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An Experimental Verification on the Development of an Innovative Diamond Wire Saw Cutting Technology

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새로운 다이아몬드 와이어 쏘 절단 기술 개발에 관한 실험적 검증

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ABSTRACT

This paper introduces a innovative diamond wire saw cutting technology and its experimental verification that can be utilized for cutting heavy structures. While conventional diamond wire saw cutting technologies such as water cooled cutting method and dry cutting method cause severe environmental problems due to generating massive concrete sludge or dust scattering, the proposed method can eliminate those problems considerably. Through extensive experiments using heavy structure test bed and real bridge pier structure, comprehensive analysis and comparative evaluation about various cutting methods were performed. As a result, the innovative diamond wire saw cutting method could achieve a similar cutting and cooling performance to the water cooled cutting method without generating concrete sludge and it showed an improved cutting and cooling performance to the dry cutting method without dust scattering. Consequently it is confirmed that the suggested cutting technology can be a promising environment-friendly alternative in the field of heavy structure dismantling.

Key Words : Diamond Wire Saw(다이아몬드 와이어 쏘), Heavy Structure Cutting(중량물 절단), Cutting Performance(절단성능), Cooling Performance(냉각성능), Dismantling(해체)

1. Introduction

One of the widely used methods of dismantling large building structures is to wind a diamond wire saw having a high hardness around the structure and then rotate the saw at a high speed to grind the cut surface. The concrete cutting and dismantling technologies using a wire saw can be divided into water-cooled cutting methods (WCCMs) and non-water-cooled cutting methods (non-WCCMs) based on the method of cooling the friction heat

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generated from cutting. WCCMs use water to cool the friction heat, while non-WCCMs use means of cooling other than water. Representative non-WCCMs include the dry cutting method (DCM), which uses forced cooling air of -25℃ as the means of cooling, and the liquid nitrogen cutting method (LNCM), which uses liquid nitrogen[1,2,3]. Among the conventional concrete cutting and dismantling technologies using a diamond wire saw, the WCCMs have the problem of generating an enormous amount of concrete waste sludge by the mixing of the concrete dust generated from the cutting process and the water used as the means of cooling. The DCM was developed to improve this problem, and it does not generate waste sludge, but the treatment of the concrete dust generated from the cutting process and the dust remaining on the cut surface have emerged as new problems. Fig. 1 shows the dust generated during the cutting work using DCM and the remaining dust.

Given this background, this study developed an innovative cutting technology (ICT) that solves both the concrete waste sludge problem of the WCCMs and the dust treatment problem of the DCM[4,5]. Furthermore, two testbed verification experiments and a field application verification experiment for a full-scale concrete bridge were carried out for the developed technology. This paper introduces the developed ICT and presents the potential of the ICT as a new environmentally friendly alternative technology in the field of concrete cutting and


(a) Scattered dust during dry cutting


(b) Remaining dust after dry cutting

Fig. 1 Scattered dust and remained dust by dry cutting method

dismantling using a diamond wire saw through a comprehensive analysis of various verification experiments.

2. ICT Overview

The biggest environmental problem of the WCCMs, which uses water to cool down the heat generated from the cut surface when a structure is cut with a wire saw, is the treatment of waste sludge generated by the mixing of ground dust and water. To solve this problem, this study devised a system that cools down the wire saw by using a separate cooling device outside the cut surface instead of the conventional cooling method that directly applies water to the cut surface. Fig. 2 shows

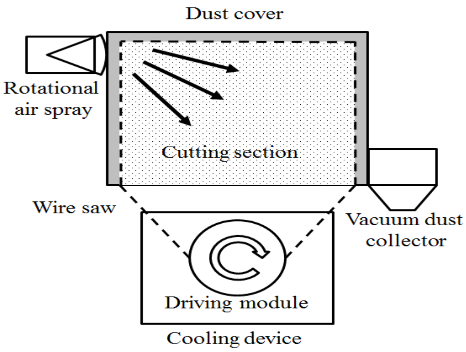


Fig. 2 Schematic diagram of a innovative diamond wire saw concrete cutting technology(ICT)

