A STUDY ON THE MECHANICAL CHARACTERISTICS OF RESISTANCE MULTI-SPOT WELDED JOINTS WITH PITCH LENGTH

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ABSTRACT

For clarifying the mechanical phenomena of thermal elasto-plastic behavior on the multi-spot welded joints, this study has tried to carry out three-dimensional thermal elasto-plastic analysis on them. However, because the shape of multi-spot welded joints is not axi-symmetric, unlike the case of single-spot welded joint, the solution domain for simulation should be three-dimensional.

Therefore, in this paper, from the results analyzed using the developed the three dimensional unstationary heat conduction and thermal elasto-plastic programs by an iso-parametric finite element method, mechanical characteristics and their production mechanism on single- and multi-spot welded joints were clarified. Moreover, effects of pitch length on temperature, welding residual stresses and plastic strain of multi-spot welded joints were evaluated, indicating that a pitch of 30mm was advantageous compared to a pitch of 15mm.

Key Words : Resistance multi-spot welded joints, Heat conduction, Finite element method, Pitch, Thermal elasto-plastic analysis, Plastic strain

1. Introduction

Resistance spot-welding is a very effective and fast process for joining sheet metals. As such, it finds wide applications in the automotive and electronic goods industries. The residual stress and deformation that occurs in the welded structures before welding should be estimated to clarify their mechanical characteristics.

In this paper, the three-dimensional heat conduction and thermal elastic-plastic numerical analysis programs which were developed in this work are used to compare and verify the results of previously verified two-dimensional axi-symmetric analyses and three dimensional heat conduction, thermal elastic-plastic analyses. By changing the pitch, one of important factors that affect weldability, various analyses of multi-spot welding are accomplished to clarify the mechanical and distributional characteristics of residual stress and plastic strain in welding.

2. Analysis Model and Method

The shape and principal dimensions of the model for analysis are shown in Fig. 1. The chemical composition of the materials used (SWS490B) and its welding conditions applying the AWS standard are given in Tables 1 and 2 respectively.

The two-dimensional axi-symmetric analysis is carried out for a quarter part of a cross-section of a spot-welded specimen because it is geometrically symmetrical. The analysis' procedures in this report are as follows: First, a two-dimensional axi-symmetric and a three-dimensional analysis for single-spot welding were carried out and the results of the two-dimensional axi-symmetric and the three dimensional analysis were compared and reviewed to demonstrate the propriety of the developed program. Second, the results of the three-dimensional analysis were compared, due to changes in pitch (15mm, 30mm) in the multi-spot welding. Single-spot welding and first-welding in multi-spot welding was carried out at the position of x=55mm (welding line direction). Second-weldings in multi-spot welding were carried out at the position of x=70mm in the cases where the pitch was 15mm and at the position of x=85mm in the cases where the pitch was 30mm, respectively.

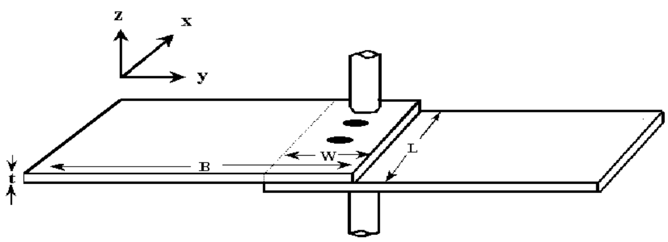


Fig.1 Configuration of spot welded specimen and coordinate

Table 1 Chemical compositions of specimen

Chemical composition	C	Mn	Si	P	S	Cu	Al
Base Metal	0.13	1.36	0.35	0.24	0.11	-	0.31

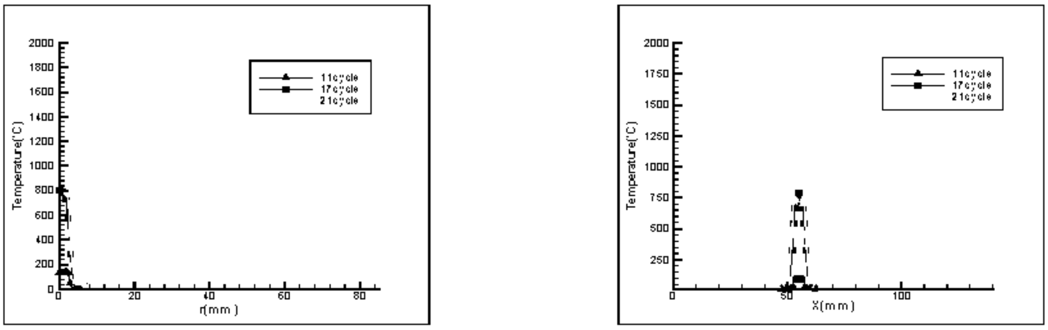
Table 2 Resistance spot welding condition of mild steel

