Development of Effective Case Depth Measurement Technology by Non-Destructive Inspection for Induction Hardened Parts

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Induction hardening is a thermal treatment method that hardens the surface of steel parts, and it is widely applied to automotive parts, construction machinery parts, machine tools, etc. to improve abrasion resistance, fatigue resistance and toughness. While the effective case depth needs to be measured as a quality inspection of induction hardened parts, this inspection involves hardness tests after cutting the parts; the inspection is time-consuming and the cut parts cannot be used. We have therefore developed a system of measuring the effective case depth quickly without damaging the product by using the principle of eddy current testing, and have confirmed its accuracy.

Keywords: *induction hardening, effective case depth, non-destructive inspection, eddy current testing*

1. Introduction

Induction hardening is a type of surface hardening thermal treatment that combines rapid heating by electromagnetic induction and rapid cooling mainly by water spray cooling, and it is applied to improve fatigue endurance and wear resistance of steel parts such as automotive and construction machinery. It is necessary to measure the effective case depth as a quality inspection of induction hardened parts. However, this inspection requires many man-hours because it have to be cut the parts for hardness testing. In addition, the parts used for the inspection cannot be used as products.

To solve this problem, we have developed the measurement method for measuring the effective case depth of induction hardened parts by the eddy current testing method which is a non-destructive inspection method. In eddy current testing, flaw detection is performed by placing a magnetizing coil through which an alternating current is applied near the inspection point and using the detection coil to detect the magnetic resistance that changes depending on the presence or absence of flaws at the inspection point. Using a similar to this flaw detection method, the measurement method is used to measure the effective case depth by focusing on the difference in magnetic resistance of the metal structure before and after quenching. This method is possible for quick and non-contact measurement of effective case depth without damaging the parts and is expected to reduce the man-hours for quality assurance work and improve product reliability.

In this study, a comparison of the measured values obtained by this method and the hardness test of the induction hardened part was performed. As a result, the accuracy of effective case depth measurement by using eddy current testing was confirmed.

2. Measurement Principle

2.1 Magnetic characteristics of carbon steel

Fig.1 indicates the magnetic characteristics of the metal structure of 0.45% carbon steel, standardized as JIS-S45C in Japan. This shows that the maximum relative permeability μ_m decreased by approximately 56.1% when the structure of ferrite and pearlite was changed to the structure of martensite. The measurement method was developed utilizing the phenomenon that the relative magnetic permeability decreases due to the quenching of materials. It is possible to measure the effective case depth by detecting the difference in the magnetoresistance of the inspected parts using the eddy current testing.

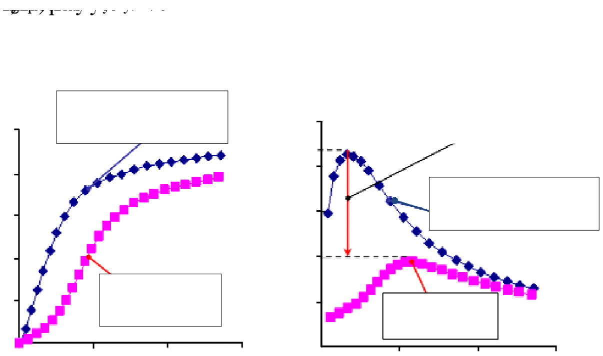

Fig. 1. Initial magnetization curves of 0.45% carbon steel (JIS-S45C steel)

2.2 Mechanism of effective case depth measurement

Fig. 2 shows the mechanism of measuring effective case depth. The measurement sensor consists of the exciting coil and the yoke, the search coil. When the sensor is brought closer to the surface of the object to be inspected and current is applied to the exciting coil, a closed magnetic flux loop is formed between the sensor and the object. The state of the magnetic flux changes with the depth of a hardened layer because the magnetoresistance increases or decreases depending on the metal structure, and the leaking magnetic flux from the surface of the object into the air also changes. By capturing the amount of the leaking magnetic flux as the change of the detected voltage in the search coil, the effective case depth of the object to be inspected can be obtained using the previously prepared relationship curve between the effective case depth and the detected voltage.