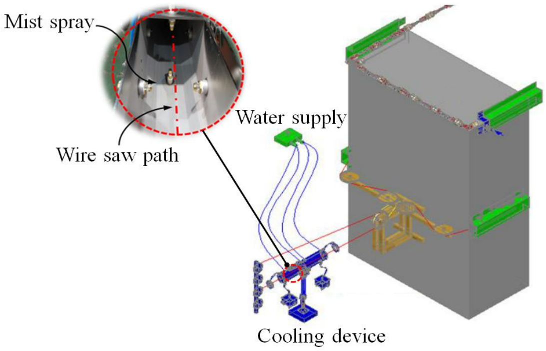
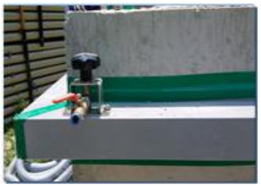


Fig. 3 Cooling device configuration of ICT

a schematic of the cutting system using the ICT developed in this study.

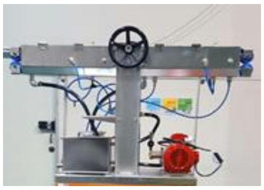
As shown in the figure, there is a cooling device outside the cut surface that cools and washes the wire saw. Fig. 3 illustrates this cooling method applied to the ICT. The cooling device outside the cut surface sprays mist, which cools the hot wire saw that comes out through the cut surface.

However, as in the DCM, the dust scattered from the cutting process negatively affects the workplace environment, and the dust remaining on the cut surface is blown into the air when the cut workpiece is lifted, causing a secondary environmental pollution problem. In this study, as shown in Fig. 2, a dust cover was installed around the cut surface to prevent the dust from being discharged to the outside, and the dust was actively suppressed by installing a vacuum dust collector in the location where the dust was discharged. Furthermore, a rotating air sprayer was installed opposite the vacuum dust collector to guide the dust into the dust collector. Fig. 4 shows the actual devices comprising this cutting system and the cut surface.



(a) Rotational air spray & dust cover

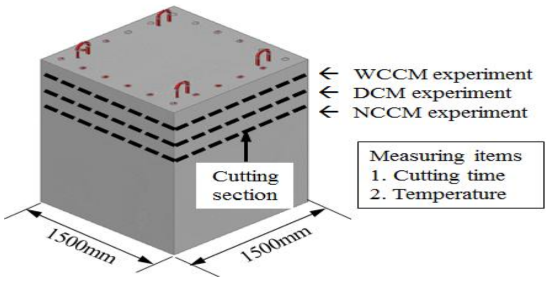
(b) Vacuum dust collector



(c) Cooling device

(d) Cutting section

Fig. 4 Components and cutting section of ICCT



(a) 3D model of heavy structure

(b) Test bed site

Fig. 5 Test bed for cutting experiments

3. Testbed Verification Experiment

3.1 Outline of Testbed Experiment

To verify the newly developed ICT, a model concrete specimen similar to bridges seen in actual cutting demolition work was fabricated. Fig. 5 shows the 3D shape of the bridge specimen with a 1.5m×1.5m cross-section and testbed, which were used to perform two verification tests. The developed technology was verified using WCCM, DCM, and the ICT proposed in this study for the same cross-section area. The tension and driving speed of the wire saws used in this study were set identically to 48 kg/cm^2 and 11–12 m/sec, respectively.

For measurement items, the cutting time for evaluating the cutting performance and the maximum temperature for evaluating the cooling performance were selected. Furthermore, the remaining dust treatment capacity was also verified by measuring the amount of remaining dust.

3.2 Cutting Performance Evaluation Test

To evaluate the cutting performance of the three cutting methods, the cutting times determined through two verification tests are compared in Table 1. The selected performance measure was the time required for cutting a 1-m^2 section. As shown in Table 1, a concrete section of the same size of 1.5 m×1.5 m was cut and the time was measured, which was then converted to the time required for cutting a 1-m^2 section. The average of the two verification tests was 11.75 min/m^2 for WCCM, 14.85 min/m^2 for DCM, and 12.65 min/m^2 for ICT. The standard deviation of the cutting time per unit area was approximately 0.92 min/m^3 for all three cutting methods performed twice each. When compared to the DCM, the proposed ICT showed a cutting performance improvement effect of approximately 17%, which is relatively large, but when compared to the WCCM, the cutting speed of the ICT was approximately 7% slower, which is not a large effect. This appears to be because the WCCM performs the cooling and washing relatively efficiently by directly spraying water on the cut surface. However, the enormous amount of waste sludge that is generated by this process creates significant environmental pollution, as described above.

