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Application News

AGX™-V Precision Universal Testing Machine

Evaluation of Electric Vehicle (EV) Motor Shafts Produced by Radial Forging:

Radial Forging Processing Affects Static Tensile Characteristics

F. Yano

User Benefits

- Tensile testing of metallic materials conforming to JIS Z2241 is possible by using the AGX-V and TRViewX.
- Visualization of the strain distribution during tests is possible by using Real-Time Strain View™.
- The region where mechanical properties are improved by radial forging processing can be estimated by conducting a static tension test.

■ Introduction

The trend toward decarbonization for reduction of greenhouse gas (GHG) emissions has accelerated in recent years, and as part of those efforts, the shift to electric vehicles (EVs) in the automobile industry will play a large role in the realization of a decarbonized society. Since extending the cruising range of EVs is a key requirement for popularizing electric vehicles, vehicle weight reduction for this purpose has been taken up as a development theme. Among candidate parts, reduction of the weight of motor shafts is a particularly important issue for development, since it will not simply increase the cruising range of EVs, but is also expected to improve motor responsiveness by reducing inertial force. Radial forging is a new forging technology for hollow shafts, and makes it possible to form the inner and outer diameters simultaneously by applying force to the hollow shaft or the hollow axis in the radial direction with a hammer (die) while inserting a core bar to transcribe the inner diameter shape [(1)]. Since hollow shafts manufactured by radial forging can satisfy both strength and weight reduction, this technology has attracted considerable interest as a next-generation shaft manufacturing method.

In forging processes such as radial forging, the product is formed to the target shape while also increasing its strength by refinement of the crystal grain structure by deformation of the metal surface by hammering (i.e., forging). For this reason, it is important to identify the region which is affected by the forging process, that is, how far the effect of forging extends from the surface layer into interior of the material. This article introduces an example in which samples were actually cut from a radial forging, and differences in their mechanical properties depending on the position were assessed from the surface layer to the interior.

■ Test Piece Information

Test pieces were cut from two types of products, one being a radial forging product and the other an unprocessed Blank. The radial forging was forged so that the cross-sectional area was 50 % that of the Blank. Fig. 1 shows an image of the positions where the test pieces were cut out. The test pieces were taken from 5 positions at intervals of 6 mm at depths of 4 to 28 mm from the product surface. Table 1 shows the test piece information.

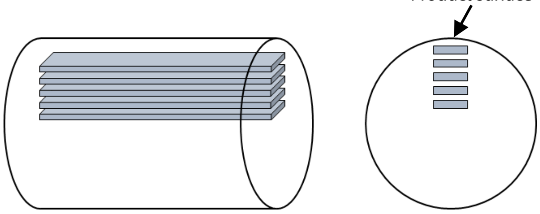

Fig. 1 Image of Test Piece Sampling Positions

Table 1 Test Piece Information

Test piece dimensions	: Thickness: 2.5 mm, width: 11 mm Parallel length: 56 mm
Types of test pieces	: Radial forging product, Blank
Test piece sampling depths	: 4, 10, 16, 22, 28 mm

■ Measurement System

The tensile test was conducted using a Shimadzu AGX-V precision universal testing machine. Fig. 2 shows the condition of the test. As shown in Fig. 2, a TRViewX non-contact extensometer was mounted on the AGX-V to measure the percentage elongation after fracture of the test pieces. In addition, the strain distribution of the test piece surface was visualized by Real-Time Strain View, an optional software program of TRViewX. Fig. 3 shows the condition of the back side of a test piece. As shown here, when conducting the test, a biaxial strain gauge was attached to the back of the test piece to enable accurate measurement of the elastic modulus (tensile modulus) and Poisson's ratio.

