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ANALYSIS OF EFFECTIVE NUGGET SIZE BY INFRARED THERMOGRAPHY IN SPOT WELDMENT

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ABSTRACT–Spot welding is a very important and useful technology in fabrication of thin sheet structures such as the parts in an automobile. However, because the fatigue strength of the spot welding point is considerably lower than that of the base metal due to stress concentration at the nugget edge, the nugget size must be estimated to evaluate a reasonable fatigue strength at a spot welded lap joint. So far, many investigators have experimentally studied the estimation of fatigue strengths of various spot weldments by using a destructive method. However, these destructive methods poses problems so testing of weldments by these methods are difficult. Furthermore, these methods cannot be applied to a real product, and are time and cost consuming, as well. Therefore, there has been a strong, continual demand for the development of a nondestructive method for estimating nugget size. In this study, the effective nugget size in spot weldments have been analyzed by using thermoelastic stress analysis adopting infrared thermography. Using the results of the temperature distribution obtained by analysis of the infared stress due to adiabatic heat expansion under sinusoidal wave stresses, the effective nugget size in spot welded specimens were estimated. To examine the evaluated effective nugget size in spot weldments, it was compared with the results of microstructure observation from a 5% Nital etching test.

KEY WORDS : Effective nugget size, Thermoelastic analysis, Infrared thermography, Infrared stress analysis, Spot weldment

1. INTRODUCTION

The spot weldments welded by a point phase of several millimeters are the main reason for fatigue cracks because these cracks are strongly influenced by the tensile-shear strength due to a structural deformation, residual stress, stress concentration, and the like. Particularly, the fatigue cracks caused by a repeated external loading are concentrated on the spot weldments in a dynamic structure such as an automobile (Suh *et al.*, 1988; Yu, 1999).

The fatigue strengths of spot weldments are difficult to evaluate because they are influenced by various factors, including geometric shape, pressure, residual stress, material, etc., The strength of a thin plate heavily depends on the extent of the stress concentration around the nugget, but an influence from residual stress deteriorated by a repeated load or a reduction of fatigue stress are very minor comparatively. For this reason, the nugget size and the welding must be evaluated (Pollard, 1982; Lawrence, 1983).

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The nugget size and welding in the spot weldments, which are used in the parts of sheet metals in an automobile, were evaluated wholly by destructive tests, that is, by experimental methods, including the peel test for joint strength, the tensile-diagnosis test, and the cross tensile test.

But the traditional welding conditions based on a tensile strength require many iterative tests, and they have been proved by a number of peel tests at the manufacturing sites in automobile factories. It is very difficult to apply in a real weldment or a weldment with a complicated shape in a practical manufacturing line (Vandenbossche, 1977; Suzanne, 1985).

Recently, an evaluation method for spot welding strength using finite element method or methametical method was studied (Lee *et al.*, 1988; Han *et al.*, 2000), Sohn *et al.*, 2000). In either of these methods, the nugget size is defined by the nugget cut-off surface observed through a microscope. This observation is traditionally carried out by nondestructive methods that pick out from the characteristic values of using materials and similar materials or estimates, characteristic values of fatigues from the mechanical properties of using materials (Bannantine, 1990).

The nugget size obtained by finite element analysis is defined to the effective nugget size, which the effective nugget size evaluated by the infrared stress measuring method for the spot welding specimens in ordinary cold rolled steel plates (SPC) widely used now in the study. The feasibility of the effective nugget size was examined by comparing the effective nugget size with the results of the ruptured surfaces made by 5% Nital etching test.

2. INFRARED STRESS ANALYSIS

2.1. Specimen of Spot Weldment

The features of spot weldments are evaluated by using a nondestructive method. The test was done by using SPC (cold rolled steel plates), whose chemical compositions and mechanical properties conform to Table 1, and by manufacturing the spot tensile shearing specimens which conform to Figure 1.

The specimens were manufactured by a double fold weldment on a thin plate of 100 mm × 30 mm × 1 mm. The electrodes of R type (dome shape) with aluminum oxide or dispersed reinforced copper were used in the point welding. The thickness of welding parts conformed to $5\sqrt{t}$, as recommended by the RWMA (Resistance Welder Manufacturers' Association).

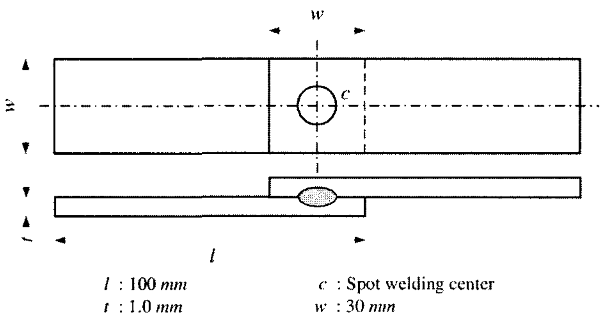

Figure 1. Specimen of spot weldments.