Table 1 Cutting performance result for 1.5m×1.5m cross-sectional area

Cutting method	First test		Second test		Avg. cutting time per unit area (min/m^2)
	Cutting time (min)	Cutting time per unit area (min/m^2)	Cutting time (min)	Cutting time per unit area (min/m^2)	
WCCM	28	12.4	25	11.1	11.75
DCM	35	15.5	32	14.2	14.85
ICT	30	13.3	27	12.0	12.65

3.3 Cooling Performance Evaluation Test

When cutting a concrete structure using a diamond wire saw, high heat is generated by the friction of the wire saw beads and the structure, which has a considerable effect on the cutting performance. To compare the generated temperatures of the proposed ICT, WCCM, and DCM, the maximum temperature in the cutting process was measured. Tests were conducted twice. The maximum temperature was acquired by measuring the temperature of the wire saw continuously through the cutting process using a thermal imaging camera from FLIR Systems. Fig. 6 shows the temperature measuring positions of the wire saw. It was assumed that the maximum temperature of the wire saw would be measured at the position where the wire saw comes out after cutting the structure. The results can be seen in Tables 2 and 3.

The numbers at the top and bottom of the right-side bar on the camera image indicate the maximum and minimum temperatures, respectively.

Table 2 Temperature measurement of diamond wire saw

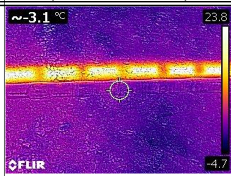
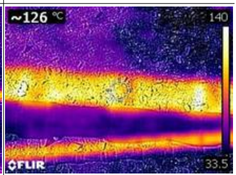
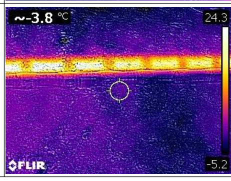
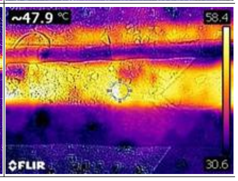
Cutting method	First test (winter season)	Second test (summer season)
WCCM		
DCM		
ICT		

Table 3 Cooling performance result (maximum temperature) for 1.5m×1.5m cross-sectional area

Cutting method	Maximum temperature (°C)		Avg. temperature (°C)
	First test	Second test	
WCCM	23.8	53.2	38.5
DCM	82.4	140.0	111.2
ICT	24.3	58.4	41.4

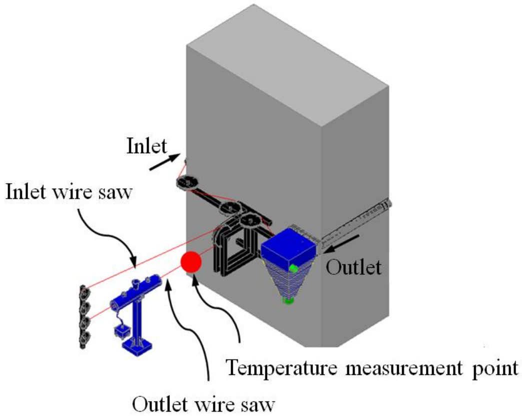


Fig. 6 Temperature measurement configuration

The estimation results for the maximum temperature of the wire saw are outlined in Table 3. The maximum temperature of the wire saw when the specimen was cut using each cutting method on average was 38.5°C for the WCCM, 111.2°C for the DCM, and 41.4°C for the ICT. In these results, the ICT and WCCM showed similar temperatures, but the DCM showed a relatively higher temperature. Thus, the ICT was found to have excellent cooling performance even though it does not directly spray water on the cut surface. However, the temperature deviations in the two tests were 20.8°C, 40.7°C, and 24.1°C for the WCCM, DCM, and ICT, respectively. This appears to be due to the difference in the temperature of the surrounding environment resulting from the seasonal factor, because the tests were performed in winter and summer.