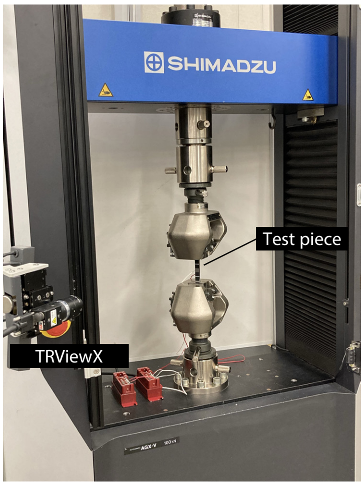

Fig. 2 Condition of Test

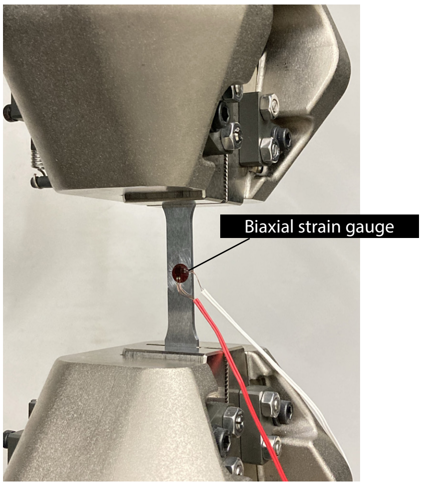

Fig. 3 Condition of Back Side of Test Piece

Table 2 shows the device configuration. The test conditions were set referring to JIS Z2241 "Metallic Materials-Tensile Testing." Table 3 shows the test conditions.

Table 2 Device Configuration

Testing machine	: AGX-V
Load cell	: 100 kN
Grips	: Non-shift wedge grip
Extensometer	: TRViewX120S
Software	: TRAPEZIUM™X-V

Table 3 Test Conditions

Test speed	: V1 10 MPa/s V2 5 %/min (switched to V2 when V2>V1) V3 40 %/min (switched at 1 % strain)
Gauge length	: 30 mm (TRViewX)
Number of tests	: n = 3

■ Test Results

As an example of the test results, Fig. 4 shows the stress-strain curves of the test pieces at the depth of 4 mm from the surface. Fig. 4 (a) and (b) show the results for the radial forging and the Blank, respectively. Focusing on the portion surrounded by the dotted line in Fig. 4, a yield point due to radial forging processing clearly appeared. Fig. 5 shows various mechanical properties at each test piece sampling position from the product surface. From Fig. 5 (a) and (b), it was found that tensile strength and the elastic modulus were improved by radial forging independent of the test piece sampling position. From Fig. 5 (c), the Poisson's ratio showed an almost constant value regardless of whether radial forging was applied or not. In Fig. 5 (d), the percentage elongation after fracture of the Blank and the radial forging shows similar values from 4 to 16 mm, but displays a decreasing tendency after 16 mm. In other words, the depth until 16 mm is a region with excellent mechanical properties, as the tensile strength and elastic modulus of the forging continue to improve, while percentage elongation after fracture is similar to that of the Blank.

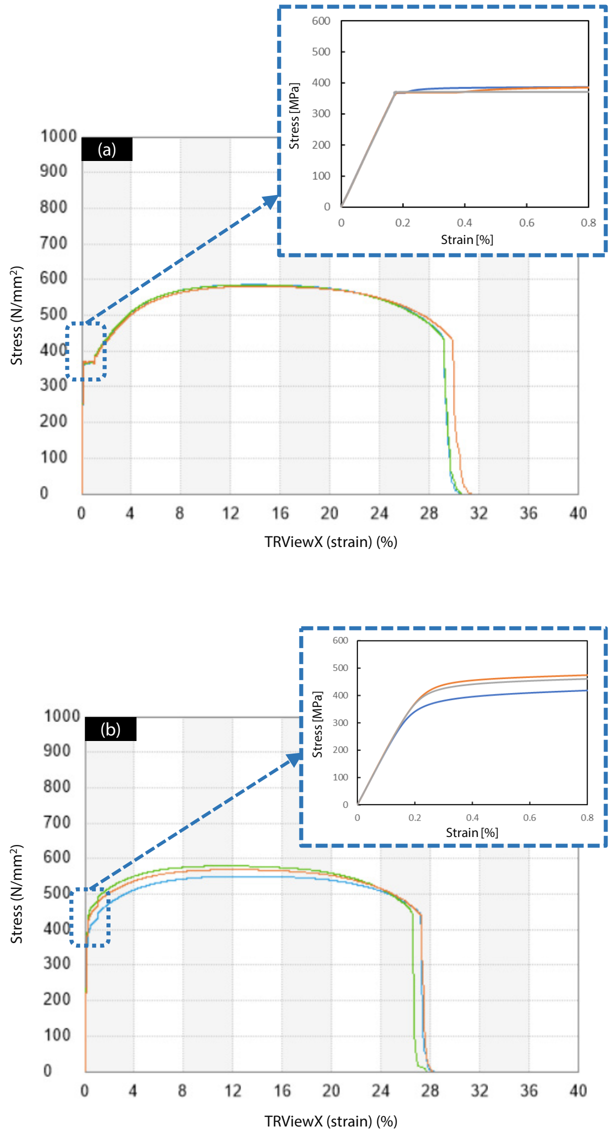

Fig. 4 Stress-Strain Curves of Test Pieces at 4 mm from Surface
(a) Radial Forging, (b) Blank

