Fundamental study on development of stainless steel ultrasonic

Endo-Chip break detector

OZEKI Ryousuke, FUNAKI Hiroshi

Nihon University Graduate School of Dentistry at Matsudo
Department of Endodontics

Keywords:
Ultrasonic Endo-Chip, crack of instrument, detection of crack, eddy current

Running title:
detection of cracks of stainless steel instruments using eddy current

Corresponding author:
OZEKI Ryousuke, Department of Endodontics, Nihon University School of Dentistry at Matsudo,
870-1, Sakaecho 2, Matsudo, Chiba, 271-8587, Japan
Tel: +81-473-360-9369
Facsimile: +81-473-360-9370
E-mail: nmdental@basil.ocn.ne.jp

Abstract

In recent years, an ultrasonic tip (Endo-Chip) mounted on a handpiece-type ultrasonic generator has been used for root canal enlargement. However, it is difficult to predict the fracture that often occurs in the root canal. Thus, we applied the eddy current flaw detection method and prototyped a crack detection device for the instrument. When the coil in which the alternating current flows is brought close to the conductor, an eddy current is generated in the conductor through electromagnetic induction.

Stainless steel rods having a diameter of 1.3 mm were grooved at 5 and 10 mm from the tip with depths of 1/4, 1/2, and 3/4 of the diameter. Stainless steel rods without grooves were used as the control and reference. The excitation coil was subjected to alternate currents of 1, 10, and 100 kHz. The specimen was placed near the coil, and the voltage generated in the sensor coil located next to the excitation coil was measured. As a result, a voltage drop in the sensor coil was recognized at a position corresponding to that of the specimes's groove with depth of 1/2 and 3/4.

In conclusion, the possibility of detecting cracks in stainless steel instruments is suggested.

Introduction

The purpose of endodontics is to sterilize the root canal through root canal enlargement and maintain it through root canal filling. The most effective means of removing bacteria from the root canal is mechanical root canal enlargement of the infected dentin with an endodontic device. In recent years, a Chip (Endo-Chip) in the form of a root canal spreader, made of stainless steel, with a thin tip has been attached to an ultrasonic generator. Then, the root canal wall is cut under a microscope, and the isthmus, root canal filling material, and root canal wall are removed (1). This Chip is used for cleaning, as well as to remove broken instruments from the root canal (1–4). However, the Endo-Chip undergoes considerable stress, and an accident where its tip breaks in the root canal frequently occurs. Cutting by Endo-Chip to dentin differs from case to case in terms of time of use and amount of force, and it is difficult to prevent instrument breakage by limiting the number of uses. The operator must rely on visual observation of the instrument before use; however, it is difficult to predict a broken instrument. Non-destructive techniques are used in the metal industry and science in order to evaluate the properties of a wide variety of materials without causing damage. Some of the most common non-destructive techniques are electromagnetic, ultrasonic and liquid penetrant testing. One of the conventional electromagnetic methods utilized for the inspection of conductive materials such as copper, aluminum or steel is eddy current non-destructive testing (5,6). Eddy currents are induced in proportion to the rate at which the magnetic flux through the specimen changes over time. As is used in materials such as electromagnets, a magnetic flux is generated when a current flows through a coil. If the coil current is alternating, the magnetic flux is also alternating and changes over time. When the alternating magnetic flux penetrates the conductive specimen, an eddy current is induced by electromagnetic induction. This eddy current is used for phenomena such as high-frequency induction heating. In the eddy current flaw detection test, an eddy current is induced near the test piece surface by using a test coil to which an alternating current (AC) is applied. Since the electromotive force fluctuates due to a defect, such as a crack on the test piece surface, the electromotive force of the test coil changes. Therefore, it was considered that flaw detection can be performed by using the change in the electromotive force of the test coil (Fig. 1).

This study focuses on the eddy current inspection method, detecting the presence or absence of cracks in the End-Chip, and examining whether this method can be used for detecting fracture.

