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Application News

HITS™-TX High Speed Impact Testing Machines,
EPMA™-8050G Electron Probe Microanalyzer

High-Speed Tensile Testing and Fracture Surface Analysis of EV Drive Motor Shaft Produced by Radial Forging

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User Benefits

- It is possible to evaluate the velocity (strain rate) dependence of mechanical properties and identify inclusions in metallic materials.
- High-speed tensile tests at up to 20 m/s can be conducted by HITS-TX.
- EPMA enables elemental analysis on uneven fracture surfaces to be performed as is.

■ Introduction

Radial forging is a new forging method for hollow shafts and is used in various fields such as transport equipment, medicine, and tools. In radial forging, while a hammer (mold) applies force from the radial direction of the shaft to deform it plastically, core metal can be inserted and the internal shape can be transferred, making it possible to form both internal and external diameters simultaneously.[1] Processed hollow shafts can achieve both strength increase and weight reduction, and this is attracting attention as a manufacturing method for next-generation shafts, especially in the transportation field. Considering such applications in transport vehicles, it is necessary to evaluate the impact characteristics and the velocity dependence of mechanical properties.

In a previous article, static tensile tests were conducted using test pieces obtained from radial forging products and the blank before processing.[2] In this article, test pieces were collected in the same way, and the velocity dependence of mechanical properties was evaluated using HITS-TX high-speed impact testing machines. Fracture surface observation and elemental analysis of the fractured test pieces were also performed using an electron probe microanalyzer (EPMA).

■ Measurement System

A HITS-TX high speed impact testing machine (Fig. 1) was used for the high-speed tensile tests. The test equipment used is shown in Table 1, and Fig. 2 shows a view of the test.

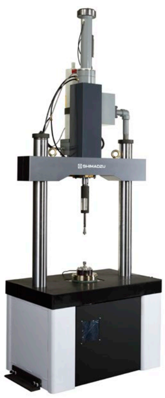

Fig. 1 HITS™-TX High-Speed Impact Testing Machines

Table 1 Test Equipment

Testing Machine:	HITS-TX high-speed impact testing machine
Load Cell:	10 kN
Jig:	Grip for flat plate samples
Displacement Measuring Device:	Chuck Displacement gauge
Dynamic Strain Gauge:	DC-97A
Software:	High-Speed impact testing software TRAPEZIUM™ HITS

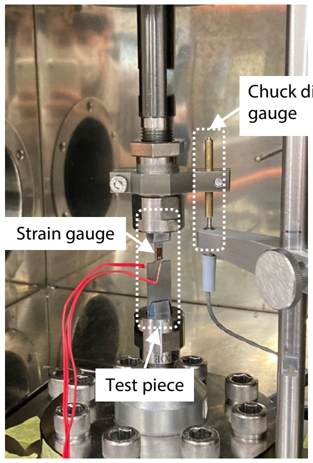

Fig. 2 View of the Test

■ Test Piece Information and Measurement Conditions

Test pieces were cut from two types of product: radial forging products and unprocessed blanks. Radial forging products are forged so that the cross-sectional area is 50 % of that of the blank. The test piece was cut from a position about 16 mm below the product surface;. Fig. 3 shows an image of the test piece cut position. Strain gauges were attached to both sides of the parallel part of the test piece. By using the average of the values measured by the strain gauges on both sides, it is possible to reduce the effect of warping of the test piece and the axial center of the test equipment. Fig. 4 shows the test piece geometry.

In addition, to evaluate the velocity dependence of mechanical properties of radial-forging and blank products, the test speeds were set to 3 conditions: 0.01, 0.1, and 1 m/s. Table 2 shows the test piece information and test conditions.

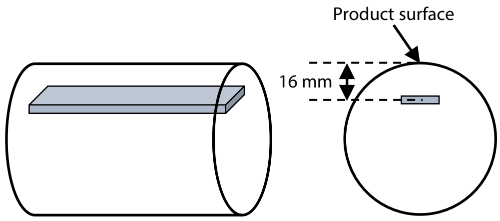

Fig. 3 Image of the Test Piece Cut Position

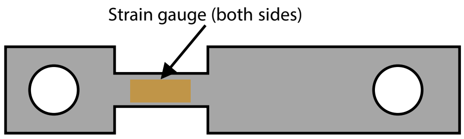

Fig. 4 Test Piece Geometry

Table 2 Test Piece Information and Test Condition

Test Piece Dimension:	t 1.5 mm, w 4 mm, L 10 mm (parallel part)
Test Piece Type:	Radial forging product, blank
Number of Tests:	N = 3
Test Speed:	0.01, 0.1, 1 m/s (Strain rate 1, 10, 100 /s)

■ Measurement Results

Fig. 5(a) shows the stress-strain (chuck displacement gauge) diagram of the radial forging product at each test speed, and Fig. 5(b) shows the same for the blank. It can be seen that the tensile strength of both the radial forging product and the blank increases with test speed. In addition, it was confirmed that distinct yield points appeared due to radial forging.