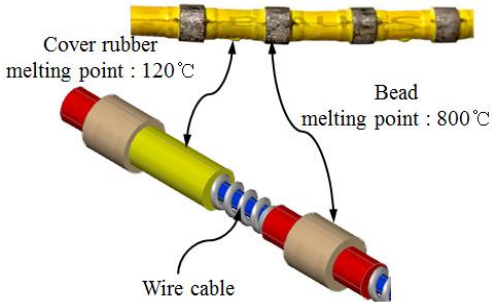
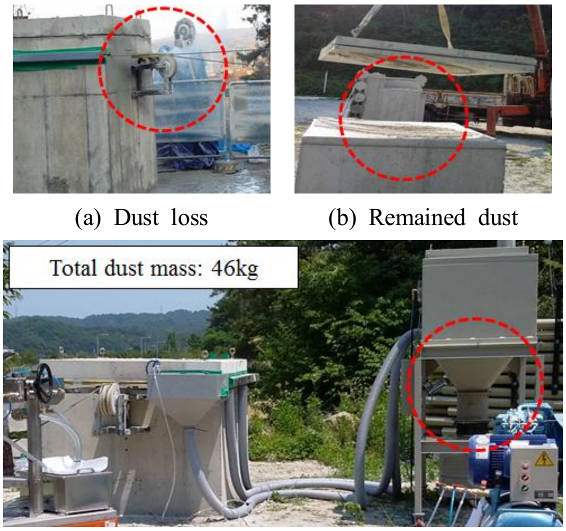


Fig. 7 Structure of diamond wire saw



(a) Dust loss (b) Remained dust

(c) Vacuumed dust

Fig. 8 Generated dust components

Fig. 7 shows the allowable melting points for the structure and each element of the diamond wire saw. In the case of the beads, the allowable melting point is approximately 800oC, which is far from the temperature at the time of cutting. However, the allowable melting point of the cover rubber between the beads of the wire saw is approximately 120oC, which is close to the maximum temperature. In particular, the maximum temperature in the summer test of the DCM was higher than the allowable melting point of the cover rubber, which is expected to shorten the durability/lifespan due to deterioration.

3.4 Remaining Dust Treatment Capacity

As shown in Fig. 8 (a), a large amount of dust is generated when a concrete structure is cut by the DCM. To solve this problem, a vacuum dust collector is generally installed. However, due to poor dust collection efficiency and other problems, the dust is not completely suppressed, and a significant amount of dust remains on the cut surface, as shown in Fig. 8 (b). This remaining dust on the cut surface causes air pollution by being spread into the air during the structure demolition process, and because the bridges that are demolished are frequently located in rivers, the dust in the rivers can even pollute the surrounding waters. In this study, to solve the problem of remaining dust on the cut surface, a rotating air sprayer (Fig. 2) was developed, and the remaining dust on the cut surface was blown in the direction of the vacuum dust collector to improve the dust collection efficiency.

The wire saw used in the verification test for the remaining dust treatment capacity was a general-purpose wire saw with a 9-mm diameter. Assuming that the 1.5 m×1.5 m testbed is ground in this height, dust corresponding to a volume of 0.02025 m^3 is generated. As described in Fig. 8, the total dust generated by this can be categorized into three types: dust entering the vacuum dust collector, dust remaining on the cut surface, and dust spread into the air. The total mass of these three types of concrete dust generated from the cut surface using the density of concrete used in the verification test becomes 46 kg.

To compare the dust treatment efficiency of the conventional DCM and the ICT applying a rotating air sprayer, the amount of concrete dust collected in the vacuum dust collector and the amount of dust remaining on the cut surface when the specimen was cut in each method were measured. Table 4 lists the amounts of dust generated by type. The measured amount of concrete dust collected was 30.7 kg, and the measured amount of remaining dust was 6.8 kg when the specimen was cut with the DCM (35.9 kg and 1.9 kg in the case of the ICT, respectively). If the total mass of the dust generated from the cut surface is assumed to be 46 kg as mentioned above, the amount of dust spread into the air during the structure demolition process after cutting can be calculated as 15.3 kg for the DCM and 10.1 kg for the ICT. This shows that the ICT significantly reduces the dust entering the air to approximately two-thirds by decreasing the remaining dust on the cut surface.