Materials and Methods

1. Specimen

A 1.3-mm-diameter stainless steel rod (manufacturer undisclosed, Japan) was used, on which an Endo-Chip was manufactured. It was cut to a length of 30 mm, and as shown in Fig. 2, a 0.5-mm-thick diamond disc was placed at 5 and 10 mm from the stump and the stainless steel rod was cut perpendicular to its long axis. Grooves with depths of 1/4, 1/2, and 3/4 of the rod diameter were made. Specimens without a groove were classified into Group A, as control and reference. Specimens having a groove at 5 mm from the stump with depths of 1/4, 1/2, and 3/4 of the rod diameter were designated as Groups B-1, B-2, and B-3, respectively. Similarly, those having a groove at 10 mm from the stump were designated as Groups C-1, C-2, and C-3. Ten specimens were prepared for each group.

2. Prototype device

Fig. 3 shows an outline of the prototype device. The excitation coil was a polyester copper wire (diameter 0.1 mm) wound 3,000 times around a ferrite rod (diameter 0.75 mm, Fair-Rite Products Co., NY, USA) with a width of 30 mm. The sensor coil was polyester copper wound on the same ferrite rod. The wire (0.05 mm diameter) was wound 300 times with a width of 3 mm. A sine wave with frequencies of 1, 10, and 100 kHz and a voltage of 6 V (peak to peak) was generated by an oscillator (JYE Tech Ltd. Guangxi, China), and then amplified by an amplifier (LM7171, National semiconductor Co., CA, USA) three times and supplied to the excitation coil. The specimen was located 1 mm from the end of the sensor coil and moved by 1 mm along to the long axis. The AC average voltage of the electromotive force generated in the sensor coil was measured with a digital multimeter (PC500A, Sanwa Electric Instrument Co., Tokyo, Japan).

3. Statistical analysis

Tukey's test was used for Statistical analysis.

Results

Fig. 4 shows the difference between the voltage of the sensor coil when the specimen was located and not located at supply frequencies of 1, 10, and 100 kHz. At 1 kHz, the specimen voltage was 136.8 mV when the specimen was not positioned and 137.7 mV when it was positioned; the difference was 0.9 mV. Similarly, at 10 kHz, the specimen voltages were 140.1 and 143.1 mV; the difference at 10 kHz was 3.1 mV, whereas at 100 kHz, they were 121.0, 121.9

mV; the difference at 100 kHz was 0.9 mV. At 10 kHz, the difference was the largest, and this frequency was subsequently used for crack detection.

Fig. 5 shows the sensor coil voltage from -5 to 15 mm at the tip of Group A, which is the control. The same voltage was applied to all 10 specimens, and the standard deviation was 0.0. At the -5 mm tip, it was not affected by the specimen, the voltage started increasing at -2 mm at the tip, reaching 3 mV at 2 mm at the tip, and showed no change thereafter. The curve obtained here was used as a reference for comparing the grooved specimen (B-1, 2, 3, C-1, 2, 3).

Fig. 6 shows a difference of the sensor coil voltage between group A as reference and specimens (B-1, B-2, B-3, C-1, C-2 and C-3) having a groove. In each specimen, a negative peak was observed at the grooved position. In Group B, a peak was observed at a position of 5 mm. B-1 showed an average peak of -0.05 ± 0.05 mV, B-2 showed -0.18 ± 0.06 mV, and B-3 showed -0.26 ± 0.05 mV. In addition, a significant difference was found in B-2 and 3 at a risk of 1% with respect to the reference. In Group C, a peak was observed at a position of 10 mm. C-1 showed an average peak of -0.05 ± 0.05 mV, C-2 showed -0.17 ± 0.05 mV, and C-3 showed -0.27 ± 0.05 mV. In addition, a significant difference was found in C-2 and C3 at a risk of 1%, relative to the reference. Furthermore, there was no difference in the voltage generated in the sensor coil depending on the direction of the groove with respect to the coil.

