A method for evaluation of tensile properties of a nugget zone in a spot-welded joint considering the strain rate

Namsu Park1, a, Hoon Huh1, b* and Moonsu Park2, c

[1]School of Mechanical, Aerospace and Systems Engineering, KAIST

291 Daehak-ro, Yuseong-gu, Daejeon 305−701, Republic of Korea

[2]SAMSUNG HEAVY INDUSTRIES CO., LTD., Central Research Institute

271 Munji-ro, Yuseong-gu, Daejeon 305−380, Republic of Korea

[a]nshosiu@kaist.ac.kr, [b]hhuh@kaist.ac.kr, [c]meister.park@samsung.com

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Abstract. This paper deals with a method for evaluation of tensile properties of a nugget zone in a spot-welded joint at various strain rates using a micro material testing machine. In order to properly consider the load requirement, a driving and a load measuring part were replaced both for a static micro material testing machine (SMMTM) and a high-speed micro material testing machine (HSMMTM). A jig and a gripping device were designed to meet the requirements of the specimen shape and strength. Two kinds of specimens for the tensile tests were fabricated from the center of the welded spot and 1 mm away from the centerline at the spot welded joint of the DP980 by wire electric discharged machining (EDM). Digital image correction method (DIC) was applied to measure the longitudinal strain. A method for speckle pattern generation was improved for application of the DIC method to the micro-specimen. Quasi-static tests were performed with SMMTM at strain rates of 0.001 s^{-1} and 0.1 s^{-1} and dynamic tests were performed with HSMMTM at strain rates of 1 s^{-1}, 10 s^{-1} and, 100 s^{-1}, respectively. A comparative evaluation was performed between the material properties of the base metal and the nugget region in spot welded joint, based on the obtained true stress−true strain curves.

Introduction

In a design of the car, it is essential to obtain the reliability and the stability of the structural member for the auto-body, which is directly related to the safety of the passenger as well as the durableness of the car. From this reason, the research on the crash worthiness and the characteristic of the connection joints of the structural member has been remarkably increasing, especially for the advanced high-strength steels utilized in the car body [1-6]. In general, structural members of the auto-body are simply connected by the resistance spot welding. There are about 7,000~13,000 spot welding points in the car, which is firstly employed by Ford in the consideration of the economic efficiency, productivity, easy handling in manufacturing and the uniformity in connection quality. The spot welding has special advantages that it can be readily utilized in the connection of members regardless of how the structural shape complicated is and there is no increase in weight since it connects the members by melting the designated spot for welding, compared to connections by the simple bolt and nut, the rivet, and self-piercing. Despite the extensive use of spot weld, evaluation of the mechanical behavior of the connection joints is still insufficient while the quantitative evaluation of the mechanical properties of the advanced high-strength steel is extensively conducted. Due to the small area of spot welding point, it takes high effort and tremendous time to delicately fabricate the specimen for the material test.

Materials generally show the strain rate sensitivity on their mechanical behaviors. When the car crash takes place, spot welding parts undergo severe dynamic plastic deformation with accompanying high strain rate. Consequently, it is necessary to evaluate the mechanical property of the nugget zone according to various strain rates for the application to the numerical simulation to properly consider the material behavior beforehand.

Preparation of the micro tensile test specimen

In order to evaluate tensile properties of the nugget zone in the spot-welded joint, the resistance spot welding was conducted using the DP980 1.2t steel sheets with the condition given in Table 1. In this process, two overlapped components were welded together as a result of the heat generated by electrical resistance. The welding condition was determined by ISO standard which sets the size of a diameter of the nugget zone as around 5.5 mm after the U-tension test. For the convenience of fabricating the test specimen, DP980 1.2t steel sheets were cut out with the size of 120 mm x 30 mm. The gap between spot weld points was determined as 20 mm to avoid the interference of heat among the spot weld points as shown in Fig. 1. Two kinds of specimens for the tensile tests were fabricated from the center of the welded spot and 1 mm away from the centerline at the spot welded joint of the DP980 by wire electric discharged machining (EDM) to minimize the influence of heat when the specimen is fabricated. The dimension of the micro tensile specimen, as shown in Fig. 2, was determined by KS D 2715. Due to the small size of the specimen, the dimensions of the test specimen was measured at the five positions along the longitudinal direction with the aid of the optical microscope, DMRBE model of LEICA, and the thickness was measured by the stage micrometer of Nikon as shown in Fig. 3.

