Fatigue Analysis of Spot Welded Joints in Suspension Mounting Part

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Experimental and numerical analyses were performed to characterize the fatigue behavior of spot welded joints in suspension mounting of a passenger car body. Static and fatigue tests were carried out for the tensile-shear and cross-tension specimens. S-N curve and fatigue strengths were obtained from the fatigue test of various specimens. Nonlinear finite element analysis showed that fatigue behavior of spot welded joints could be well estimated in terms of Von Mises stress at the nugget edge. Fatigue behavior of spot welded joint was represented by Von Mises stress better than the fatigue load.

Key Words : Spot Welding, Suspension Mounting, Fatigue Strength, Tensile-Shear, Cross-Tension, Von Mises Stress

1. Introduction

Importance of fatigue analysis on the spot welded part has grown since steel sheets having higher strength become thinner to meet the necessity of reducing the weight of an automobile effectively. Strength of spot welded part is much lower than that of its constituents and fatigue crack usually initiates from the welded point. Fatigue crack failure yields noise and vibration and often leads to fracture of structural member. External dynamic loads act on the suspension mounting part of an automobile body in which fatigue cracks initiate and propagate at the spot welded joints. The reliable methods of fatigue life prediction of spot welded joints are needed.

Assessment of fatigue life has been performed by many researchers. Bae (1991) showed that fatigue strength of various spot welded lap joint could be estimated by the stress intensity factor more effectively than the maximum stress at the edge of the spot weld part. Jung et al. (1996) and Oh et al. (1998) analyzed the fatigue behavior of IB-type single spot welded lap joint numerically and experimentally and concluded that fatigue strength could be effectively and systematically rearranged by principal stress at the nugget edge. Sohn and Bae (1999, 2001) showed that fatigue strength of IB-type single spot welded lap joints could be well explained in terms of strain energy density. Davidson and Imhof (1984) showed that fatigue life was independent of base-metal strength for lives greater than 10,000 cycles and fatigue performance improved with increasing base-metal strength at shorter lives.

Pollard (1982) also stated that spot weld fatigue strength was insensitive to base metal strength. Vanden-Bossche (1977) proposed an empirical equation of minimum weld diameter required for heat affected zone failure in terms of metal strength, thickness and joint width.

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Sheppard and Strange (1992) showed that structural stress could be successfully used to estimate life for crack initiation and growth and Sheppard (1993) estimated fatigue life in spot welded joints using the relationship between structural stress and life and verified experimentally. Quantitative and systematic estimation of fatigue life of spot welded part is needed.

In this study, fatigue test and numerical analysis will be performed to establish the assessment method of fatigue behavior of spot welded joints at the suspension mounting part. Fatigue life of spot welds will be predicted by stresses rather than forces and its validity will be checked by experimental results for the tensile-shear and cross-tension specimens with various combinations of thicknesses and materials.

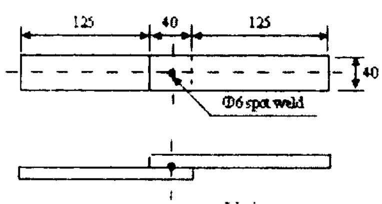
2. Experiment

2.1 Specimen preparation

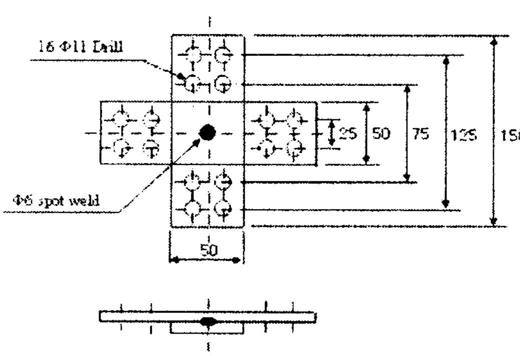
Three primary materials which constitute suspension mounting part of a passenger car are SPCC, SPRC35 and SAPH38P, and their measured material properties are shown in Table 1. SAPH38P shows the highest strength value. Tensile-shear (TS) and cross-tension (CT) specimens were tested and their geometries are shown in Fig. 1. Nugget diameter is 6 mm for both types of specimens. Combinations of materials and thicknesses followed those of suspension mounting part of a real automobile.