Discussion

Although root canal instruments can fracture at any stage of treatment, several studies have demonstrated that smaller instruments are more prone to fracture (7–10). An Endo-Chip hits dentin more than 30,000 times per second, and thus, considerable force is likely to be applied repeatedly. Continued use without noticing that there is a crack is thought to result in breakage. If the possibility of breaking can be detected in advance, the number of accidents in which the instrument breaks in the root canal can be reduced. At present, this can only be confirmed through visual inspection of the surgeon. The fracture of the instrument in the root canal results from the occurrence of cracks due to fatigue failure. If the onset of cracking can be detected, it can be avoided before it breaks.

When the coil in which the AC flows is brought close to the conductor, an eddy current is generated in the conductor through electromagnetic induction. Using this phenomenon, the electrical properties of the test object can be evaluated or the scratches in the test object can be detected without destroying the object. Non-destructive inspection using this method is called eddy current testing. This inspection technique is easier to handle and faster than ultrasonic flaw detection and radiation inspection (11). Since the Endo-Chip is made of stainless steel and is a magnetic conductor, it can be applied to this eddy current testing.

In this study, we examined whether Endo-Chip fracture can be detected using eddy current testing. A stainless steel rod for producing an Endo-Chip was provided by the manufacturer as a specimen. The results in Fig. 5 indicate that an eddy current was generated in the specimen by bringing it closer to the coil, where an AC of 10 kHz was applied, and the magnetic flux generated from the eddy current increased the sensor coil voltage. The grooves at 1/4, 1/2, and 3/4 of the specimen diameter were then cut with a diamond disc, in order to detect cracks. The position of the groove was 5 mm near the tip and 10 mm near the center of the specimen. The specimen was mounted on the prototype device, and measurement was performed in 1 mm increments from -0.5 mm at the tip to 15 mm at the center, as shown in Fig. 2. As a result, as shown in Fig. 6, a drop in the voltage generated in the sensor coil was recognized according to each groove. The specimen (B-1, C-1) having the groove with the depth of 1/4 showed no significant difference as compared with the reference group A. However, specimens with a groove with a depth of 1/2 or more (B-2, B-3, C-2, C-3) showed a significant difference at a 1% risk rate compared to Group A.

In fact, because the crack width of the Endo-Chip is narrower and shallower than those of the grooves studied here, it cannot be clinically applied immediately with this prototype device; however, it is necessary to apply mathematical analysis and improve sensor accuracy. Thus, clinical application may be possible.

References

1. Thomas A, Johnson ZR. Ultrasonic endodontics: a clinical review. JADA, 114, 198 655–657, 1987.
2. Chen S, Liu J, Dong G, Peng B, Yang P, Chen Z, Yang F, Guo D. Comparison between ultrasonic irrigation and syringe irrigation in clinical and laboratory studies. J Oral Sci, 58, 373–378, 2016.
3. van der Sluis LW. Passive ultrasonic irrigation of the root canal: a review of the literature. Int Endod J, 40, 415–426, 2007.
4. De - Deus G, Carvalho MS, Belladonna FG, Cavalcante DM, Portugal LS, Prado CG, Souza EM, Lopes RT, Silva EJNL, Arrowhead design ultrasonic tip as a supplementary tool for canal debridement. Int J Endodon, 2019.
5. Javier GM, Jaime GG, Ernesto VS, Non-destructive techniques based on eddy current testing. Sensors, 11, 2525–2565, 2011.
6. Janousek L, Capova K, Yusa N, Miya K, Multiprobe inspection for enhancing sizing ability in eddy current nondestructive testing. IEEE Trans Magn, 44, 1618–1621, 2008.
7. Yared GM, Bou Dagher FE, Machtou P, Kulkarni, GK, Influence of rotational speed, torque and operator proficiency on failure of Greater Taper files. Int Endod J, 35, 712, 2002.

8. Berutti E, Chiandussi G, Gaviglio I, Ibba A, Comparative analysis of torsional and bending stresses in two mathematical models of nickeltitanium rotary instruments: ProTaper versus Profile. J Endod, 29, 15–19, 2003.
9. Parashos P, Gordon I, Messer HH, Factors influencing defects of rotary nickel-titanium endodontic instruments after clinical use. J Endod, 30, 722–725, 2004.
10. Shen Y, Haapasalo M, Chueng GS, Peng B. Defects in nickel-titanium instruments after clinical use. Part 1: Relationship between observed imperfections and factors leading to such defects in a cohort study. J Endod, 35, 129–132, 2009.
11. Kameari A, Solution of asymmetric conductor with a hole by FEM using edge-elements, COMPEL. The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 9(A), 230–232, 1990.

