG hybrid welding instead of MAG welding to decrease welding deformation is better.

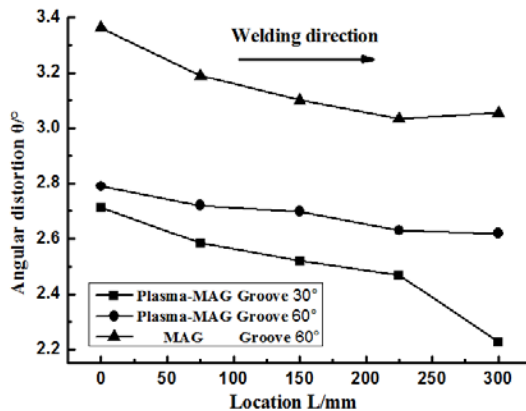


Fig. 6 The welding deformation of weldments

### Summary

(1) Compared with the traditional MAG welding, the residual stress of SMA490BW weldment is decreased obviously when the plasma-MAG hybrid welding process is adopted. At the same time, with the decrease of the weld groove angle, the residual stress reduced accordingly.

(2) In the case of other welding conditions unchanged, by using plasma-MAG hybrid welding instead of MAG welding, or by reducing weld groove angle, the welding deformations can all be reduced.

(3) Plasma-MAG hybrid welding technology with narrow groove of weldment can reduce the

welding residual stress and deformation more effectively.

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