2.2 Static and fatigue test

Static and fatigue tests for the TS and CT specimens were performed with the MTS 819 dynamic testing machine. Table 2 shows the static fracture loads for the various TS and CT specimens. Fracture loads of TS specimens were higher than those of CT specimens. Order of magnitude of static strength follows that of tensile strength of its constituents, however, SPCC 1.0/SPRC 1.0 specimen has the lowest strength. Load-fatigue life curves for various spot welded specimens were plotted in Fig. 2. TS specimens generally show superior fatigue characteristics to CT specimens. Fatigue strength in the low fatigue life region shows large differences for the combinations of



(a) Tensile-Shear specimen



(b) Cross-Tension specimen

Fig. 1 Configuration of the spot-welded specimen

Table 1 Material properties of steel sheets

Material	Material Properties			
	Yield strength (MPa)	Ultimate strength (MPa)	Young's Modulus (GPa)	Elongation (%)
SPCC	162.85	273.69	193	53.6
SPRC35	233.48	335.50	204	40.1
SAPH38P	277.62	376.70	198	44.1

Table 2 Static test results of the spot-welded specimen

Spot-welded joint		Fracture load (N)	
		TS type	CT type
1	SPCC 1.0/SPCC 1.0	6259	5170
2	SPRC 1.0/SPRC 1.0	6681	5631
3	SPCC 1.0/SPRC 1.0	5915	5101
4	SPCC 1.0/SAPH 2.0	7063	6131
5	SPRC 1.0/SAPH 2.0	7691	6637

TS : Tensile Shear
CT : Cross Tension

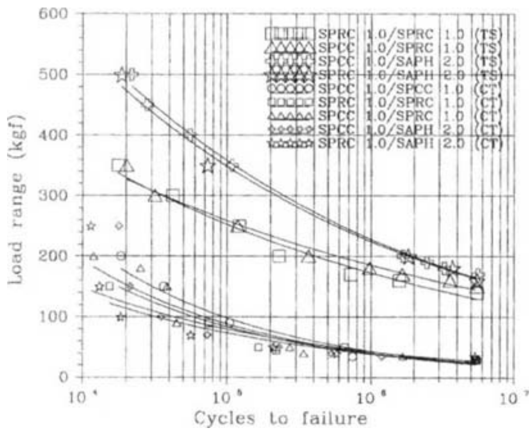
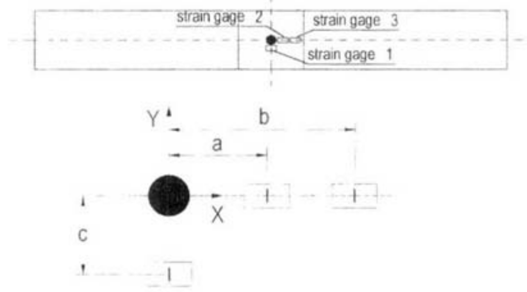


Fig. 2 Load range-fatigue life curves for the tensile-shear and cross-tension specimen



Specimen Type	Material	a	b	c
Tensile-Shear	SPRC 1.0/ SPRC 1.0	5.43 mm	12.62 mm	5.05 mm

Fig. 3 Strain gages around the weld nugget

materials and thicknesses. However, in the high fatigue life region they converge to some value irrespective of materials and thicknesses of spot welded specimens. Fatigue limit of CT specimens were about 20% of that of TS specimens. It is concluded that fatigue strength of spot welded joint cannot be assessed by its static strength.

3. Finite Element Analysis

3.1 Finite element modeling

In order to investigate the stress and strain distributions around the weld nugget of TS and CT specimens, finite element analysis was performed. Commercial software NISA was used for FE analysis. Quadrilateral 3D-shell element was utilized and the number of elements were 928 and 484 for TS and CT specimens respectively. Number of nodes were 1026 and 564 for each specimen type. Round nugget (6 mm diameter) was divided into 32 elements circumferentially and 6 elements radially. Elements in the nugget were modeled as rigid links. Fine meshing was used around the nugget including HAZ whose smallest element size was 0.5 mm.