Figures

Fig. 1 Eddy current test

In the eddy current flaw detection test, an eddy current is induced near the test piece surface by a test coil to which an AC is applied. As the electromotive force fluctuates due to defects such as a crack on the test piece surface, the electromotive force of the test coil changes. Therefore, flaw detection can be performed by using the change in the electromotive force of the test coil.

Fig. 2 Preparation of stainless steel specimens

Stainless steel rods having a length of 30 mm and a diameter of 1.3 mm was prepared.

Group A: Specimens without a groove, as control and reference

Group B: Specimens having a groove at a position 5 mm from the tip

- Group B-1: Groove depth was 1/4 of diameter.
- Group B-2: Groove depth was 1/2 of diameter.
- Group B-3: Groove depth was 3/4 of diameter.

Group C: Specimens having a groove at a position 10 mm from the tip

- Group C-1: Groove depth was 1/4 of diameter.
- Group C-2: Groove depth was 1/2 of diameter.
- Group C-3: Groove depth was 3/4 of diameter.

Ten specimens were prepared for each group.

Fig. 3 Outline of the prototype device

Fig. 4 Difference between the voltage of the sensor coil and that when the specimen was located and not located at supply frequencies of 1, 10, and 100 kHz. At 10 kHz, the difference was the largest.

n = 10, values are averages, S.D. was 0.

Fig. 5 Sensor coil voltage from -5 to 15 mm at the tip of Group A (no glove)

At -5 mm tip, it is not affected by the specimen, the voltage starts increasing from -2 mm at the tip, rises to +2 mm at the tip, reaches 3 mV, and shows no change thereafter. n = 10; values are average, S.D. is 0.

Fig. 6 Differences among the reference and B-1, B-2, B-3, C-1, C-2, and C-3

In Group B, a peak is observed at a position of 5 mm.

In Group C, a peak is observed at a position of 10 mm.

* Significant difference compared to the reference ($p < 0.01$, $n = 10$)

