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Reliability Evaluations for Shear Strength of Resistance Welded Ball Stud according to Different Cooling Methods

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Abstract: As a type of bolt with a spherical head, the ball stud is widely used as a part of a ball joint in steering or suspension systems in automobiles. Balls and studs are subjected to heat treatment suitable for each material; in particular, the shear strength of the ball stud must meet the specifications of the production company. This study evaluated the shear strength of joints according to the cooling method of ball studs subject to resistance welding. The shear stress of water cooling was higher than that of air cooling (as-received material). Note, however, that oil cooling showed lower stress than that of as-received. When judged by standard deviation, mean, and coefficient of variation according to the arithmetic statistics and shape parameter as well as scale parameter, oil cooling is suitable.

Key Words : Ball stud, Cooling method, Shear stress, Heat treatment, Weibull analysis

1. Introduction

As a sphere-shaped fastening element for mechanical parts, ball stud is used as a component in ball joints. Unlike ordinary bolt fasteners, the ball stud distributes the overloads and over-momentums acting on the mechanical parts through the slippage and rotation of the sphere. It also ensures that the mechanical part can move in multi-directions. Because of this characteristic, the ball stud is widely used in nearly all types of mechanical devices from suspension systems to steering systems in cars.[1-3)]

In their manufacture, the ball and stud each undergo heat treatments optimized for their constituent materials and then get bonded together with resistance welding. Because the welded junction produces detrimental effects on the structure,[4-7)] such as residual stresses, however, the ball studs are heat-treated to give it structural uniformization which increases toughness and manufacturability.[8-11)] Note, however, that this kind of heat treatment significantly impacts the shear strength of the resistance-welded ball stud. Depending on the material, air cooling, water cooling, and oil cooling give rise to different resistance characteristics against damage or destruction. Thus, the characteristics of the ball stud attributable to the different cooling method[12-14)] are very important factors in guaranteeing the stability of the mechanical structure.[15-17)]

This paper compares the shear strengths of the bonded area of the resistance-welded ball stud by

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changing the cooling method and evaluates the stability using Weibull analysis.

2. Materials and Testing method

The ball stud in this study is used as a ball joint component. The ball was made with SS400 carburized steel and allowed to harden. Surface hardness was HRC 55-65, and carburization depth was 1.0~2.0 mm. The stud was made with SCM435, hardened, and tempered. The surface hardness was HRC 33~37, and the surface was coated with black Zn-Ni.

The resistance welding device used in this study was WT70-V-M, made by Weltech. The optimal welding conditions (current of 10.3kA, pressure of 3.75 ㎏/㎠) determined through the air cooling mentioned earlier were used in the welding of the ball stud. To evaluate the shear strength characteristics for each type of cooling, the ball stud was kept at 820, 840, 860, and 880℃ for an hour, and then subjected to water cooling and oil cooling.

Shear strength testing was performed at room temperature using tester NT-502A made by CAS (Inc.) at speed setting of 5 mm/min. The cut cross section was observed with SEM.

3. Results and Review

Figs. 1 and 2 show the shearing stresses on the test sample after it had been resistance-welded, kept for an hour at the four heat treatment temperatures, and then subjected to water cooling and oil cooling. The earlier reported results ("As received" in Figs. 1 and 2) of the shearing stress test on the air-cooled sample exhibit a substantial degree of scattering and distribution. This sample underwent water cooling and oil cooling because, prior to welding, the material was considered to have gone through very uneven heat treatment. The shearing stress results displayed in Figs. 1 and 2 were obtained by cooling the basic material at room temperature right after welding under the condition of pressure = 3.75 ㎏/㎠ and welding current = 10.3 kA. While there are differences in the degree of spread, it could be observed that the shear stress measurement data followed a distribution curve. Probabilistic evaluation based on the distribution curve is viewed as increasingly important for improving the accuracy of material strength evaluations. The shearing stress levels were also found to contain variations that were probabilistic and non-determinable. Based on these considerations, for ease of interpretation and to follow the weakest link hypothesis, Weibull statistical analysis was done by applying the 2-parameter Weibull distribution shown below.[18-21)]

$$F_{(x)} = 1 - \exp[-(\frac{x}{\beta})^{\alpha}] \quad (1)$$

In this expression, α is a shape parameter representing variations in the probability factor, and β is a scale parameter representing the characteristic lifetime when the probability of malfunction reaches 63.2%.