3.2 Strain measurement

Strain gages were attached as closely as possible from the weld nugget (Fig. 3) and strains were measured in order to determine the numerical analysis method ; linear static or nonlinear

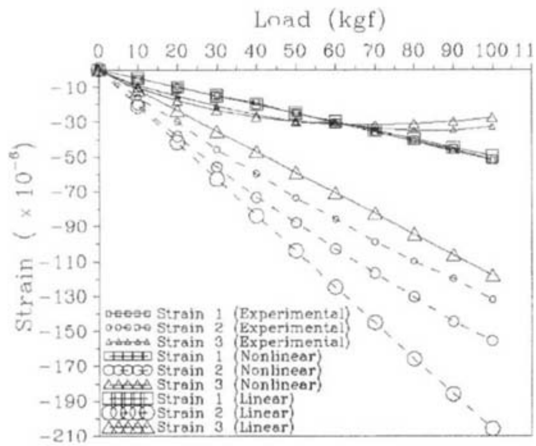
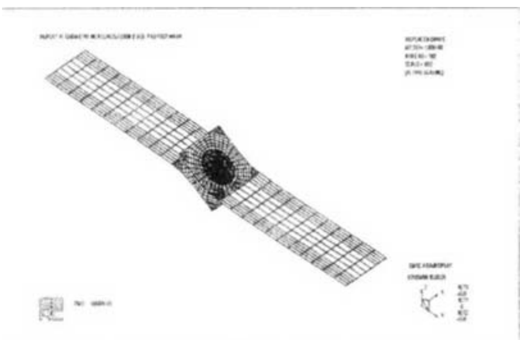


Fig. 4 Comparison of experimental and numerical strain values

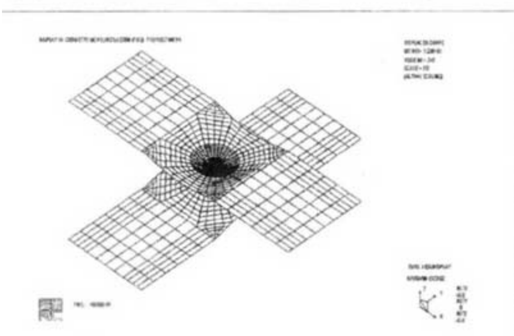
static. Only SPRC 1.0/SPRC 1.0 TS specimen was selected for comparison and results are shown in Fig. 4. Compressive strain at gage 3 increases initially due to increase of nugget rotation, however, its slope changes sign at some load level since bending effect becomes smaller than stretching effect beyond that level. Nonlinear static FE analysis showed this trend very well, however, linear static FE analysis could not simulate experimental result. For the strains at gage 1 both of linear and nonlinear FE results showed coincidence with the measured strain value, however, we can see that linear static FE analysis quite overestimated experimental strain values at position of gage 2. Based on these results nonlinear static FE analysis were performed to investigate the fatigue characteristics of spot welded joints.

3.3 Finite element analysis

Typical deformed shapes of SPCC 1.0/SPCC 1.0 TS and CT specimens are shown in Fig. 5. Fig. 6 shows the Von Mises stress distribution of nodes along the center line (x axis) on the inner surface on the loading side of the plate. Maximum stress occurred at 0.5 mm from the nugget edge (3.5 mm from the nugget center). The other specimens showed that maximum stresses were generated at the same location. For the specimens with dissimilar materials, the stress of sheet which failed first was considered. Load-fatigue life curve (Fig. 2) was transformed to Von Mises stress-fatigue life curve and shown in Fig. 7. Von Mises stresses at the fatigue load of various specimens are shown in Table 3. From these figure



(a) Tensile-Shear SPCC 1.0/SPCC 1.0 specimen



(b) Cross-Tension SPCC 1.0/SPCC 1.0 specimen

Fig. 5 Deformed shapes of spot welded specimens

Table 3 Von Mises stresses at the fatigue load

Spot-welded joint		Yield Strength (MPa)	Fatigue load (N)		Von Mises stress (MPa)	
			TS	CT	TS	CT
SPCC	SPCC 1.0/ SPCC 1.0	162.9		294		194.2
	SPCC 1.0/ SPRC 1.0		1472	294	182.5	194.2
	SPCC 1.0/ SAPH 2.0		1668	294	182.5	194.2
SPRC	SPRC 1.0/ SPRC 1.0	233.5	1472	294	243.3	255.1
	SPCC 1.0/ SPRC 1.0		1570	294	246.2	255.1
	SPRC 1.0/ SAPH 2.0		160	294	243.3	256

