Application News

Micro Vickers Hardness Tester HMV™-G31-FA Series
Electron Probe Microanalyzer EPMA™-8050G

Evaluation of EV Drive Motor Shaft by Radial Forging Process
—Confirmation of Correlation between Hardness Distribution and Element Distribution—

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User Benefits

- Fiber flow produced in the forging process can be checked and investigated using hardness and element distributions.
- Measurement positions can be selected from the overall view of the test specimen surface, so hardness measurements can be easily performed at target positions.
- Element distributions can be obtained from the EPMA in a wide range from large to micro area.

■ Introduction

Metal is forged by applying impacts or compressing it, which promotes uniformity of the metal microstructure and improves the mechanical properties. The internal microstructure of forged metal also acquires directionality, which is referred to as fiber flow. This is where the mechanical properties are strengthened along the direction of flow. One of the new forging processes is radial forging, where force is applied in the radial direction to a hollow shaft or tube using a hammer (die). Then by inserting a core bar, the internal diameter shape is transferred, and the internal and external surfaces can be formed at the same time. Hollow shafts produced this way are strong and light, so it is attracting attention as the next-generation method of manufacturing shafts.

This article introduces an example of the Vickers hardness test using a hardness tester on a cross-section of a forged item. The hardness measurement results were additionally verified by comparing them with the distribution of elements, which were measured using an EPMA electron probe microanalyzer.

■ Test Specimen

Fig. 1 shows the cross-section of the test specimen, which was a forged part of SCr420 material, a type of chromium steel. It was sectioned in part and polished. Fig. 1 shows the overall view taken using the Stage Viewer function of the HMV-G31-FA Micro Vickers Hardness Tester. The left side of Fig. 1 is the side that was subjected to the forging hammer blows, and the right side is the interior of the material.

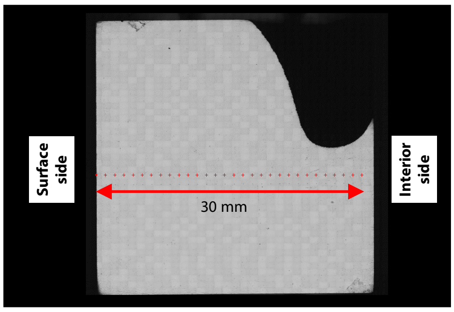

Fig. 1 View of Test Specimen Taken Using the Stage Viewer Function
(The red symbols indicate the measurement positions.)

■ Hardness Measurement Results

The test conditions are shown in Table 1. From the surface of the test specimen, 29 consecutive measurements were taken at 1 mm intervals. The results are shown in Fig. 2. It can be seen that the hardness was stable at shallow depths from the surface, but as the depth increased, the variation in the hardness tended to increase. Fig. 3 shows images of the indentations. Normally the indentation of a Vickers indenter is a clean square. However, in these measurements, there were some indentations where the shape was distorted.

Table 1 Measurement Conditions

Tester:	HMV-G31-FA Series Micro Vickers Hardness Tester
Indenter Type:	Vickers indenter
Force:	1.96 N (HV 0.2)
Holding Time:	10 sec
Number of Measurements and Interval:	29 measurements at 1 mm interval

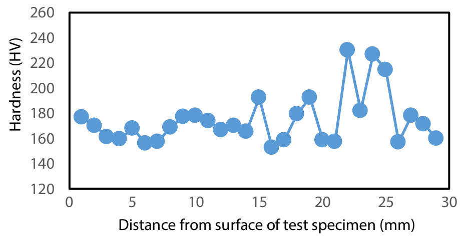

Fig. 2 Measurement Results

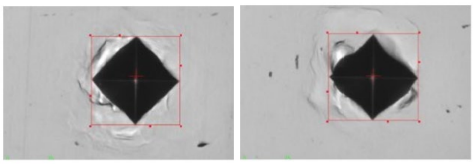

Fig. 3 Image of Indentations (Left: 5th Indentation, Right: 18th Indentation)

■ Distorted Indentations

Fig. 4 shows the results of the mapping analysis by the EPMA at the position of a distorted indentation. Secondary electron (SE) images and carbon (C) distribution maps are shown. Straining like a wrinkle was found around the indentation (the yellow arrows). At these positions (within the orange outlines in the lower part of Fig. 4) C intensity were lower. However, at the surrounding positions where the strain was lower, C intensity tended to be higher. It is likely that the hardness varied locally due to this uneven distribution of carbon concentrations, and this is inferred to be a cause of the unstable measurement values of the hardness tester.