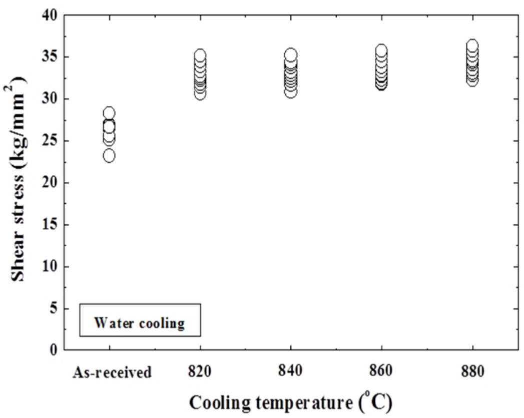


Fig. 1 Shear stress according to cooling temperature in water cooling

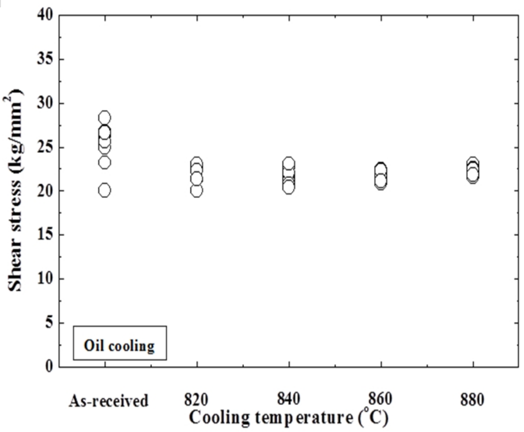


Fig. 2 Shear stress according to cooling temperature in oil cooling

In Figs. 3 and 4, the shear stress on the welded sample in Figs. 1 and 2 based on different cooling methods was represented in a Weibull probability distribution paper. The data points form a straight line; thus, it can be concluded that the shear stress follows the Weibull probability distribution.

Fig. 3 is the result for water cooling. In water cooling, the welded sample showed much higher shear stress distribution than the base metal (as-received material) but the variances remained the

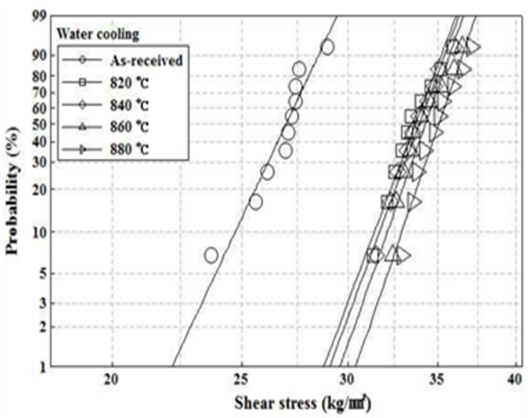


Fig. 3 Weibull probability distribution of shear stress from water cooling

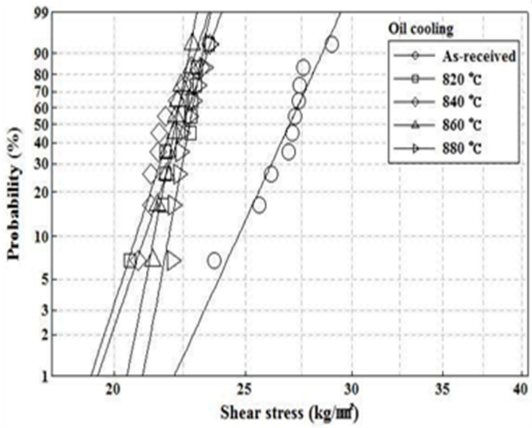


Fig. 4 Weibull probability distribution of shear stress from oil cooling

same. Shear stress exhibited a tendency to increase slightly with increased heat treatment temperature.

Fig. 4 is the result for oil cooling. In oil cooling, the welded sample showed lower shear stress levels than the base metal (as-received material) but the variances were smaller. The result also suggests that the heat treatment temperature has little effect on stress.