Table 4 Dust elimination efficiency test results

Cutting method	Dust elements	Dust weight(kg)
DCM	 Vacuumed dust	30.7
	 Remained dust	6.8
	Dust loss	8.5
	Dust scattered in the air	**15.3**
ICT	 Vacuumed dust	35.9
	 Remained dust	1.9
	Dust loss	8.2
	Dust scattered in the air	**10.1**

4. Field Application Verification Test

After completing the testbed verification test, a verification test was performed for an actual bridge to examine the field applicability of the ICT. The bridge used in this experiment was a concrete structure with a cross-section of 0.7 m×0.7 m, and its shapes before and after the verification test are shown in Fig. 9. Two bridge structure specimens were prepared for this verification test, and the verification using the testbed was judged to be sufficient for the comparison with the DCM related to the remaining dust treatment capacity. Thus, it was determined to compare the WCCM and the ICT developed in this study for the field application test. Focusing on whether the ICT can replace the WCCM, which directly sprays water as a means of reducing the high friction heat generated in the concrete cutting process, this study measured the maximum temperature in the cutting process and the cutting time, which is related to the cutting performance. The field application test and the results are shown in Fig. 10 and Table 5, respectively. As shown in Table 5, the maximum temperatures were similar: 33.9℃ for the WCCM and 36℃ for the ICT. Therefore, it is believed that the ICT, which has a similar maximum temperature to that of the WCCM without applying cooling water on the cut surface, can sufficiently replace the conventional WCCM.

Furthermore, the cutting performances were also similar between the two methods and showed a tendency similar to the results of the first and second testbed verification tests. However, the cutting time per unit area, which indicates the cutting performance, was somewhat larger compared to the first and second testbed verification tests. The reason for this seems to be as follows. Unlike the testbed verification tests using a structure consisting of concrete only, the bridge structure used in the field application test contained a large number of reinforcement bars. Moreover, as shown in Fig. 9 (b), in this study, the plastic hinge section (i.e., a connection of the column and the base, where the reinforcement placement is the most complex among the actual bridge structures) was cut, and as a result, the cutting time was somewhat longer. What was most regrettable in this field application test was that because there were only two structures, a comparison of the ICT with the DCM was not performed. In future, the reliability of the developed ICT should be further increased by performing field

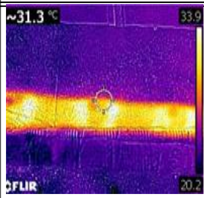
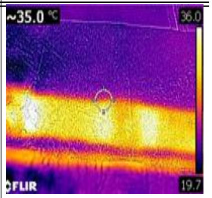
(a) Before cutting (b) After cutting

Fig. 9 Cutting test specimen using real bridge piers

(a) WCCM (b) ICT

Fig. 10 Field application experiment

Table 5 Field application experiment results

Performance	WCCM	ICT
Maximum temperature	 33.9°C	 36°C
Cutting time per unit area	26min/m^2	30min/m^2

application tests for more diverse concrete structures.

5. Conclusions

In this study, a new diamond wire saw cutting method (ICT) that can be used for large structures was introduced and experimentally verified. The conventional WCCMs cause environmental pollution by generating concrete waste sludge, and the DCM causes air and water pollution due to the remaining dust on the cut surface. However, the ICT proposed in this study can solve both of these problems. The cutting methods were compared through two testbed verification tests and field application tests using an actual bridge. In the case of the cutting performance, which was the first measure of performance evaluation, the ICT showed a performance improvement by approximately 17% compared to the DCM, and when compared with the WCCM, the ICT showed slightly lower but similar performance. However, unlike the WCCM, the ICT generated no waste sludge, because it does not use cooling water. In the maximum temperature measurement test conducted to examine the cooling performance, which was the second measure of performance evaluation, the ICT and WCCM showed similar temperatures, but compared to the DCM, the temperature of the ICT was lower by approximately 70℃ on average, indicating a significant improvement effect. Finally, regarding the remaining dust treatment capacity, the ICT showed a significant improvement effect by reducing the amount of dust to approximately two-thirds compared to the DCM. The actual bridge cutting test performed for the field application confirmed that the proposed ICT showed an improvement effect similar to that of the testbed verification test. Therefore, this study confirmed the possibility of using the ICT as a new environmentally friendly replacement technology in the field of concrete cutting and dismantling using a diamond wire saw.

Acknowledgement

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