Plate thickness (mm)	Electrode force (kgf)	Welding current (A)	Squeeze Time (cycle)		Welding Time (cycle)	Holding Time (cycle)
1	220	9,400	10		10	10
Number of point (point)	Welding speed (point/sec)	Welding method	Pitch (mm)		Lap (mm)	Nugget dia.(mm)
2	1/2	Direct	15	30	30	4.8

3. Results and considerations

Comparisons of Characteristics in two and three-dimensional heat conduction analyses

Figs. 2 (a) and (b) show the temperature variations along the welding line in the faying surface of the specimen with z=0 from cycle 11 in which the weld stage starts to cycle 21, right after its finish. When comparing the results of the three-dimensional analysis with those of the already verified two-dimensional axi-symmetric analysis, the value of the temperature distribution by the three-dimensional analysis is a little higher than that of the two-dimensional analysis but its amount is minute and their distributional aspects of temperature are the same.

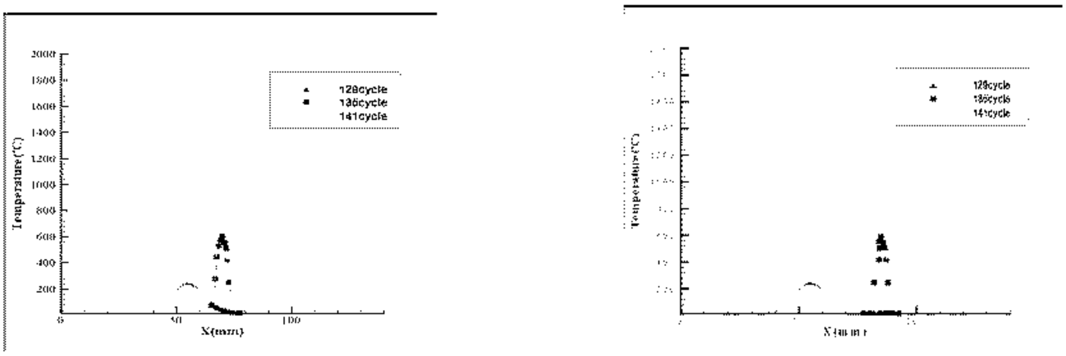


(a) 2-D axi-symmetric heat conduction analysis (b) 3-D heat conduction analysis

Fig.2 Temperature variation

Variation of thermal Characteristics with Pitch length

The thermal characteristics were observed through the three-dimensional analyses in two cases of pitch in multi-spot welding,15mm and 30mm respectively. Fig. 3(a), (b) show the temperature variations along the welding line from cycle 129, which is right before the weld stage of the post-spot welding to cycle 141, which is right after the finish of the weld stage of second-spot welding in multi-spot welding. In cycle 141, right after finish of the weld stage of second-spot welding when the pitch is at 15mm and 30mm, the temperature of the second-weld joint with 15mm of pitch is much higher than that of the second-weld joint with 30mm of pitch.