As shown by the results, water cooling and oil cooling produced smaller variances than those of the as-received material. This is because the material undergoes uniformization at high temperatures of the heat treatment process. The shear stresses in the as-received material, water cooling, and oil cooling all meet the 180kg/㎟ shear stress specification of the production company. When the fracture lifetime is considered, however, oil cooling can be deemed more suitable because of its smaller variances.

Tables 1 and 2 show the shape parameter and scale parameters of the Weibull distribution function estimated for the shear stress in the water-cooled and oil-cooled welded sample. The standard deviation, mean, and coefficient of variation were also included.

Table 1 Estimated Weibull parameters for shear stress from water cooling

Water cooling temp. (℃)	Shape parameter	Scale parameter	Std/Mean/COV
As-received	21.6	27.4	1.40/26.8/0.052
820	26.9	34.1	1.43/33.5/0.043
840	27.6	34.3	1.38/33.7/0.041
860	28.9	34.7	1.41/34.1/0.041

Table 2 Estimated Weibull parameters for shear stress from oil cooling

Oil cooling temp. (℃)	Shape parameter	Scale parameter	Std/Mean/COV
As-received	21.6	27.4	1.40/26.8/0.052
820	29.1	22.8	0.87/22.4/0.029
840	30.5	22.4	0.87/22.0/0.040
860	51.8	22.4	0.49/22.2/0.022

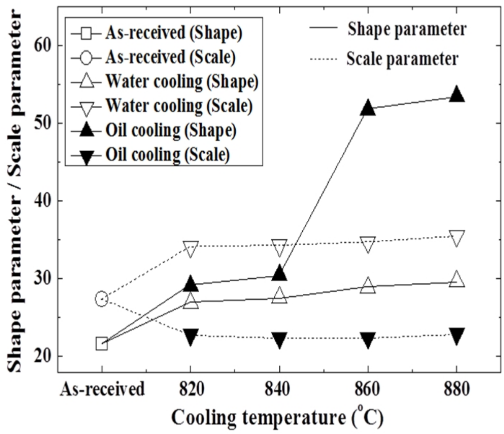


Fig. 5 Shape parameter and scale parameter of Weibull probability from cooling type

A graphical representation of the shape parameter and scale parameter in Tables 1 and 2 is shown in Fig. 5. The data markers ○,□ indicate the as-received material; the data markers △, ▽ are for water cooling, and the data markers ▲,▼ are for oil cooling. The shape parameter for the oil-cooled sample appears larger than that for the as-received material and the water-cooled sample, indicating small variances. In other words, the shape parameters for the as-received material and water cooling lie between 21.6 and 29.7, and the shape parameter for the oil-cooled sample is between 30.5 and 53.5. On the other hand, the scale parameter for the water-cooled case is much larger than that of the as-received material and the oil-cooled sample. This indicates a 63.2% characteristics lifetime, the as-received material is 27.4, and the oil-cooled sample is 22.4∼22.9, but the water-cooled sample is 34.1∼35.5. In this manner, the characteristic lifetime for the water-cooled sample was shown to be high. When the variances and shear stress level specified by the production customer are considered, however, oil cooling is deemed to be superior.

Fig. 6 shows the mean shear stress according to the cooling type. In the figure, the standard deviations are represented as a solid line. The mean shear stress for the water-cooled sample was higher than that of the as-received material, whereas the mean shear stress for the oil-cooled sample was lower than that of the as-received material. The shear stresses in both types of cooling were almost at the same levels. Note, however, that the standard deviations in water cooling (0.038~0.043) were