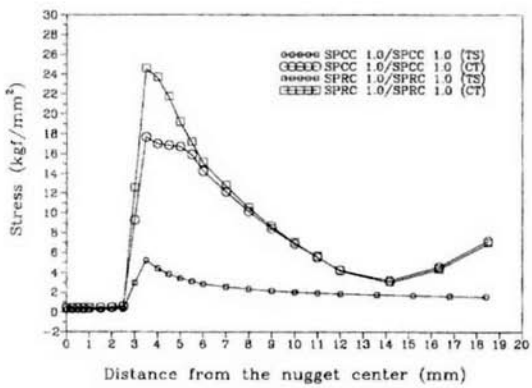


Fig. 6 Von Mises stress at the inner surface with distance from the nugget center

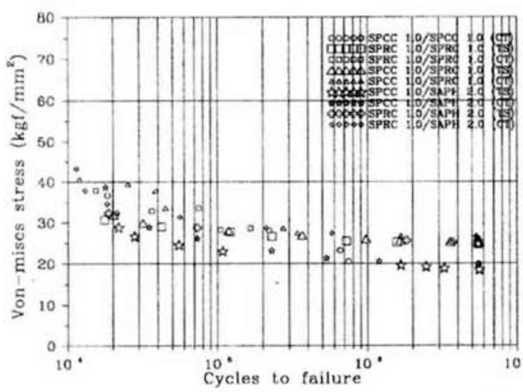


Fig. 7 Transformed relationship of Von Mises stress and fatigue life

Table 4 Mechanical properties of SPCC and SPCE spot-welded specimens

Specimen Type	Material	Mechanical property		
		Y.S. (MPa)	T.S. (MPa)	Elongation (%)
LT, TT	SPCC 0.8/ SPCC 0.8	193.3	328.6	50.0
UT, AT	SPCE 1.4/ SPCE 1.4	157.0	284.5	49.0
TS-IB	SPCE 0.8/ SPCE 0.8	184.4	336.5	45.4

LT : L-type Tension, TT : T-type Tension
UT : U-type Tension, AT : Angular Tension
TS-IB : Tensile Shear under In-plane Bending

and table, we can conclude that the fatigue failure occurs at the same Von Mises stress slightly higher than yield stress of constituent steel sheet. Maximum Von Mises stress rather than normal or shear force can be considered as a major factor affecting local failure of spot welded joints.

Results of references (Japan Automotive Technology Committee, 1986 and 1987) which contain numerous test data of various types of spot welded specimens were checked to confirm the validity of assumption that Von Mises stress at the nugget edge governs the fatigue failure of spot welded joints. Finite element analyses were additionally performed for the spot welded joints whose constituents are SPCC and SPCE steel sheets with thicknesses of 0.8 and 1.4 mm. Material properties and finite element modeling of spot welded joints are shown in Table 4 and Fig. 8. Load-life data from the handbook are plotted in Fig. 9 and the figure shows no consistent trend. Transformed relationship of Von Mises stress and the fatigue life are shown in Fig. 10 which shows consistent behavior. All the data points falls in the narrow bands which tells that Von Mises stress at the nugget edge governs the fatigue failure of spot welded joints. Von Mises stresses obtained at the fatigue load are summarized in Table 5. It was proved anew that Von Mises stress at the fatigue load is slightly higher than yield stress of constituent steel sheet irrespective of types of specimen.