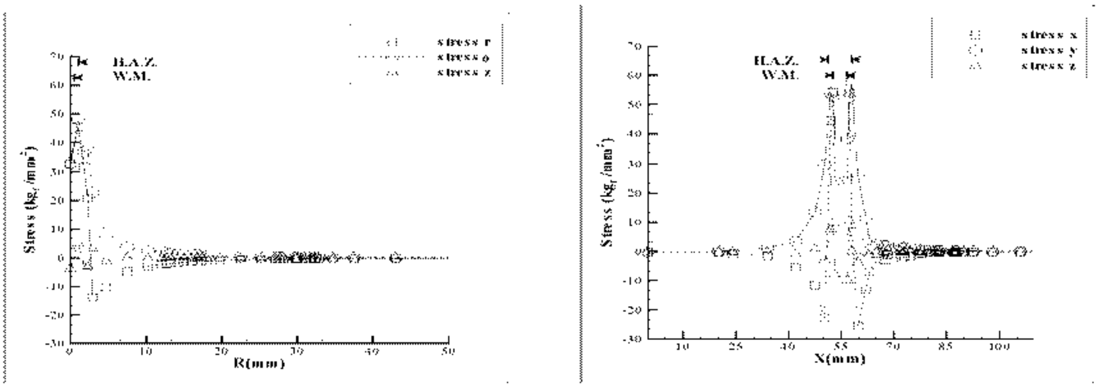


(a) Pitch: 15mm (b) Pitch: 30mm

Fig.3 Temperature variation with pitch

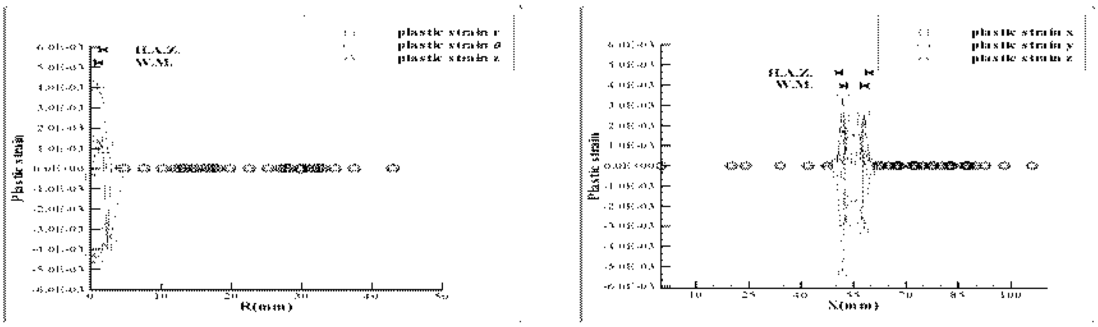
Comparisons of Mechanical Characteristics in two and three-dimensional analyses

Figs. 4(a) and (b) show the welding residual stress along the welding line found by two-dimensional axi-symmetric and three-dimensional elastic-plastic analyses on single-spot welded joint. The residual stress in the radius direction, σ_r, the residual stress in the welding line direction, σ_x, are tensile over the whole welding line and reach a maximum in the heat affected zones, as referred to in Figs. 4(a) and (b). The residual stress in the circumferential direction of the welding line, $\sigma_\theta$and the residual stress in the perpendicular direction to the welding line, σ_y, are tensile in the weld metal region and the greatest tension of these appears in the heat affected zones. The residual stress in the thickness direction, σ_z, becomes compressive in the weld metal but shows a tensile component in the heat affected zone. Figs. 5(a) and (b) show the distribution of the plastic strain along the welding line found by two-dimensional axi-symmetric and three-dimensional elastic-plastic analyses on single-spot welded joint. The plastic-strain in the radius direction, ε_r, and the plastic-strain in the welding line direction, ε_x, are tensile in the entire region, as shown in Figs. 5(a) and (b). The plastic-strain in the circumferential direction of the welding line, ε_θ, and the plastic-strain in the perpendicular direction to the welding line, ε_y, become tensile in the weld metal region and these change into a compressive component in the base metal adjacent to the heat affected zones. The plastic-strain in the thickness direction, both the ε_z found by the two-dimensional axi-symmetric analysis and the ε_z found by the three-dimensional analysis, become a significant compressive component in the weld metal region and the heat affected zones.



(a) 2-D axi-symmetric analysis (b) 3-D analysis

Fig.4 Distribution of welding residual stress of the single-spot welded joint



(a) 2-D axi-symmetric analysis (b) 3-D analysis

Fig.5 Distribution of plastic strain of the single-spot welded joint

Variation of Mechanical Characteristics with Pitch length

The distribution of welding residual stress and plastic strain along the welding line where the pitch was 15mm of the multi-spot welding is shown in Figs. 6(a), (b). The residual stress in the welding line direction, σ_x, is greater tension in the base metal region and the residual stress in the perpendicular direction of the welding line, σ_y, is greater tension in base metal adjacent to heat affected zone. The plastic strain in the welding line direction, ε_x, and the plastic strain in the perpendicular direction to the welding line, ε_y, become compressive components in the weld metal region and the heat affected zone. And the plastic strain in the thickness direction, ε_z, is greater tension and its maximum tension component appears in the heat affected zone. Figs. 7(a), (b) show the distribution of welding residual stress and plastic strain along the welding line direction in the case of 30mm pitch. The plastic strain of second-weld joint increases slightly compared with first-welded joint, however, is smaller than the case of 15mm pitch. The welding residual stress and the plastic strain of the increasing degree second-weld joint with a pitch of 30mm shows nearly identical distributional aspect and amount with those of first-weld joint.

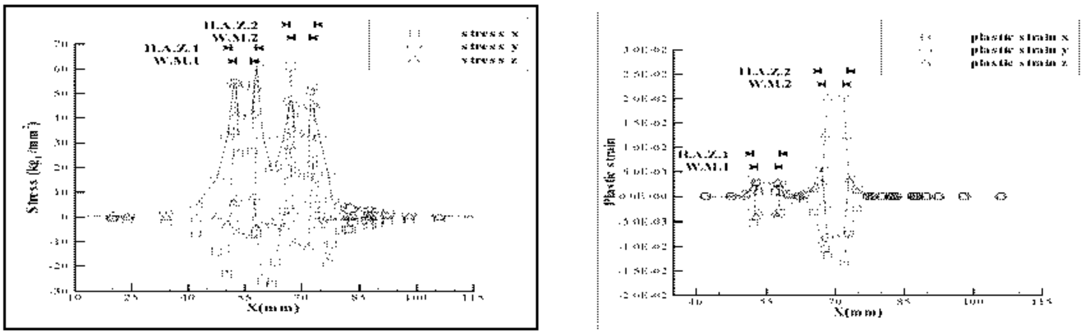


Fig.6 Distribution of welding residual stress and plastic strain in the multi-spot welded joints on pitch 15mm

