FRICTION SPOT JOINING OF HIGH STRENGTH STEEL SHEETS FOR AUTOMOTIVES





R. Ohashi **M. Fujimoto** **S. Mironov** **Y. S. Sato** **H. Kokawa**

ABSTRACT

In this study, friction spot joining (FSJ) was applied to dual-phase steel DP980 using a newly-developed silicon nitride (Si_3N_4) tool with a threaded pin, after which microstructure and strength of the joint were examined. The cross-sectional microstructure was distinctly classified into four zones which experienced the different heat cycles and deformation histories during FSJ. Electron probe micro analyzer revealed that silicon, oxygen and nitrogen were involved in the alternate band patterns observed in the stir zone, which could be attributed to contamination from the tool. The contamination was prevented by coating of the tool surface and the use of Ar shielding. The mechanical tests showed that the contamination reduced the joint strength, especially the cross tensile strength.

IIW-Thesaurus keywords: *Automobile engineering; Friction welding; Hardness; Lap joints; Microstructure; Strength; Mechanical properties.*

1 INTRODUCTION

The demand for the reduction of CO_2 emissions which cause global warming has recently intensified in consideration of environmental protection. In the automotive industry, in particular, carmakers are greatly interested in improving fuel and drive-train efficiency to decrease CO_2 emissions. Production of light-bodied structures is one of the solutions for improving fuel efficiency, thus the use of aluminium alloys and high strength steels (HSSs) in car body structures is increasing year after year.

Dual-phase (DP) steel is one of the advanced high strength steels (AHSS). This steel consists of hard-phase islands such as martensite and bainite within the ferritic matrix, which shows a good balance between formability and strength. Hence, DP steel is currently used for automotive parts [1]. However, it is well-known that AHSS shows poor weldability in resistance spot welding, a major method used in the construction of car bodies due to the easy formation of weld defects and the brittle-hard microstructure [2-4].

Friction spot joining (FSJ) is a solid state joining technique recently developed from friction stir welding (FSW). This process is expected to solve the problems occurring in resistance spot welding of AHSS, since these problems arise mainly from solidification and high heat input. But there have been few studies dealing with FSJ of AHSS. Therefore, the present study applies FSJ to an AHSS steel (DP980), then examines the microstructure and mechanical properties of the joint. The present paper shows the potential of FSJ as a suitable spot joining method for AHSS.

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2 EXPERIMENTAL PROCEDURES

The AHSS used for this experiment is DP980 steel, 1.2 mm in thickness, with nominal strength of 980 MPa. The chemical composition and tensile properties are shown in Table 1.

FSJ was applied to two sheets of DP980 steel in the lap configuration. A picture of the FSJ equipment used in this experiment is shown in Figure 1. The machine was equipped with two AC servo-motors for controlling the tool load and rotational speed precisely, developed for the FSJ process. The tool used in this experiment was made of silicon nitride (Si_3N_4). The tool had a 14 degree, concave-angled shoulder with a threaded cylindrical pin. The shoulder diameter, the pin diameter and the pin length were 10 mm, 4 mm and 1.5 mm, respectively. Two types of surface treatments on the tool were prepared for this experiment, i.e., one was left bare and the other was coated with TiC/TiN multi layer by chemical vapour deposition. The coated tool was used with Ar shielding gas during FSJ in order to prevent oxidization of the coating.

The processing parameters used in this experiment are shown in Table 2. All joints were produced without shielding gas at a tool load of 5.39 kN and rotational speed of 3 000 rpm. The process time varied from 1.2 s to 2.6 s during this experiment.

Figure 1 – Equipment used for FSJ

Table 2 – Process parameters used in this experiment

Tool load	5.39 kN
Tool rotation speed	3 000 rpm
Process time	1.2 s to 2.6 s (by 0.2 s)

After FSJ, the microstructure and mechanical properties were examined. Microstructural observation was conducted on the cross-section by optical and scanning electron microscopy (SEM). A sample for microstructural observation was etched in either a 3 % nitric acid ethanol solution or a 1.25 vol. % picric acid aqueous solution. Examinations of the chemical composition and the crystallographic orientation were conducted by electron probe micro analyzer (EPMA) and electron back scattered diffraction (EBSD) methods, respectively.