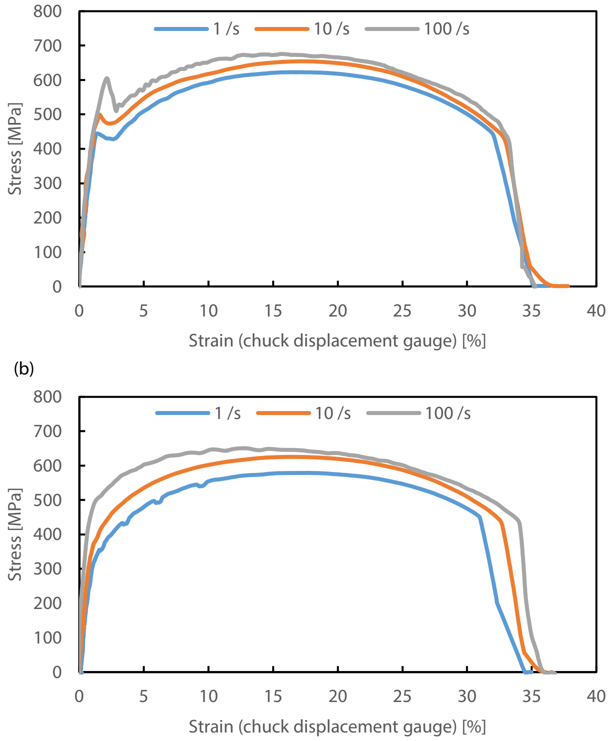

Fig. 5 Stress-Strain (Chuck Displacement Gauge) Diagram
(a) Radial Forging Product (b) Blank