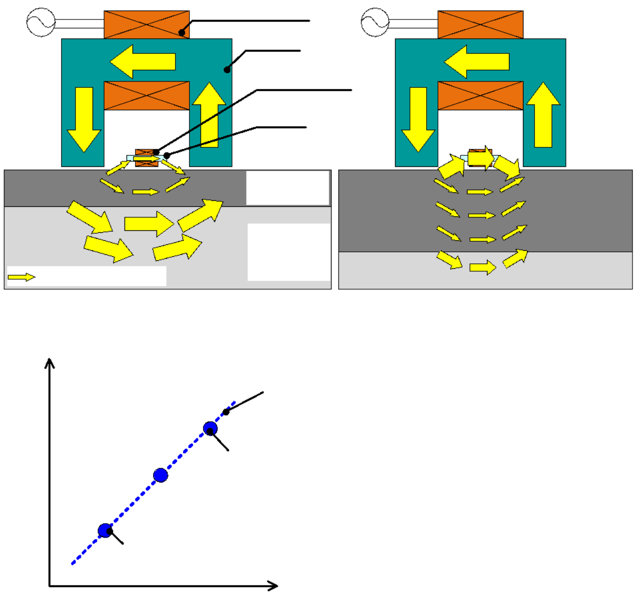

Fig. 2. Mechanism of measuring effective case depth

3. Experimental Method and Test Results

3.1 Measurement system

Fig. 3 shows the measurement system. The system consists of the main instrument body, the measurement sensor and the measurement screen. the main instrument body has consolidated control and data processing functions. It is possible to display the number of effective case depths in the object on the measurement screen in about 5 seconds.

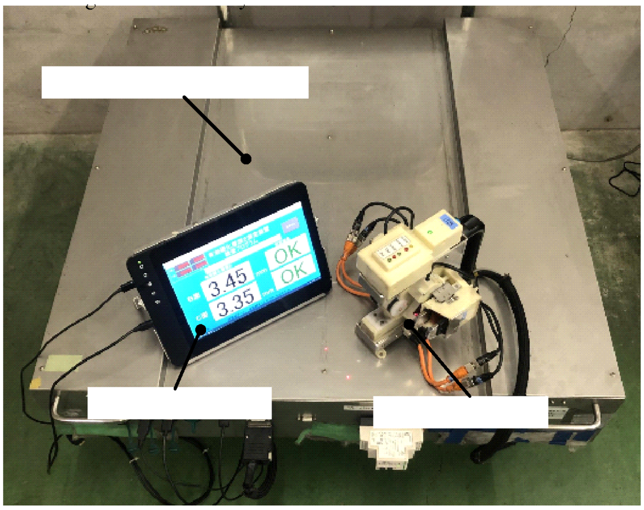

Fig. 3. Measurement system

3.2 Measurement parts and the sensor

Fig. 4 shows the shape of the measurement object and sensor as well as their installation conditions. The measurement object is a large ring-shaped gear part, and its dimensions are 1.2 m in outer diameter and module 11. Its material is 0.45% carbon steel which is standardized as JIS-S45C in Japan. The specification of effective case depth is 1.0 to 3.0 mm.