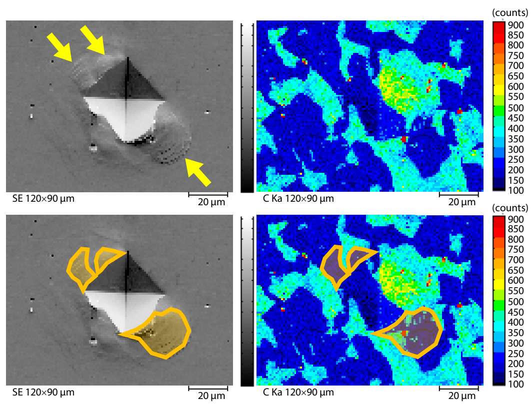

Fig. 4 Mapping Images of Indentations with Distorted Shapes
(Left: SE Image, Right: C Image)

■ EPMA Measurement Results

Fig. 5 shows the mapping analysis results over a wide area, which were measured along the positions of the indentations made by the hardness tester. The backscattered electron image (COMPO image) and the distribution maps of the main trace elements C, Cr, Si, and Mn are also shown. Fig. 6 shows the enlarged C and Cr element distribution maps at positions corresponding to depths of 7 to 9 mm, 19 to 21 mm, and 23 to 25 mm from the surface of the test specimen. Note that each point on the mapping images has been displayed in a color that is in accordance with the intensity value of the X-rays detected. The numbers on the right of the color bars are the maximum and minimum threshold values of the respective intensity values.

Focusing on the element distribution maps for each element, it can be seen that there is a distribution along the direction parallel to the surface of the test specimen (the vertical direction in Fig. 5 and 6). These are the fiber flow where it is considered that the internal microstructure is changed in the forging process and specific elements are concentrated. Also, at positions close to the surface of the test specimen, the fiber flow are very fine, but at deeper positions, the lines are thicker and show a greater difference in the intensity of elements.

■ Indentations at Places of Different Hardness

Fig. 7 shows the mapping distribution results for an indentation at a position where the hardness was low (20 mm from the surface of the test specimen), and Fig. 8 shows an indentation at a position where the hardness was high (24 mm from the surface of the test specimen).

By comparing these, it can be seen that the position with high hardness also had high intensity of C and Cr. At the position that was deep from the surface, the width of the part where C and Cr intensity were higher was large. Hence, it is considered that variations in hardness depended on the measurement position. This variation in hardness was related to the non-uniform distribution of elements in the internal microstructure of the metal, which suggests that by measuring the hardness, the fiber flow can be simply measured.

■ Conclusion

Measurements using a hardness tester and an EPMA were performed on a forged item. Variations in hardness were found in parts deeper from the surface, which suggests this was caused by the non-uniform distribution of elements created by the fiber flow. Therefore, multi-faceted analysis of a product using a combination of measuring instruments is effective for determining the effect of the forging process on the properties of materials.