Tensile shear test, cross tension test and hardness measurement were employed in this study. Configurations of tensile shear test and cross tension test are shown in Figure 2. The specimen measured 30 mm in width and 100 mm in length for tensile shear test; 50 mm in width and 150 mm in length for cross tension test. Micro-Vickers hardness measurement was carried out at the middle thickness of the upper and lower sheets.

3 RESULTS AND DISCUSSION

3.1 Microstructural properties

A typical cross-section of the joint produced at 2.0 s process time is shown in Figure 3. The joint shows a truncated cone in the vicinity of the exit hole, classified into four regions, Zones 1 to 4, according to the microstructural features.

Microstructures of the base material and of each zone are shown in Figure 4. The base material shows the typical duplex-microstructure consisting of hard phase islands (martensite and/or bainite) within fine ferrite grain matrix. The ferrite grains are elongated to the rolling direction of the cold-rolling process. On the

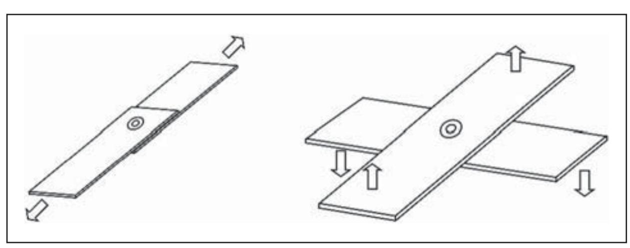

Figure 2 – Workpieces used for tensile testing

Table 1 – Chemical composition and mechanical properties of DP980

Composition (wt.%)					YS (MPa)	TS (MPa)	EL (%)	Thickness (mm)
C	Si	Mn	P	S				
0.17	1.38	2.00	0.011	0.001	766	1 001	16	1.2

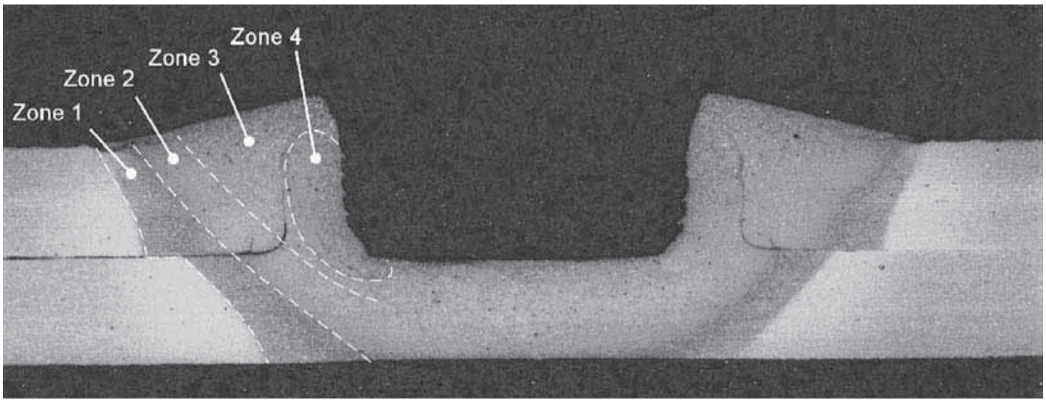

Figure 3 – Cross-section of the joint produced at 2.0 s of process time

other hand, Zones 1 to 4 have different microstructural features from the base material. Zone 1 is the microstructural transition region, where the elongated ferrite grains change to fine ones and fraction of the martensite increases, compared with the base material. The microstructure of Zone 2 contains a large amount of martensite and considerably small ferrite grains. Zones 3 to 4 are mostly martensitic structures, but the size of the martensitic structure is different in each zone, i.e., Zone 3 has a coarse lath martensite, while Zone 4 exhibits a remarkably refined martensite structure.

As a result of chemical composition analysis by EPMA, contamination of the tool material was found in Zone 4. EMPA maps are presented in Figure 5. Silicon, nitrogen and oxygen can be observed distinctly within Zone 4. A previous study reported that the Si_3N_4 can decompose when exposed to a high temperature and low nitro-