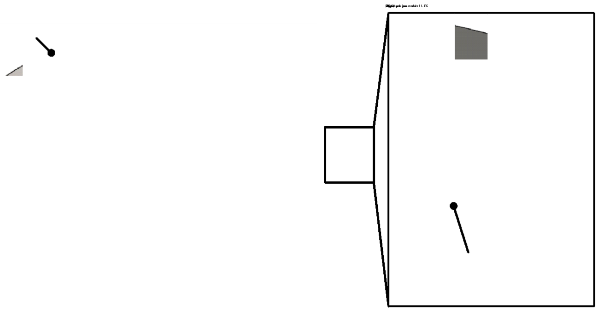

Fig. 4. Measurement object and sensor

3.3 Standard curve

This measurement method needs to prepare the standard curve in advance using the standard test blocks in which the induction hardened parts with different effective case depths. In this test, the standard test blocks with five different effective case depths were produced. The target effective case depth of the standard test block was 0.5mm, 1.0mm, 1.5mm, 2.0mm and 2.5 mm in total. Fig. 5 shows the distribution of hardness in the standard test block. Next, the standard test blocks were measured by the measurement system, and the standard curve was created from the obtained detected voltage. Fig. 6 indicates the standard curve. Since this measurement system was capable of measuring the detection voltage with good linearity to the effective case depth. Finally, the mass-produced product was measured using this standard curve to confirm the accuracy of the measurement system.

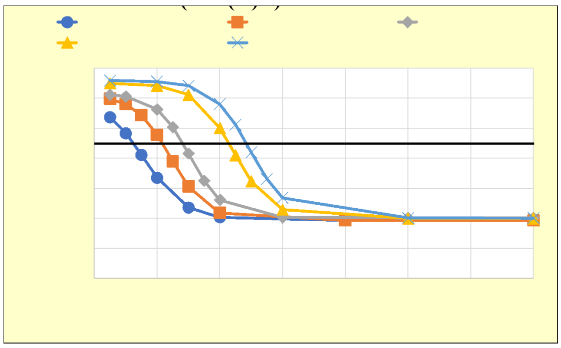

Fig. 5. Hardness distribution of standard test block

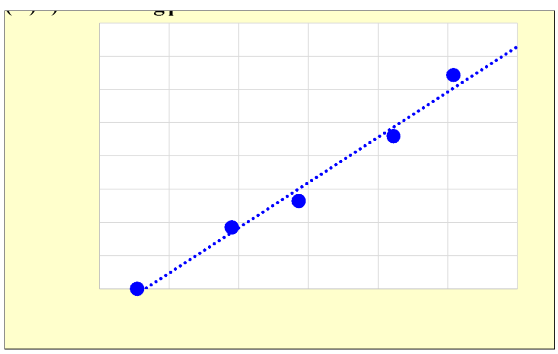

Fig. 6. Standard curve of 0.45% carbon steel

3.4 Results of measurement

To confirm the measurement accuracy of the system, we took measurements at five places around the circumference of each mass-produced part and measured the effective case depth by the hardness test by cutting the part at the measurement points. Fig. 7 indicates the results of a comparison of the effective case between this method and the hardness test. The average error was approximately 0.1 mm, the maximum measurement error was approximately 0.2 mm, and the measurement dispersion was ±0.2 mm, indicating that the measurement accuracy was sufficiently high. Therefore, it was found that the effective case depth of induction hardened parts can be measured non-destructively and in a short time by using this method.

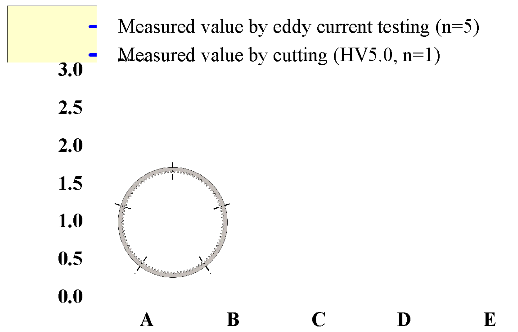

Fig. 7. Comparison result

4. Conclusions

We developed the method of measuring the effective case depth of induction hardened parts by using the mechanism of eddy current testing and confirmed its measurement accuracy. As a result, the following findings were obtained:

1) The measurement system to measure the effective case depth of induction hardened parts was developed using the principle of eddy current testing and the change in magnetic characteristics before and after hardening.
2) By verifying the accuracy of the measurement system, it was found that the maximum measurement error between the values measured with this method and the effective case depth obtained in the hardness test is approximately 0.2 mm, indicating that the method is sufficiently accurate.
3) This method can measure the effective case depth of induction hardened parts quickly in a non-contact manner and with high accuracy.

5. References

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