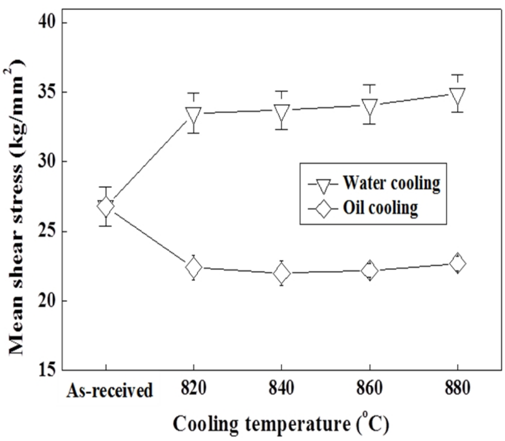


Fig. 6 Mean shear stress according to cooling type

Fig. 7 Fractured surface by cooling type. (a) water cooling, (b) oil cooling

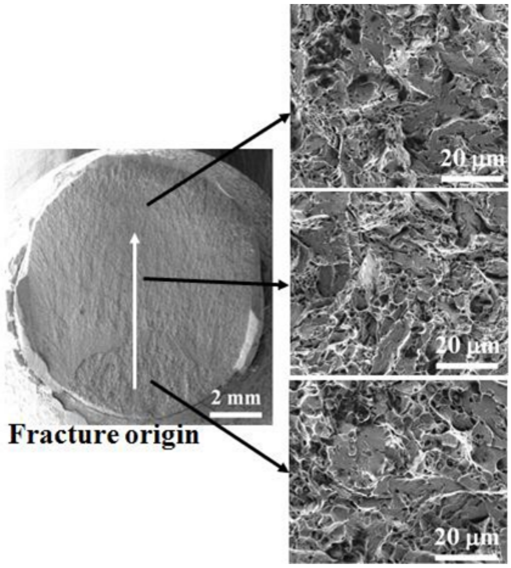
much higher than those in the oil cooling case (0.022~0.040).

When all the factors such as Weibull probability distribution, shape and scale parameters, statistics-based standard deviations, and mean and coefficient of variation are considered overall, oil cooling is judged to be the best method.

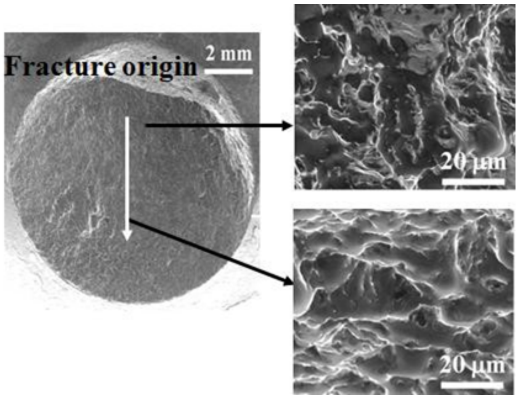
Fig. 7 shows the images of the fractured surface after the ball stud had been heat-treated at 820℃ and then subjected to water cooling and oil cooling. The arrows in the photographs indicate the directions of the fractures.

In the water-cooled case, the front and sides cooled rapidly; this caused the stud, which was made with the very hard SCM435 material, to fracture along the 45odirection. Note, however, that oil cooling increases ductility; likewise, since the ball is made with SS400, this resulted in ball fracturing in the form of a depression.

Fig. 8 shows the fractured surface when the ball studs were both subjected to heat treatment at 82 0℃ and then water-cooled and oil-cooled. Fig. 8(a) presents the case of water cooling, and Fig. 8(b) is the case of oil cooling. The starting point of the fracture is a cleavage fracture surface containing many small dimple-shaped inclusions. The center and end points are also cleavage fracture surfaces containing many small dimples.



(a) water cooling,



(b) oil cooling

Fig. 8 SEM fractography of different cooling types. (a) water cooling, (b) oil cooling

In general, because water cooling has a high gradient, it generates many grain fractures; note, however, that they are brittle fracture surfaces with a slight degree of ductility. (b) Due to oil cooling, both dimples and ductile fractures are formed at the depressed fracture starting point. The sloped portion of the fractured surface has crystallized ductile fractures due to oil cooling.

4. Conclusions

This research evaluated the reliability for the shear strength of the weld junction in the resistance-welded ball stud for each type of cooling. The shear stress of water cooling showed higher stress than the air cooling (as-received specimen), but the oil cooling showed lower stress than the as-received specimen. The shear stress of oil cooling showed lower stress than the as-received specimen, but the dispersion was less. Also, the effect of heat treatment temperature was not significant. The reliability of shear strength was analyzed by 2-parameter Weibull distribution. When judged by the shape parameter, scale parameter, standard deviation, and mean and coefficient of variation (COV), oil cooling is the best cooling method.

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