Table 1. Spot welding condition.

Material	Time [cycles]			Current [kA]	Force [kN]
	Squeeze	Weld	Hold		
DP980 1.2t	20	17	17	7.4	4.0

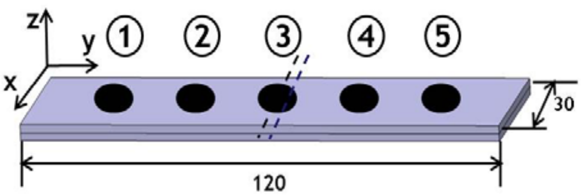


Figure 1. Schematic of resistance spot-welded DP980 1.2t.

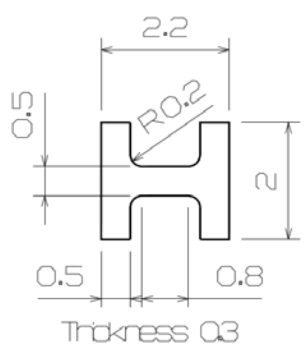


Figure 2. Dimensions of the micro-specimen [mm].

Figure 3. Equipments for measuring the dimension of the micro-specimen: (a) DMRBE model of LEICA; (b) the stage micrometer of Nikon.

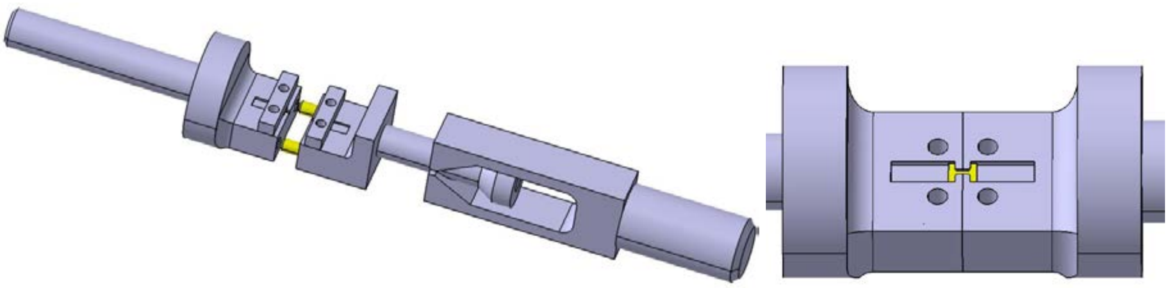
Speckle pattern generation on the surface of a test specimen

Since the size of the micro-specimen is too small to measure the strain using the conventional extensometer or the strain gauge, digital image correlation (DIC) method [7] was adopted with the aid of the high-speed camera of SA4 model of Photron to calculate the deformation evolution during experiments using a commercial digital image processing software, ARAMIS v6.3.0. Black stochastic patterns, so-called a speck pattern, were adopted to prepare surfaces of specimens to enhance the contrast of captured images. Due to the small size of the specimen, toner powder was utilized to generate the speckle pattern as shown in Fig. 4. The minimum size of black dot measured on the surface of the micro-specimen was about 6 μm.

Figure 4. Speckle pattern generated on the surface of the micro specimen using toner powder.

A micro-tensile test with various strain rates

Quasi-static tests were performed with the static micro material testing machine (SMMTM) at strain rates of 0.001 s^{-1} and 0.1 s^{-1} and dynamic tests were performed with the high-speed micro material testing machine (HSMMTM) at strain rates of 1 s^{-1}, 10 s^{-1}, and 100 s^{-1}, respectively. A jig and a gripping device are designed to meet the requirements of the specimen shape and strength as shown in Fig 5.