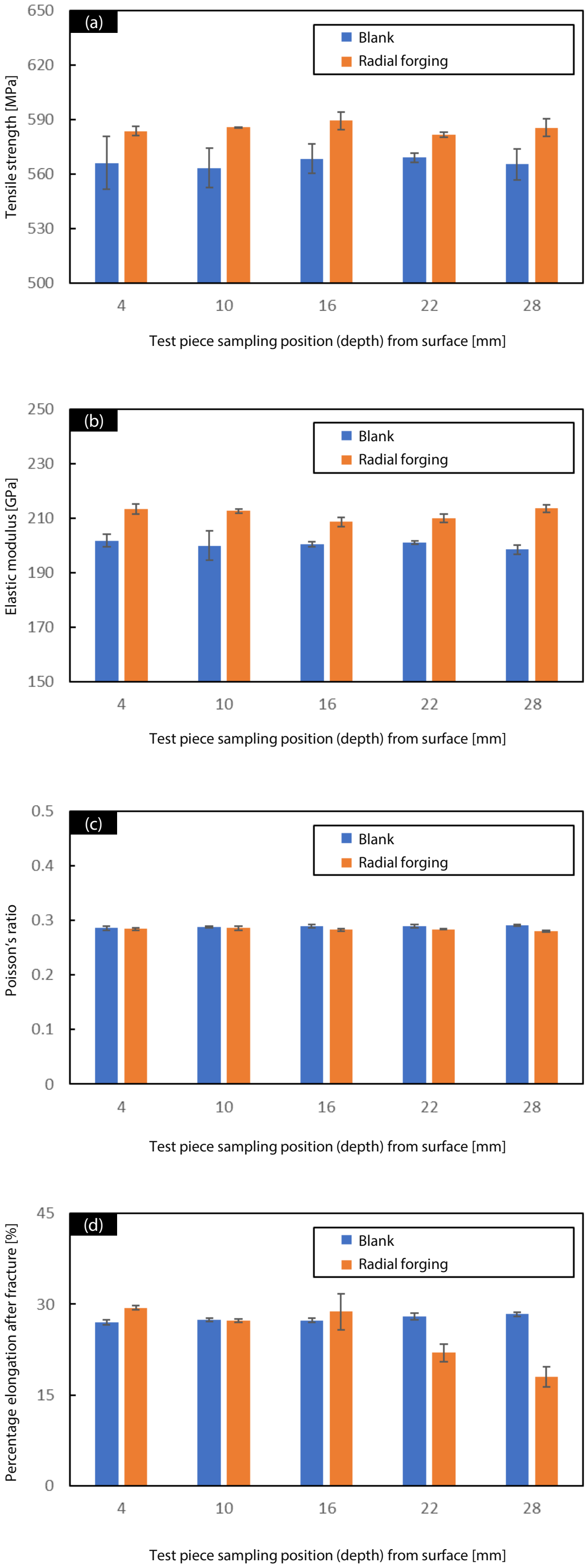

Fig. 5 Mechanical Properties at Test Pieces Sampling Positions from Surface
(a) Tensile Strength, (b) Elastic Modulus, (c) Poisson's Ratio
(d) Percentage Elongation After Fracture

Fig. 6 and Fig. 7 show examples of visualization of the strain distribution by Real-Time Strain View for the radial forging and the Blank, respectively. As shown in Fig. 4 (a), a yield point appears in the radial forging. In this case, strain occurred locally in the upper left and lower right parts of the test piece, as shown in Fig. 6 (2), and then a condition in which strain is distributed uniformly to the test piece center was observed, as can be seen in Fig. 6 (3). In test pieces in which a yield point does not appear, as in the Blank in Fig. 4 (b), it was found that the strain distribution increases uniformly, as shown in Fig. 7 (1) to (6).