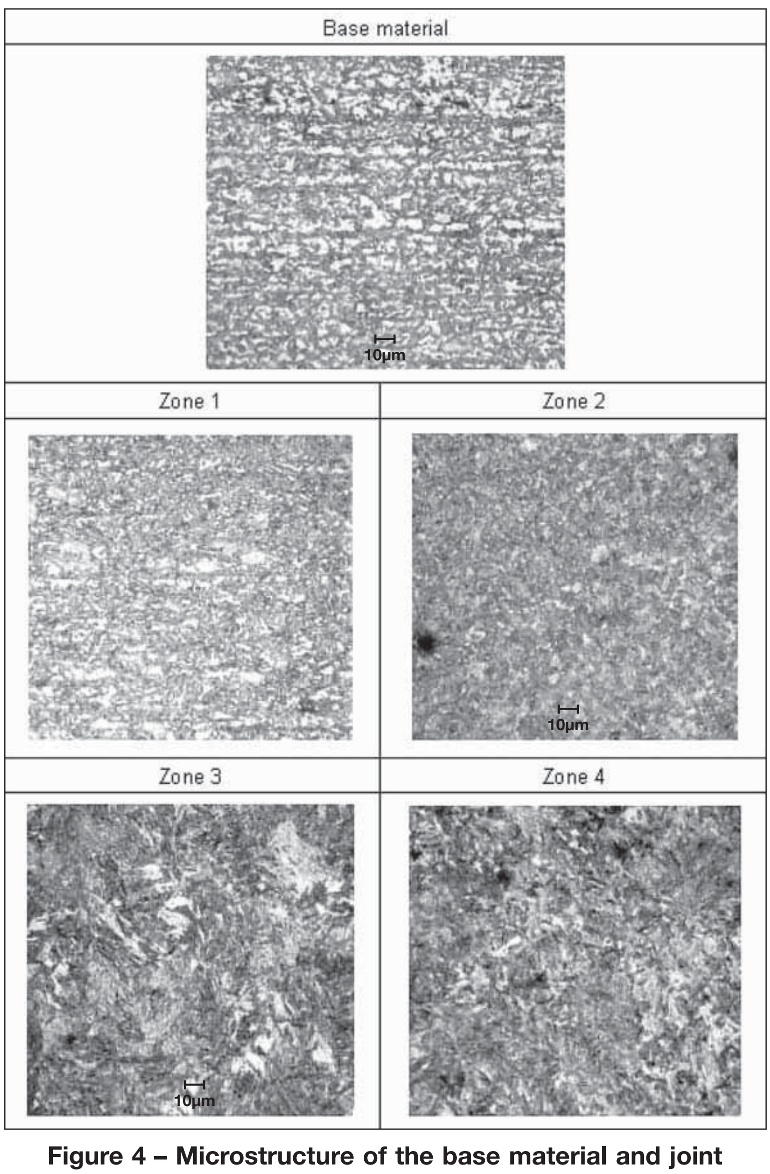

Figure 4 – Microstructure of the base material and joint

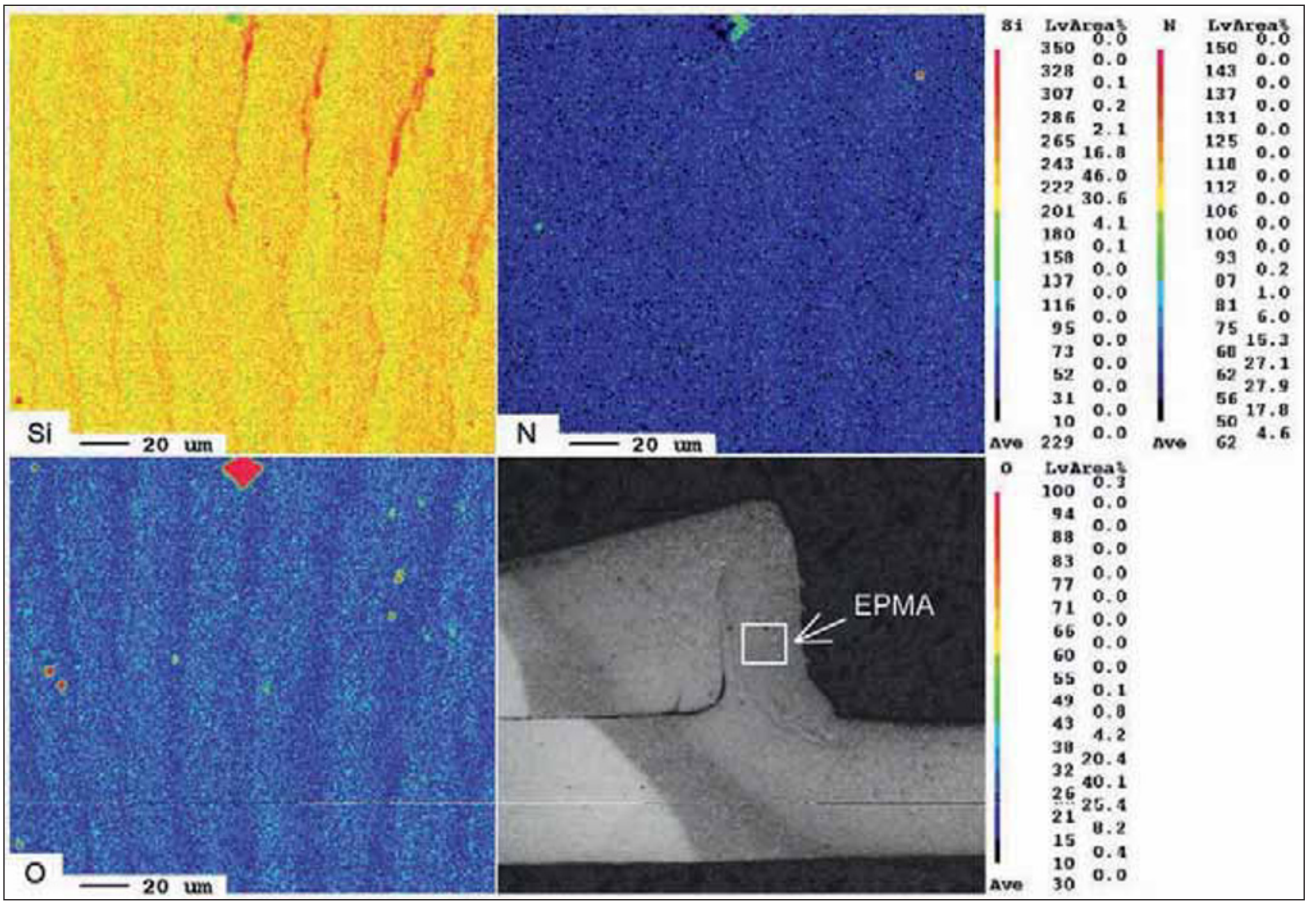

Figure 5 – Result of EPMA applied to Zone 4

gen gas pressure environment [5]. Since the Si_3N_4 tool was exposed to a similar environment during FSJ, it could have decomposed and remained inside the joint. Additionally, no shielding gas would cause oxygen contamination in the joint. Such contamination could be prevented by the use of Ar shielding gas and coating on the tool surface.

3.2 Mechanical properties

Micro-Vickers hardness profile of the joint is shown in Figure 6. Average hardness of the base material was approximately 320 Hv. The hardness was reduced near the outer border of Zone 1, then increased rapidly toward the tool exit hole. The maximum hardness of 450 Hv was measured in Zone 4, a value frequently found in a resistance spot weld of DP980 steel [6]. The lower hardness in Zone 1 was associated with tempering of the martensite, and the maximum hardness in Zone 4 would be due to the fine martensitic structure.

Strength of the joints in tensile shear and cross tension tests are shown in Figure 7. The strengths of the joint produced with the coated tool are also presented in this figure. The coated tool resulted in apparently a higher strength than the bare tool, especially since the effect of coating on the cross tension strength was significant.