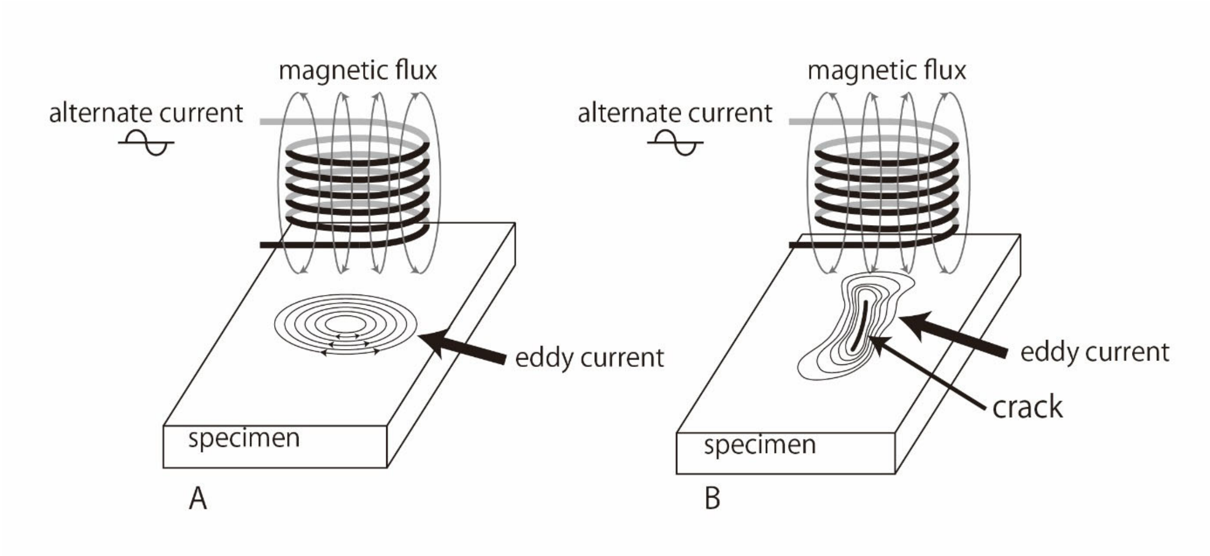
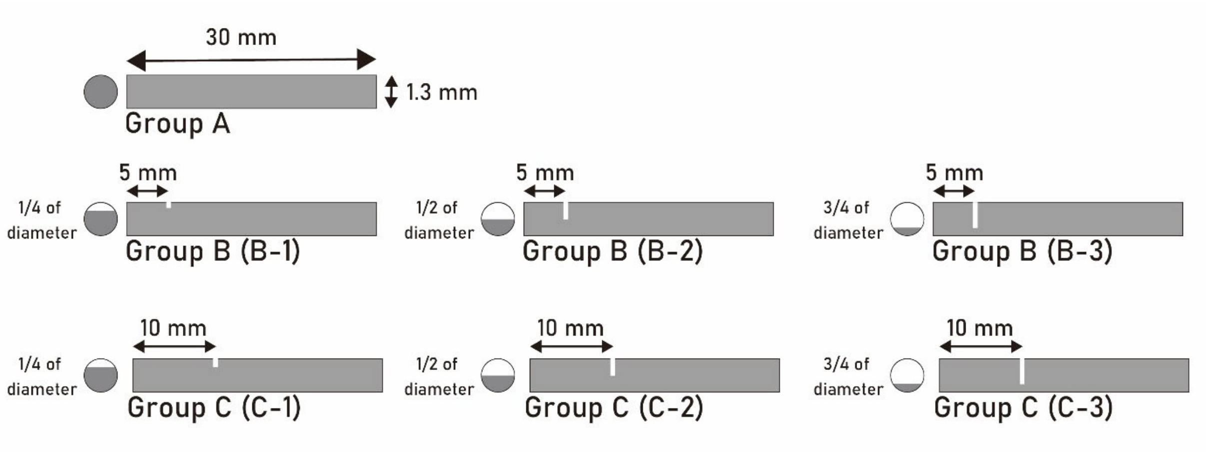

magnetic flux
alternate current
eddy current
specimen
A
magnetic flux
alternate current
eddy current
crack
specimen
B

Fig. 1


30 mm
1.3 mm
Group A
5 mm
1/4 of
diameter
Group B (B-1)
5 mm
1/2 of
diameter
Group B (B-2)
5 mm
3/4 of
diameter
Group B (B-3)
10 mm
1/4 of
diameter
Group C (C-1)
10 mm
1/2 of
diameter
Group C (C-2)
10 mm
3/4 of
diameter
Group C (C-3)