(a) (b)

Figure 5. Schematic of the jig system and the gripping part: (a) the jig system; (b) the gripping part

Specifications of linear motors utilized in testing machines are given in Table 2 and the procedure to data analysis is summarized in Fig. 6. To obtain the reproducibility of test results, tests were carried out five times for each strain rate. With the use of the Swift hardening model in Eq. (1), true stress−true plastic strain curve is extrapolated for the application to numerical simulation.

$$\bar{\sigma} = K\left(\varepsilon_0 + \bar{\varepsilon}^p\right)^n \tag{1}$$

Tensile tests of the base metal were also conducted to quantitatively compare initial yield stresses and ultimate tensile strengths to those obtained from the nugget region. As shown in Fig. 7, the level of each quantity increases as the strain rate increases. Due to the thermal influence accompanying with the resistance spot welding, the level of mechanical properties in the nugget region is increased compared to those evaluated from the base metal.

Table 2. Specifications of linear motors utilized in the testing machines.

Material test machine	SMMTM	HSMMTM
Model	Dernkermotoren, XTA3810	PI micos, MA-35 DCG-1 MLS
Maximum Speed	2.5 mm·s^{-1}	2.6 m·s^{-1}
Travel range	52 mm	104 mm
Continuous force	500 N	276.2 N
Peak force	1,000 N	444.8 N

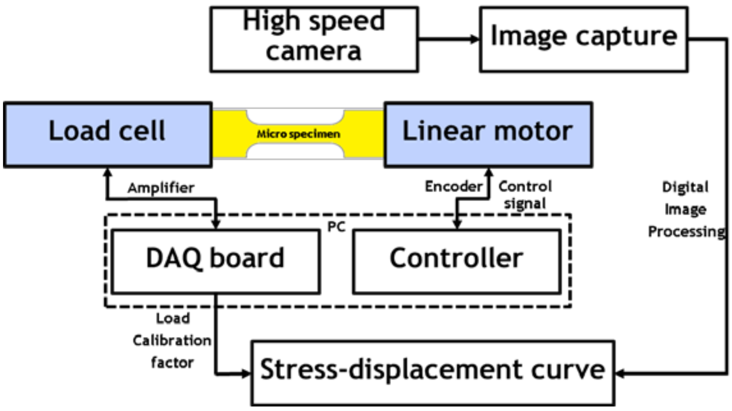
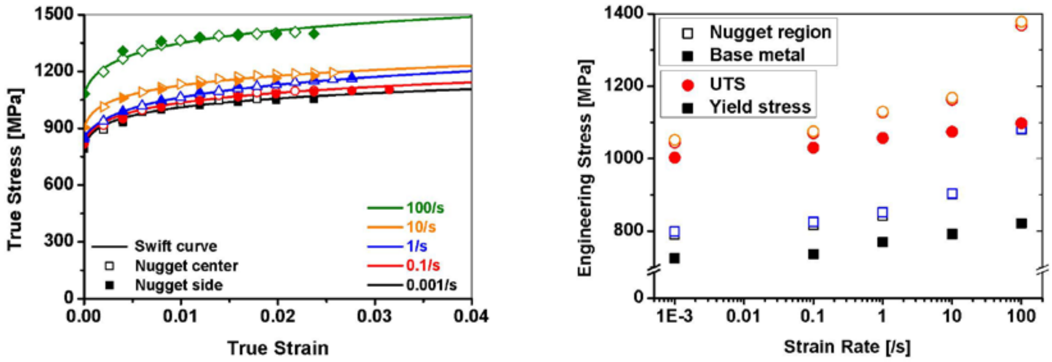


Figure 6. Schematic of the procedure for the data analysis.



(a) (b)

Figure 7. Mechanical properties evaluated at various strain rates: (a) true stress−true plastic strain curves; (b) Initial yield stresses and ultimate tensile strengths.

Conclusion

This paper deals with the testing method of evaluating tensile properties of the nugget zone in the spot-welded joint considering the strain rate. Test specimens were directly fabricated from the nugget zone by the wire electric discharged machining. From the test results, the stress level increases as the strain rate increases as well as the stress level of the nugget zone is higher than that of the base metal due to the heat generation from the resistance spot welding. Consequently, it is necessary to utilize the stress-strain response of the nugget zone considering the strain rate to properly predict the deformation behavior of the auto-body during the crash.

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