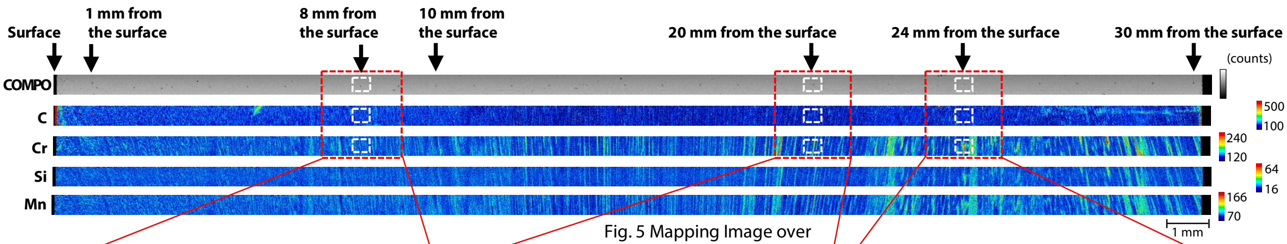

Fig. 5 Mapping Image over a Wide Range

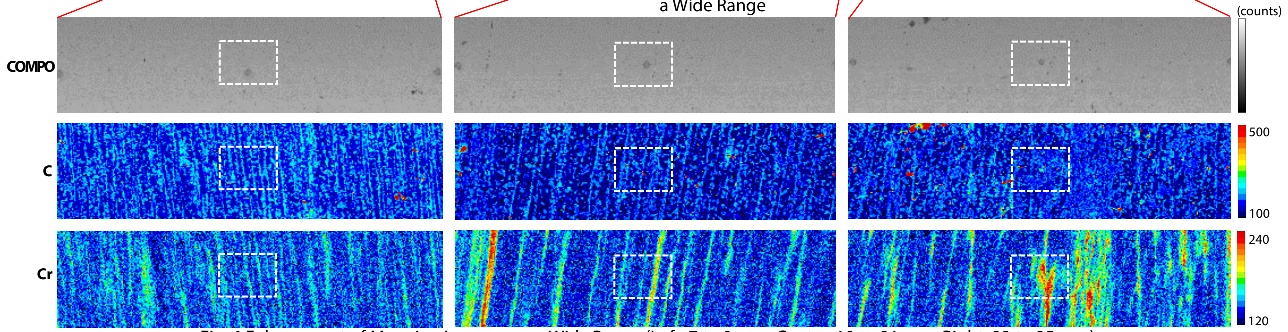

Fig. 6 Enlargement of Mapping Image over a Wide Range (Left: 7 to 9 mm, Center: 19 to 21 mm, Right: 23 to 25 mm)

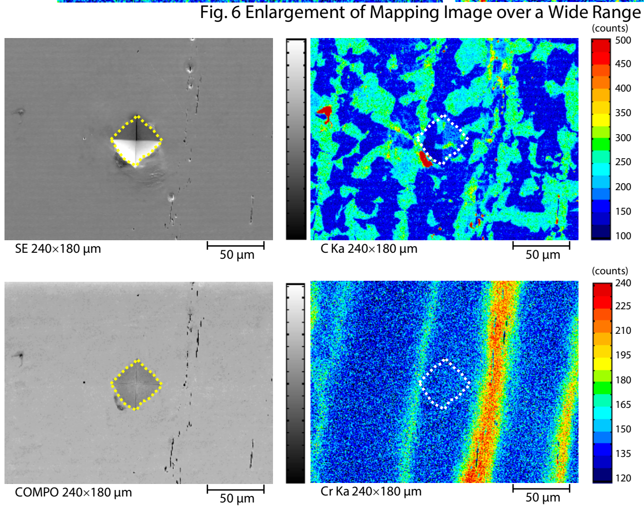

Fig. 7 Mapping Image at Low Hardness Indentation Position
(20 mm from the surface, indentation shape shown dotted)

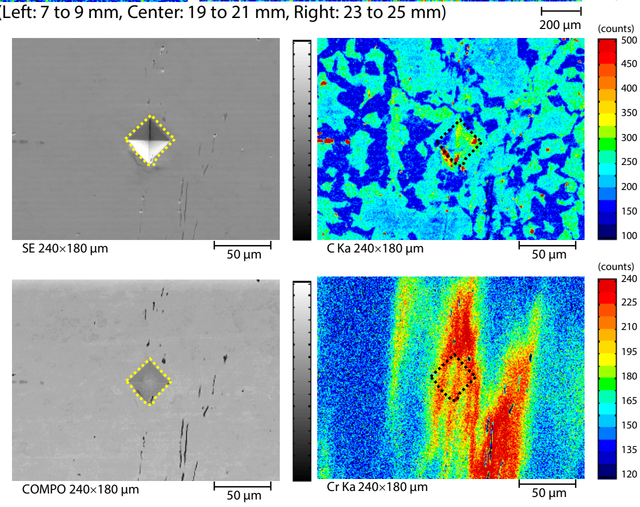

Fig. 8 Mapping Image at High Hardness Indentation Position
(24 mm from the surface, indentation shape shown dotted)

The published data show the results obtained from a joint project undertaken by Shimadzu Corporation and Tsuzuki Manufacturing Co., Ltd.

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