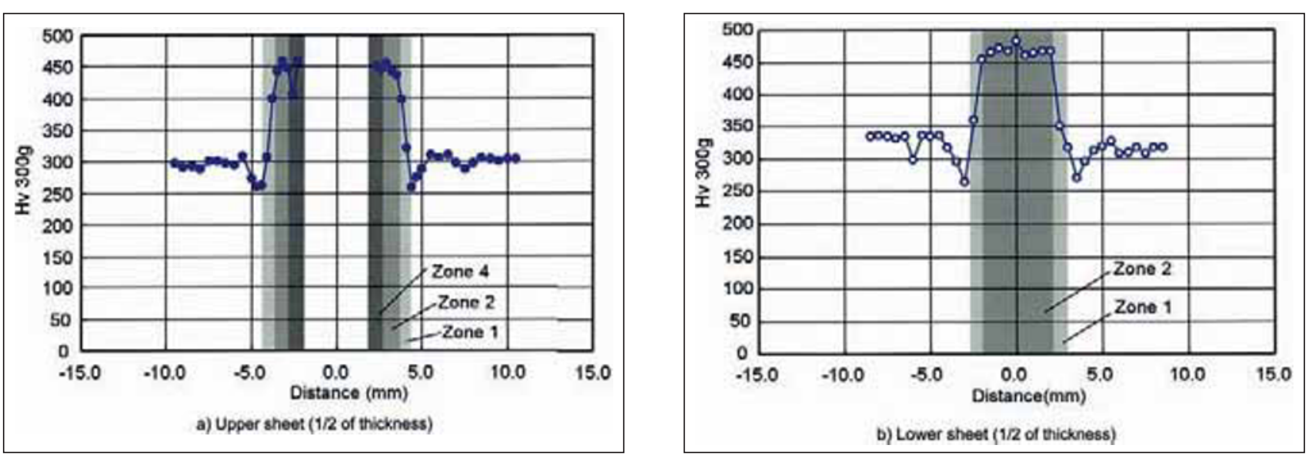

Figure 6 – Micro-Vickers hardness profile of the joint

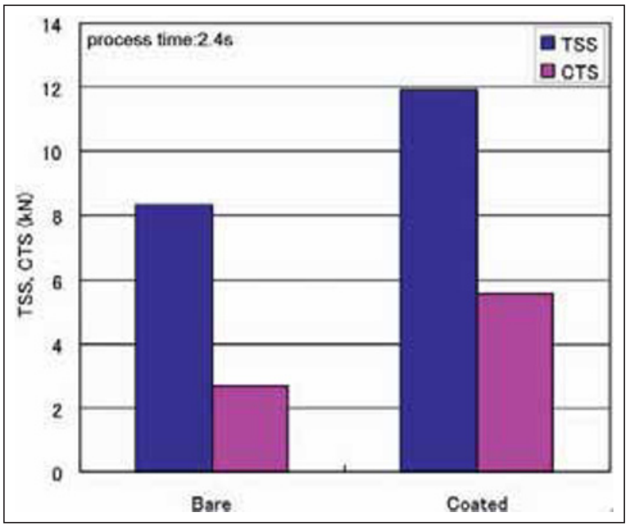

Figure 7 – Tensile shear and cross tensile strength of the joint obtained at 2.4 s

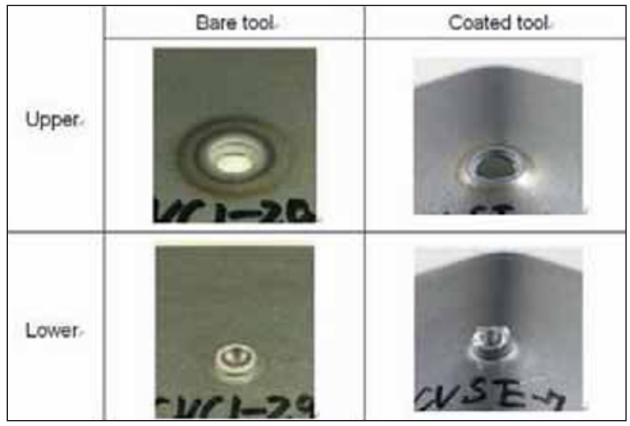

Figure 8 – Appearance of fracture parts after cross tension test

The appearance of the fractured joints produced with the bare tool and the coated tool after the cross tension test is shown in Figure 8. It was noted that there was a difference between the two in the failure mode in the cross tension test. The joint produced with the coated tool, which showed the higher strength, exhibited typical pull-out fracture, while the fracture was propagated along the periphery of the stir zone in the joint produced with the coated tool. A previous study on friction spot joining of DP590 steel showed the same results [7], but the reason for this difference remains unclear at present. Further studies on fracture mechanisms in both cases are in progress and will be reported in the near future.

4 CONCLUSIONS

FSJ using a newly-developed Si_3N_4 tool with a threaded pin was applied to the DP980 steel, after which the microstructure and mechanical properties of the joint were examined. The cross-sectional microstructure could be classified into four zones. The hardness was reduced outside the shoulder and significantly raised in the vicinity of the tool exit hole. EPMA revealed that contamination by silicon, oxygen and nitrogen were found in the alternate band patterns in the joint. The strength was improved by prevention of contamination through the use of Ar shielding gas and coating of the tool surface.

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