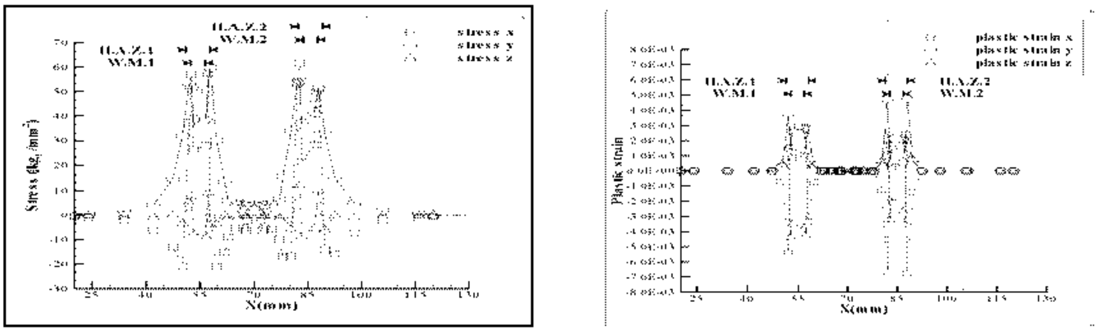


Fig.7 Distribution of welding residual stress and plastic strain in the multi-spot welded joints on pitch 30mm

Microstructural characteristics

In an attempt to investigate the microstructural variation of spot welded joint with pitch, microstructures in weld metal, HAZ and base metal were compared for single-spot and multi-spot welded joints. Fig. 8 illustrates microstructures in various locations after different welding conditions. Regardless of welding conditions, weld metals are mainly composed of ferrite, which may be attributed to low carbon content of base metal. While, HAZ microstructures are sensitively changed with welding conditions. Compared to the fine and uniformly recrystallized ferrite grain structures in base metal, ferrite microstructures in HAZ appear to be abnormally coarsened grain structures. Furthermore, multi-spot welded joints show much coarsened and irregular ferrite grain structures in HAZ, compared to that of single-spot welded joint showing fully recrystallized and uniform ferrite microstructure. With regard to the effect of pitch on HAZ microstructures in multi-spot welded joints, a pitch of 30mm reveals fully recrystallized ferrite grain structure, compared to that of a pitch of 15mm showing partially recrystallized grain structure. In terms of HAZ microstructures, therefore, a pitch of 30mm seems to be more stable than the case of 15 mm pitch.

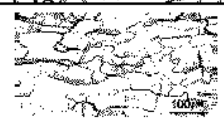
Specimens (Pitch)	Weld Metal	HAZ	Base Metal
Single-Spot Welding			
Multi-Spot Welding (15mm)			
Multi-Spot Welding (30mm)			

Fig.8 Microstructural variation in different locations with welding conditions

4. Conclusion

1. Identical results were produced through two-dimensional axi-symmetric and three-dimensional numerical analyses. For an analysis of single-spot welded joints, it is thought that the two-dimensional axi-symmetric analysis appears to be more reliable.

2. As to resistance multi-spot welding, the temperature distributions of the specimen in first-welding was superposed on to that of the second-welding resulting in a re-distribution. Therefore, with changing pitch, it can be understood that the smaller the pitch is, the more the second-weld joint is affected by the temperature of the first-weld joint.

3. As for distributional aspects of the strain in a single-spot welded joint, the greatest plastic strain appears in the directions(r and x) with the greatest mechanical constraint force. According to the Volume Constant Condition, strong compressive plastic strain appears in the direction (z) of which the mechanical constraint is the weakest.

4. When the pitch is 15mm in multi-spot welding, all of the stress components are stronger in the base metal between the first-weld joint and second-weld joint compared with a single-spot welded joint. That is because the specimen stress of first-welding in the base metal is superposed on that of the second-welding, resulting in a re-distribution of stress. The plastic strain of the second-weld joint has the opposite value of a single-welded joint and its amount increases sharply.

5. When the pitch is 30mm in multi-spot welding, the welding residual stress and plastic strain of second-welded joint are identical in the distributional aspects of those with a single- welded joint and a minute increase occurs.

As for changing the pitch of resistance multi-spot welding, in terms of the distribution of the residual stress, plastic strain and microstructural stability, a pitch of 30mm seems to be advantageous compared to the case of 15mm pitch.

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