Table 1. Chemical compositions and mechanical properties of the base metals.

(a) Chemical compositions (Fe bal. %)

C	Si	Mn	P	S	Ni	Al
4.3	1.9	42.4	7.9	0.7	2.6	4.7

(b) Mechanical properties

Tensile strength (MPa)	Elongation (%)	Young's modulus (GPa)	Possion's ratio (ν)
296.84	56	194	0.3

Table 2. Welding conditions.

Welding current (kA)	Electrode force (MPa)	Squeeze time (cycle)	Welding time (cycle)	Holding time (sec)
8	250	30	15	10

Proper welding conditions for the point welded specimens were selected by comparing with the tensile shearing strength, and the recommended values from the JIS. The conditions of the welding current specified in Table 2 were adopted in the study.

2.2. Infrared Stress Analysis

The infrared stress analysis in an analyzing method to measure a temperature change by an infrared camera and a stress of the material from the relationship of stress and temperature by using the principle that the temperature of body changes due to the heat feature when it is applied by an elastic deformation.

When an extent of stress is lower than an elastic limit, the relation between the varied amount of temperature ΔT and the varied amount of principal stress $\Delta\sigma$ can be expressed by the following Equation (1). The change of the main stresses can be measured as a function of the temperature change.

$$\Delta T = (-kT\Delta\sigma)/\rho C_v$$
$$= -K_m T\Delta\sigma \quad (1)$$

where, k : heat expansion coefficient
T : absolute temperature
ρ : density
C_v : specific heat at constant volume
K_m : heat elastic modulus
σ_{IR} : stress by infrad thermography

In order to increase the accuracy and repeatability of measurements, one measures the change in temperature due to a dynamic load repeatedly and uses an average temperature for the time. If a repeated load is applied within the elastic limit of a material, the various width of the main stresses can be obtained by accurately measuring the change in emperature. And that is vibrated to a constant frequency using a fatigue tester for the spot welding specimens as shown in Figure 2. Simultaneously, the stress is measured by measuring of the change in the temperature at the point weldmentusing an infrared camera.

The fatigue tester of an electrical hydraulic servo was added with a constant frequency by a repeated load of 980 N on the specimens, and the stresses of the specimens were measured by using an infrared stress image system (DELTA THERM TSA 1000), and the process

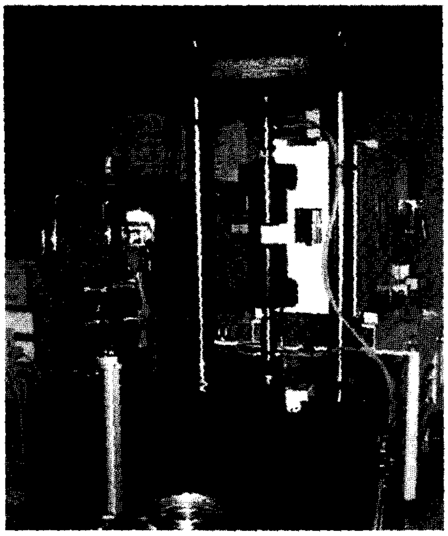

Figure 2. Stress mesurement with infrared stress analysis system.

was as follows.

(1) Stress caused by the vibrating frequency and the infrared method.

Since the IR stress (infrared stress: a stress analyzed by the infrared method) is dependent on the vibrating frequency, the stress was measured by changing the frequency from 4 to 20 Hz to acquire a vibrating frequency for the experiment.

(2) Correlation between the temperature and stress.

Dividing the spot welded specimen into 2 parts along the direction of length as shown in Figure 2, temperatures were measured for the one side of the specimen through an infrared camera and stresses were measured for the other side by a 3-axis strain gauge, and temperature and stress was correlated.

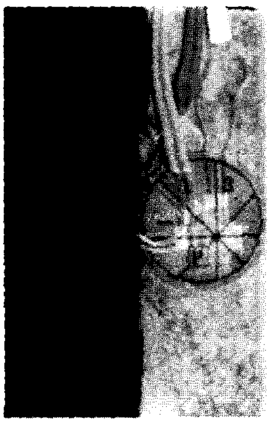

Figure 3. Stress measurement with infrared stress analysis system and strain gauge for the temperature-stress equation.

(3) Evaluation of the effective nugget size.

The effective nugget size according to the stress distribution diagram around the spot weldments was evaluated by summing the measured temperatures by the infrared camera.