Fig, 2

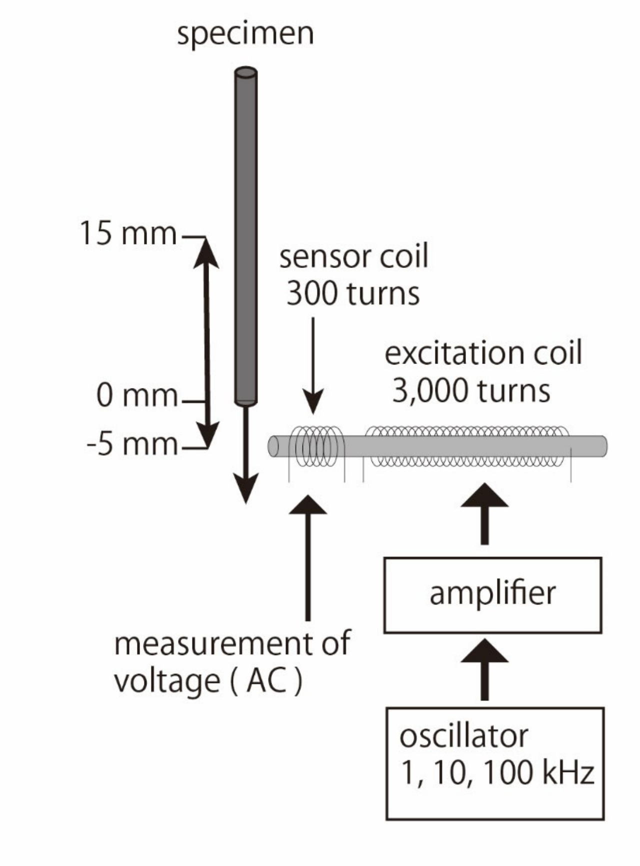

specimen
15 mm
0 mm
-5 mm
sensor coil
300 turns
excitation coil
3,000 turns
measurement of
voltage (AC)
amplifier
oscillator
1, 10, 100 kHz

Fig. 3

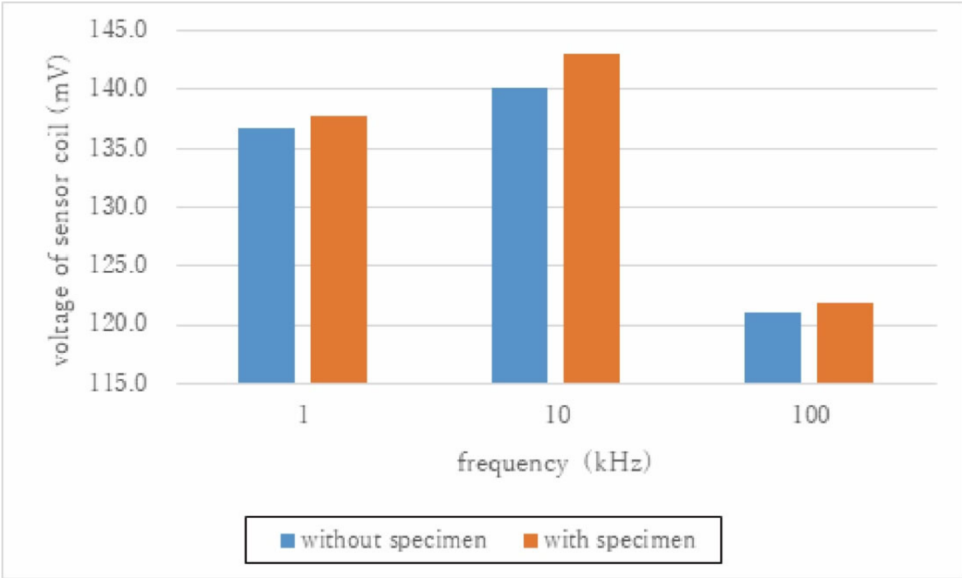
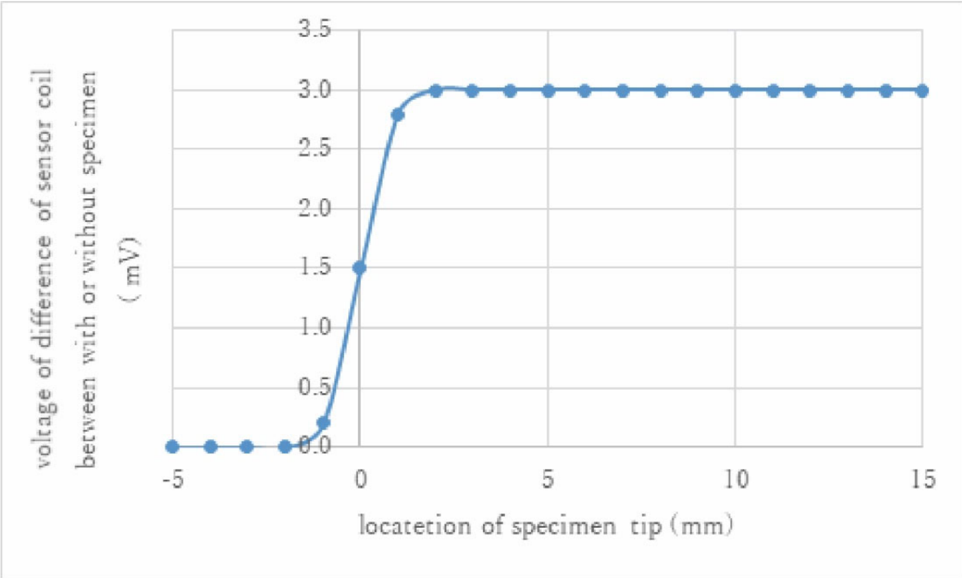