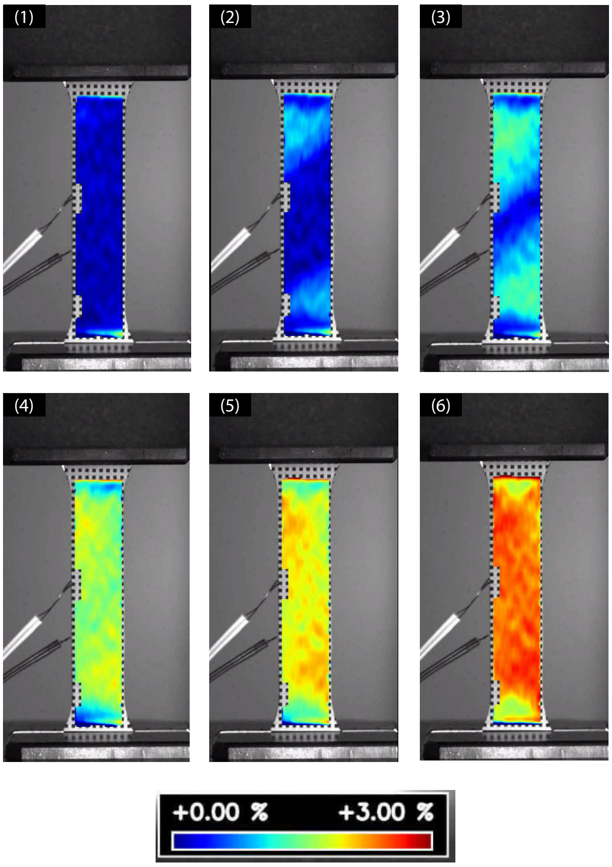

Fig. 6 Strain Distribution of Radial Forging in Tensile Test

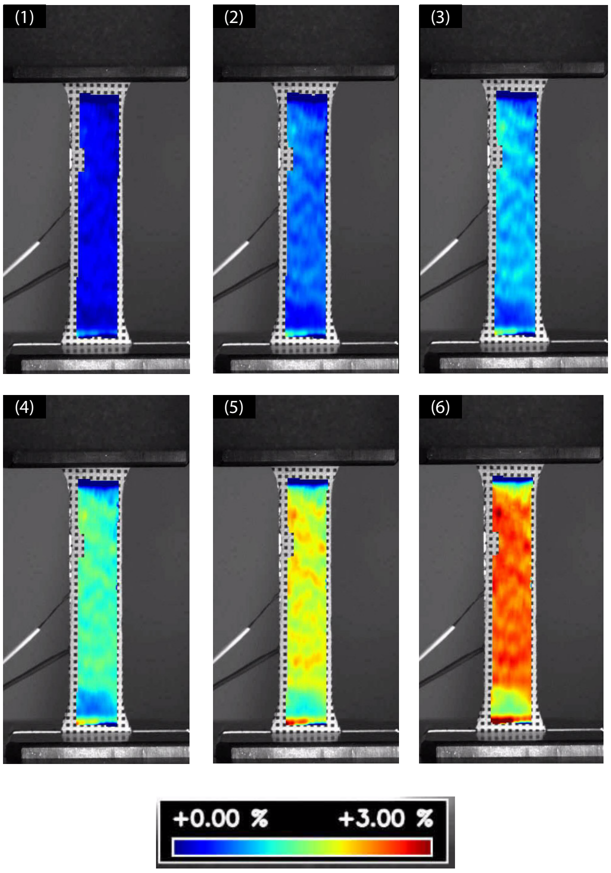

Fig. 7 Strain Distribution of Blank in Tensile Test

■ Conclusion

A static tensile test using an AGX-V was carried out with test pieces cut from a radial forging product and a Blank. As a result, it was found that the elastic modulus and tensile strength are increased by radial forging processing. On the other hand, percentage elongation after fracture decreased after the depth of 16 mm from the surface, indicating that the region where performance is improved by radial forging is from the surface to about 16 mm. As demonstrated by this experiment, the AGX-V is useful for clarifying the region of influence by processing when processing metallic materials.

The data published in this article were acquired through joint work by Shimadzu Corporation and Tsuzuki Manufacturing Co., Ltd.

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