3. EVALUATION OF THE INFRARED STRESS ANALYSIS AND THE EFFECTIVE NUGGET SIZE

The results of our experiment on the frequency and IR stress are shown in Figure 4. We could confirm by infrared thermography that the temperature changes according to the change in the stress frequency. When the vibrating frequencies were lower than 10 Hz, the stresses which were lower than those in fact were measured since the heat elastic stresses could not be got sufficiently. Therefore, an experiment in which the vibrating frequency was set to 10 Hz was conducted since the IR stresses from the measuring method of infrared stress become constant almost all when the vibrating frequency becomes more than 10 Hz.

A correlation between the temperature and stress has been derived using the specimens as shown in Figure 3. The experiment was done by a load control method using a hydraulic dynamic fatigue tester with capacity of 10 ton under the conditions that frequency was 10 Hz and stress ratio $R \approx 0$. To get a correlation between the temperature changes and stresses through an infrared camera, an experiment was conducted for the specimens attached with a strain gauge on it. A temperature distribution was measured by an infrared camera by applying a sinusoidal wave load of 10 Hz.

A stress distribution was calculated by amplifying and filtering the amounts of temperature changes which were obtained from the output terminal. The the temperature

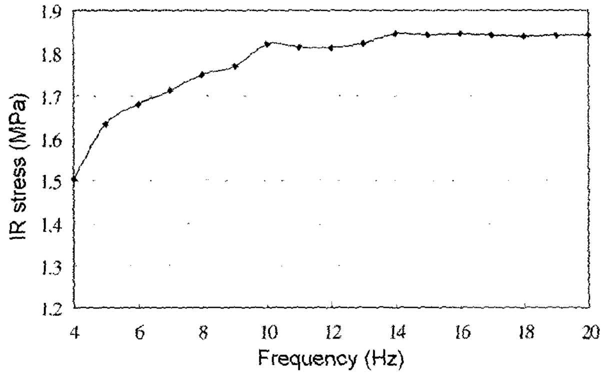

Figure 4. IR stress v.s. frequency.

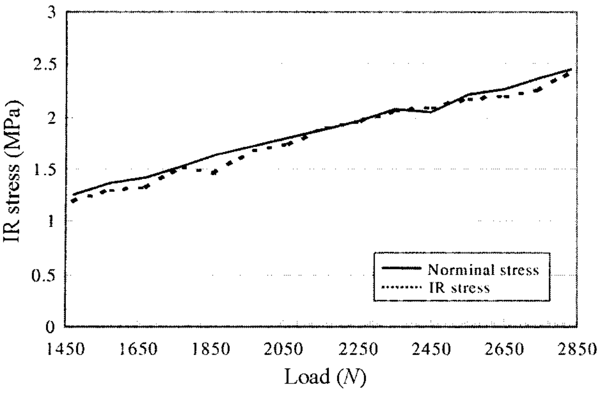

Figure 5. IR stress compared to the nominal stress.

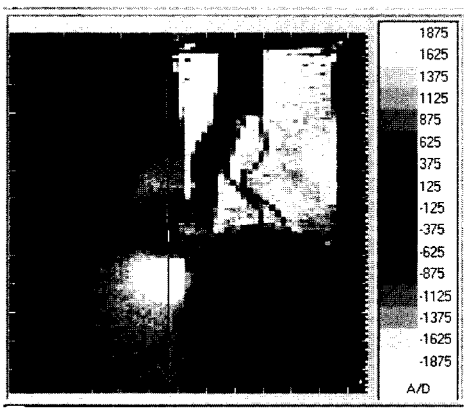

Figure 6. Infrared thermography.

varied with the stresses during the load from 1450N to 2850N, as shown in Figure 5. From the graph, the IR stress σ_{IR} can be expressed as follows:

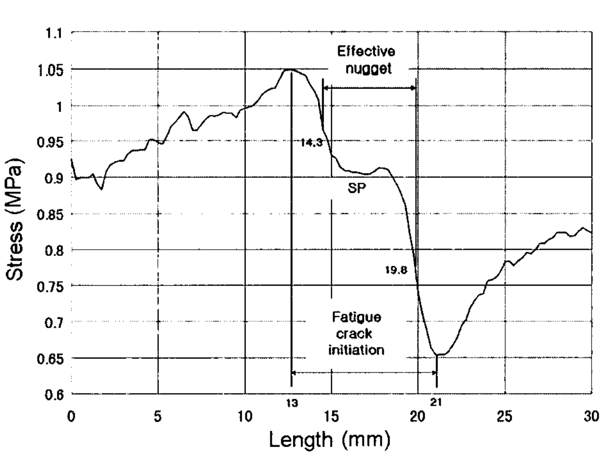

Figure 7. Stress distribution around the spot welding points and the effective nugget size.

$$\sigma_{IR} = 9.5\times10^5+120\Delta T \quad (2)$$

A temperature distribution at the spot weldment by infrared stress analysis is shown in Figure 6, which points out a relative higher temperature distribution.