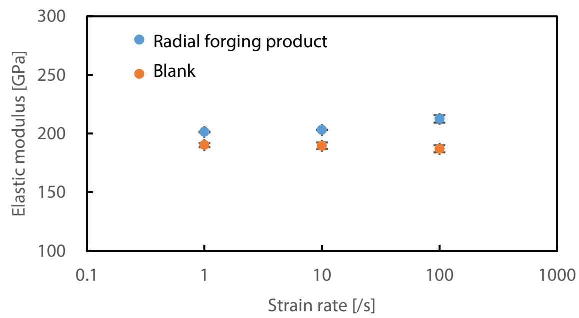

Fig. 6 Relationship between Elastic Modulus and Strain Rate

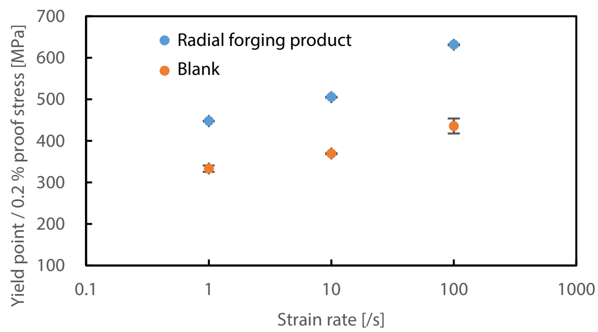

Fig. 7 Relationship between Yield Point / 0.2 % Proof Stress and Strain Rate

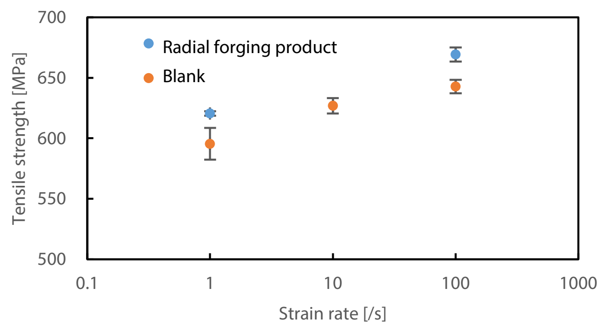

Fig. 8 Relationship between Tensile Strength and Strain Rate

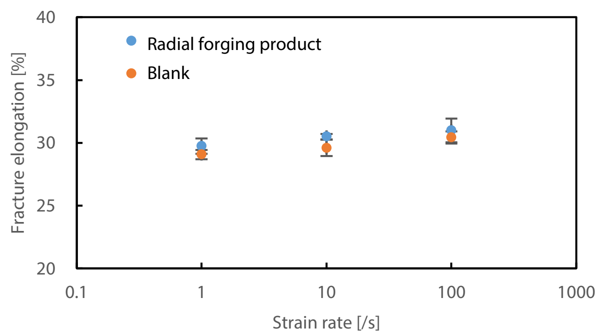

Fig. 9 Relationship between Fracture Elongation and Strain Rate

Next, the velocity dependence of elastic modulus, yield point (radial forging product), 0.2 % proof stress (blank), tensile strength, and fracture elongation were evaluated. The elastic modulus was calculated from the linear region of the stress-strain (strain gauge) diagram. Fig. 6 shows that the elastic modulus has a small strain rate dependence. The yield point and 0.2 % proof stress were strain rate dependent and tended to increase with increasing test speed (Fig. 7). Fig. 8 shows that the tensile strength also increases with increasing strain rate. Although fracture elongation tends to increase slightly with increasing strain rate, it may be within the range of variation, and the strain rate dependence is small.

Radial forging increased the elastic modulus by about 10 GPa. The tensile strength also increased by about 20 MPa. This is consistent with the trend in the static test results in the previous report.[2)]

■ Observation of Fracture Surface by EPMA and Elemental Analysis

The fracture surfaces of the radial forging and blank test pieces after high-speed tensile testing were observed by EPMA (Fig. 10). Fig. 11 shows the secondary electron images of the fracture surface at each strain rate for the radial forging and blank test pieces. There was no significant difference in the observed images at each strain rate, so it is possible that there was no significant difference in the fracture behavior. Fig. 12 shows enlarged views of the boxed areas in the image of Fig. 11 with a strain rate of 100 /s. The typical dimple shape due to ductile fracture was observed on the fracture surfaces. It is assumed that cracks are nucleated at voids and inclusions, and they expand into the surroundings and grow to fracture, resulting in a collection of depressions like plant fiber tissue. In addition, the elements were mapped in a portion of Fig. 12. From the mapping images of the fracture surfaces after the tests shown in Fig. 13, it was found that the inclusions were mainly MnS and Al_2O_3.

Fig. 10 EPMA™-8050G Electron Probe Microanalyzer

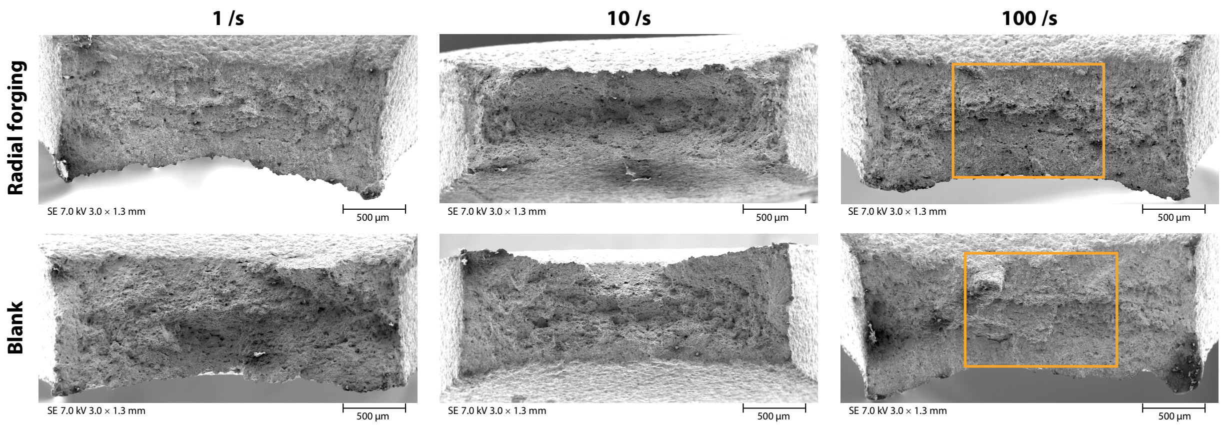

Fig. 11 Secondary Electron Image of Fracture Surface after High-Speed Tensile Test