145.0
140.0
135.0
130.0
125.0
120.0
115.0
voltage of sensor coil (mV)
1
10
100
frequency (kHz)
without specimen
with specimen

Fig. 4



voltage of difference of sensor coil between with or without specimen (mV)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-5
0
5
10
15
locatetion of specimen tip (mm)

Fig. 5

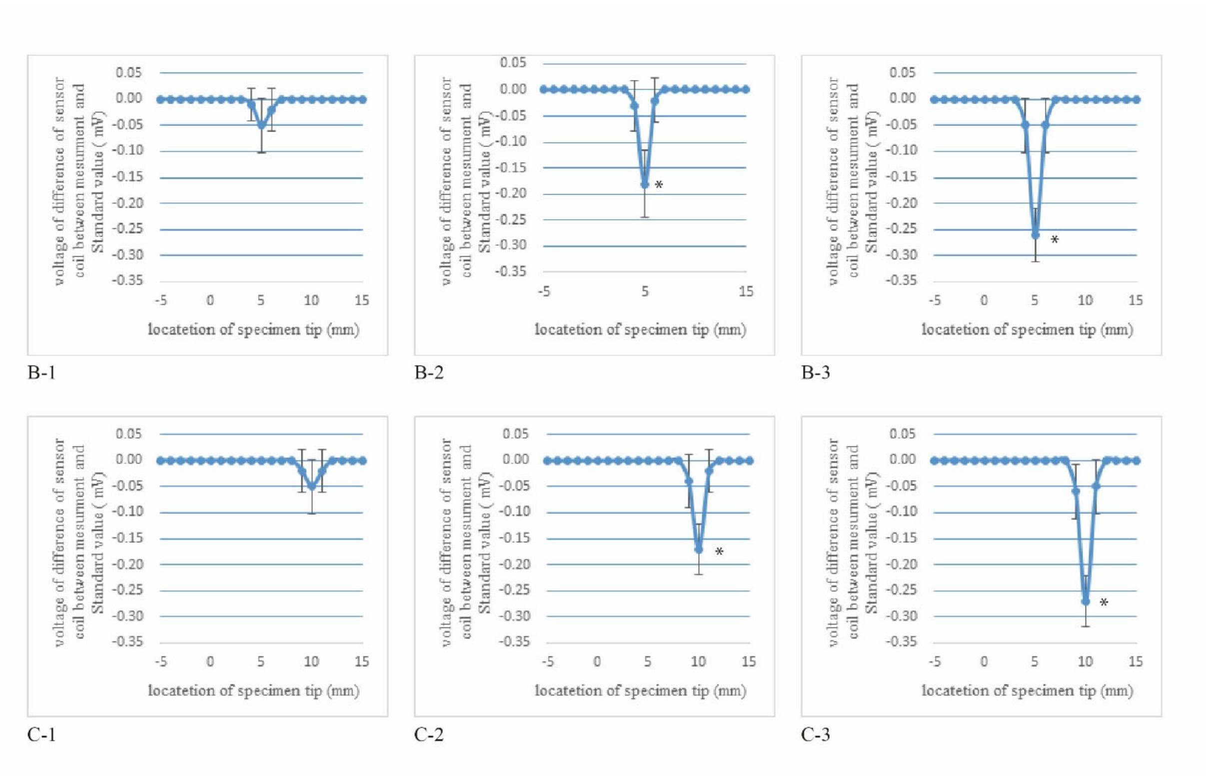

voltage of difference of sensor coil between mesurment and Standard value (mV)
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-5
0
5
10
15
locatetion of specimen tip (mm)
*
B-1
B-2
B-3
C-1
C-2
C-3

Fig. 6