The stress distribution around the spot weldment is drawn out in Figure 7 after transferring the stresses from equation (2) above. Since a particle size of nugget varies by comparing with the body material, the ingredient changes as well. Therefore, it makes us possible to confirm an intercepting point that varies from an stress ingredient of the body material to that of the nugget part. And the distance between incepting points is defined to an effective nugget size. The effective nugget around the SP (spot point) was evaluated to be 5.5 mm from the stress distribution in this study.

4. EXAMINATION OF THE EFFECTIVE NUGGET SIZE

To examine the effective nugget size bythe measurements of infrared stresses, we observed the cut-off surface of the examined specimen. After cutting off the spot weldment at the center of the surface perpendicularly, those were undergone through an emery paper and a polishing process, and then etched with 5% Nital etching liquid for 20 seconds. And the distance that was confirmed with a dendrite was defined to be a nugget and its size was measured.

The size of nugget was as 5.4 mm in the observations of the cut-off surface in Figure 8. The effective nugget size of 5.5 mm, which was measured by the infrared stress analysis, coincides with the nugget size of 5.4 mm, which was measured by observing the surface.

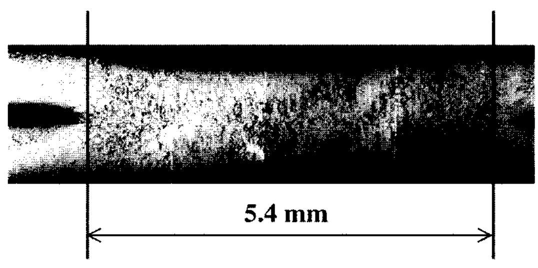

Figure 8. A nugget size of the spot weldment by a microstructure observation.

5. CONCLUSION

The concept of an effective nugget size for an analysis of finite element and an evaluation on the welding of the spot weldment specimens that were manufactured for a cold rolled steel plate for a frame were defined in the study. The effective nugget size was measured by the use of infrared stresses, which were examined by comparing the results of an observation of the cut-off surface with that of 5% Nital etching test.

We conclude the following.

(1) Infrared stress shall be measured with a vibrating frequency of more than 10 Hz since the stress is dependent on the frequency.

(2) A correlation between temperature and stress was derived by measuring the temperature distribution by an infrared camera and by measuring the stresses by a strain gauge simultaneously.

(3) The effective nugget size to be used as input for a finite element analysis of a spot weldment was defined and was analyzed by the infrared stress measurement as well.

It is expected that the infrared stress analysis will provide more useful results with regard to time and expenses, compared with the traditional destructive testing methods since it can accumulate data for a finite element analysis by evaluating the effective nugget size on the spot weldment obtained from the infrared stress analysis.

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REFERENCES

Bannantine, J. A., Comer, J. J. and Handrock, J. J. (1990). *Fundamentals of Metal Fatigue Analysis*. Prentice Hall. Englewood Cliffs. New Jersey 07632. 59–64.

Han, G. J., Jeon, H. Y. and Lee, H. C. (2000). Finite Element analysis of the shear buckling load with respect to the aspect ratio and number of spots of two rectangular plates spot-welded. *J. Korean Society of Automotive Engineers* **8, 6,** 173–181.

Lawrence, F. V. (1983). An empirical method for estimating the fatigue resistance of tensile-shear spot-welds. *SAE Paper No.* 830035.

Pollard, B. (1982). Fatigue strength of spot welds in titanium-bearing hsla steels, *SAE Paper No.* 820284.

Sohn, I. S. and Bae, D. H. (2000). A study on the fatigue life prediction method of the spot-welded lap joint. *J. Korean Society of Automotive Engineers* **8, 3,** 110–118.

Sohn, I. S., Jung, W. S., Lee, H. K. and Bae, D. H. (1998). Fracture mechanical fatigue strength evaluation of IB-Type spot welded lap joint under tension-shear load. *J. Korean Society of Automotive Engineers* **6, 5,** 20–27.

Suh, C. M. and Kang, S. S. (1988). Fatigue characteristics of spot welding between high strength steel and galvanized steel sheet(II). *J. Korean Society of Mechanical Engineers* **12, 4,** 747–754.

Suzanne, M. (1985). Zinc coating influence on spot weldability of hot-dip galvanized steels sheets. *SAE Paper No.* 850273, 1–7.

Vandenbossche, D. J. (1977). Ultimate strength and failure mode of spot welds in high strength steels. *SAE Paper No.* 770214, 1–12.

Yi, W., Lim, S. H., Shin, K. H. and Lim, K. C. (1993). Stress analysis of spot welded cross lap joint subjected to out-of-plane tension load. *J. Korean Society of Mechanical Engineers* **17, 3,** 613–623.

Yu, H. S. (1999). A study on ultrasonic test for evaluation of spot weldability in automotive materials. *J. Korean Society of Mechanical Engineers* **13, 11,** 775–782.