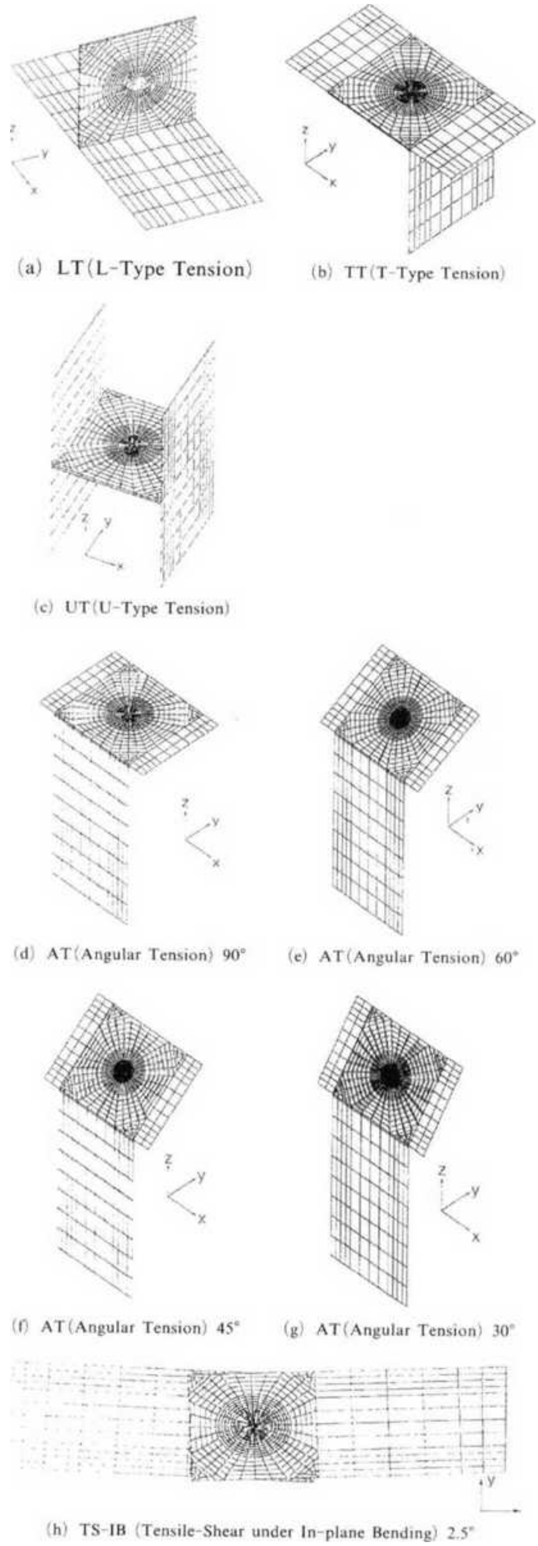


Fig. 8 FEM models of various spot-welded joints

Table 5 Von Mises stresses at the fatigue load

Spot-welded joint		Fatigue load (N)	Y.S. (MPa)	Von Mises stress (MPa)
SPCC 0.8/ SPCC 0.8	LT	39.24	193.3	204.0
	TT	49.1		204.0
SPCE 1.4/ SPCE 1.4	UT	343.4	157.0	171.7
	AT90°	147.2		174.6
	AT60°	196.2		174.6
	AT45°	245.3		172.7
	AT30°	294.3		164.8
SPCE 0.8/ SPCE 0.8	IB2.5°	981	184.4	195.2
	IB5°	882.9		192.3
	IB10°	784.8		189.3

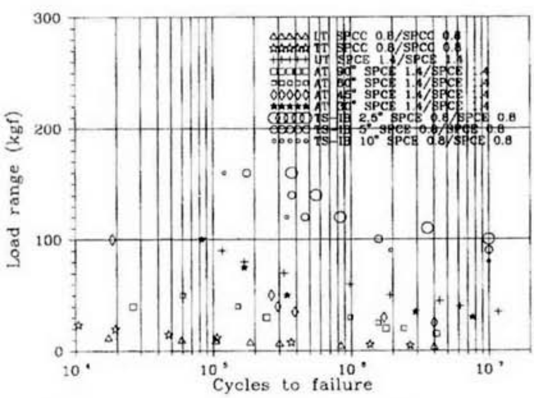


Fig. 9 Load range-fatigue life data for various spot-welded specimens

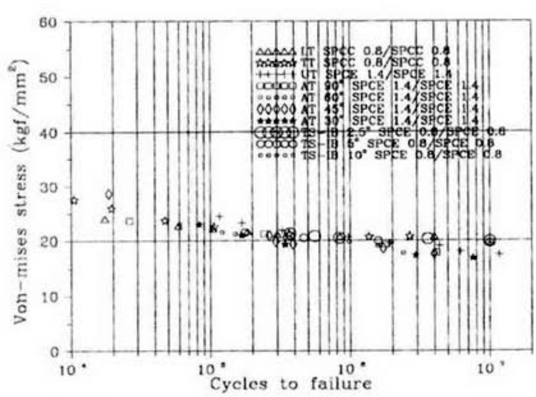


Fig. 10 Transformed relationship of Von Mises stress and fatigue life

4. Conclusion

Experimental and finite element analyses were performed to predict the fatigue life and establish failure criterion of spot welded joints in suspension mounting parts of an automobile. Investigation on the tensile-shear and cross-tension specimens yielded the criterion that Von Mises stress at the nugget edge governs the fatigue failure of spot welded joints. Von Mises stress at the fatigue failure was found to be the value slightly higher than the yield stress of constituent material. Application of this criterion to other references yielded successful result.

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