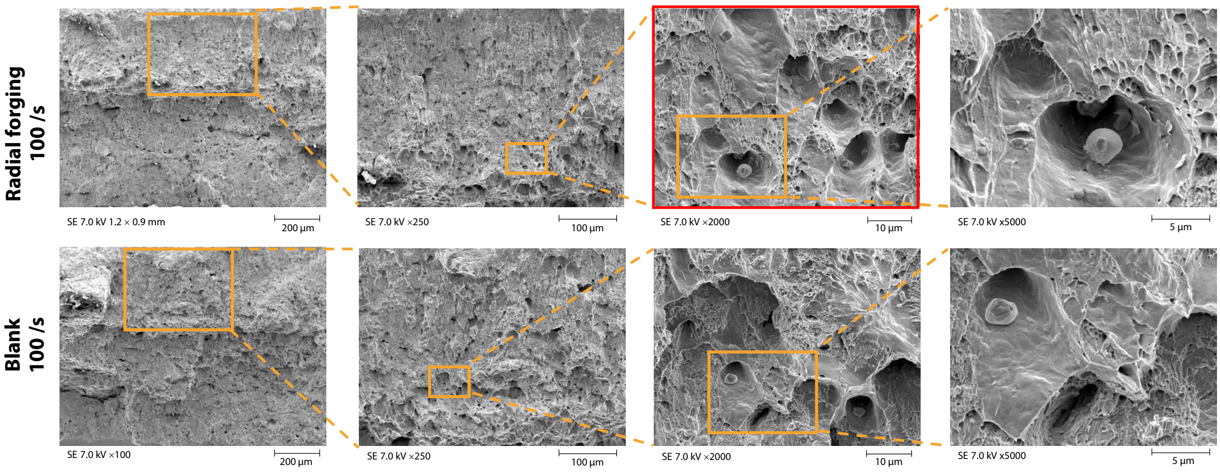

Fig. 12 Secondary Electron Magnified Image of Fracture Surface after High-Speed Tensile Test (100 /s)

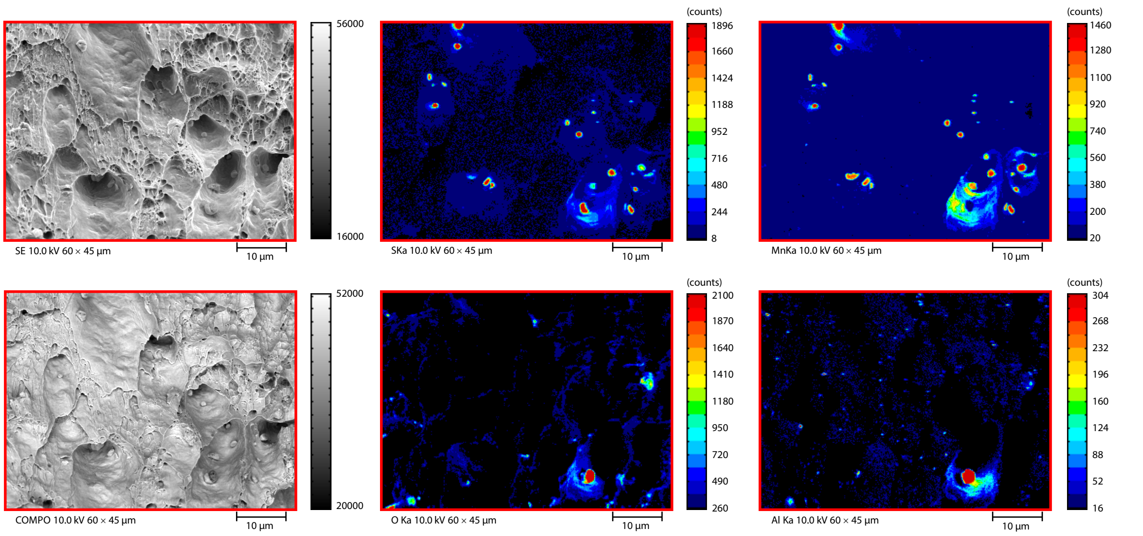

Fig. 13 Elemental Mapping Image of Fracture Surface after High-Speed Tensile Test (Radial Forging 100 /s)

■ Conclusion

In this article, the velocity dependence of mechanical properties of radial forging products and blanks were evaluated using the HITS-TX high-speed impact testing machine. Fracture surface observation and elemental analysis were also conducted by electron probe microanalyzer (EPMA).

From the results of high-speed tensile tests, it was found that the elastic modulus and fracture elongation were little affected by the velocity. On the other hand, it was found that the yield point (radial forging product), proof stress (blank), and tensile strength increased with increasing test speed. It was also confirmed that the radial forging process produced a distinct yield point on the stress-strain diagram. In addition, the elastic modulus and tensile strength increased due to the forging process, showing the same trend as the static test results.

From the results of fracture surface observation by EPMA, no difference in fracture surface was observed due to the test speed, and dimple shapes typical of ductile fracture were observed. The results of elemental mapping analysis showed that inclusions such as MnS and Al_2O_3 were the origin of the dimple shapes.

By using the measurement system introduced in this article, it is possible to evaluate the velocity dependence of mechanical properties of metallic materials such as radial forging products.

<References>

1) Tsuzuki Manufacturing Co., Ltd., Introduction to Shaft, https://www.tsuzuki-mfg.co.jp/solution/blog/04
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<Related Applications>

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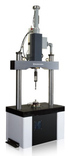

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