# Identification of Rebar Corrosion and Delamination of Concrete Cover by Hammering Test

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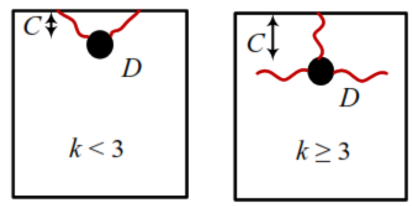
## 1. Introduction

Concrete becomes one of the most essential building materials due to its strength and durability. Despite being frequently utilized due to its simplicity of usage, concrete can experience a number of issues as well, including cracking, spalling, delamination, and honeycombing[1]. Cracking can occur for a variety of causes, such as shrinkage, temperature changes, chemical reactions, reinforcement corrosion, construction overload, poor construction techniques, incorrect design or detailing, and unsuitable cement selection[2]. Cracking can be dangerous as it can result in structural failure. It increases the structure's vulnerability and impairs the capacity to evenly distribute weight and absorb stress.

Building collapses caused by corrosion were reported in Indonesia in 2020. Long-term leakage has allowed water to penetrate a 25-year-building, located in South Jakarta, rusting the iron. According to the investigation's findings, the majority of the iron joints were rusted and the structure should be completely demolished.

To avoid situations like this from occurring again, more tests must be conducted as shared learning. Testing is done on concrete using electrolytic concrete method to determine the size and pattern of cracks that could develop under the effect of corrosion. By understanding how cracks might develop as a result of corrosion, it is expected that proper building maintenance may be carried out later.

Tsutsumi et al.[3] established an elastic theory-based criterion for the interior crack patterns of single-rebar specimens where stress concentration was considered. The illustration is shown in Fig. 1. Cracks spread diagonally to the surface of the concrete if the ratio of the cover-to-bar diameter (C/D), which determines the value of k, is less than three. A vertical crack and two horizontal cracks appear in the concrete cover if the value of k is greater than three.




$$k = \frac{2C + D}{D}$$

**Fig. 1.** Crack patterns (Tsutsumi, 1996)[4]

## 2. Experiment

It can take 5 to 15 years for active corrosion to cause cracks in concrete. It can be accelerated in harsh environments with high salt levels or extreme temperature, such as coastal or desert environments. Therefore, researchers use a variety of accelerated corrosion approaches to achieve the necessary corrosion damage in a timely manner. One method used by researchers is the Electrolytic Acceleration Corrosion Concrete (EACC) method, which involves immersing the specimen in a NaCl solution and applying direct current to the rebar.

### 2.1. Specimen

The test included 12 concrete specimens with dimension of 400 x 300 x 200 mm as shown in Fig. 2. The intended concrete strength is 30 MPa. Each speciment was embedded with rebar with dimension of 16 mm. Each variable has two specimens. After casting, the specimens were stored for 28 days before the test is conducted.

The specimens were named in the form 10-1, meaning the cover depth is 10 mm and the specimen is the specimen with the 1st order in each variable. In this study, NaCl solution is used with 3% concentration to resemble the concentration of salt in seawater. The corrosion cycle is constant for 7 days. Variable is made on the cover depth of concrete. The depth is determined every 10 mm with a range between 10 to 60 mm. Another variable is degree of corrosion which range from 0 until 10%. The voltage used here is 0.13 A.

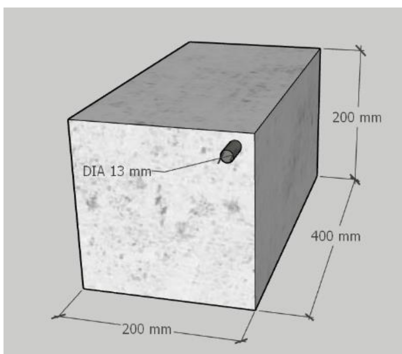



**Fig. 2.** Dimension of the concrete specimen

2.2. Test procedures

2.2.1. Hammering test

Hammering test will be conducted every time when the intended degree of corrosion is reached. Thus, in total the hammering test will be carried out 5 times. First is when the degree of corrosion is still 0% (or the EACC test is not conducted yet), and then when the degree of corrosion reaches 2.5%, 5%, 7.5%, and the last 10%. The cracks and its formed patterns that occur can be inspected later.

2.2.2. EACC method

The top side of specimen is the part that will be immersed in NaCl solution. The steel bars worked as anode and the auxiliary electrode worked as cathode. The corrosion process was initiated by impressing current flow. Then, the specimens were observed to determine how long it took for surface corrosion cracks to emerge. The immersion for each specimen was 7 days until the intended corrosion loss was obtained. A data logger was utilized to keep track of the voltage change over time.

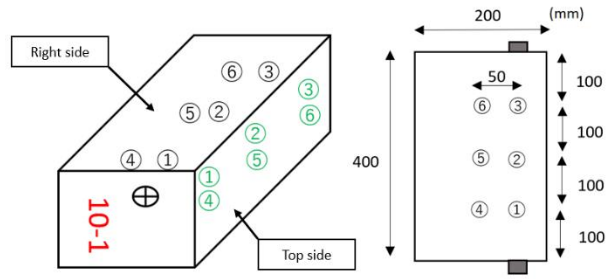



**Fig. 3.** Points for conductiong hammering test

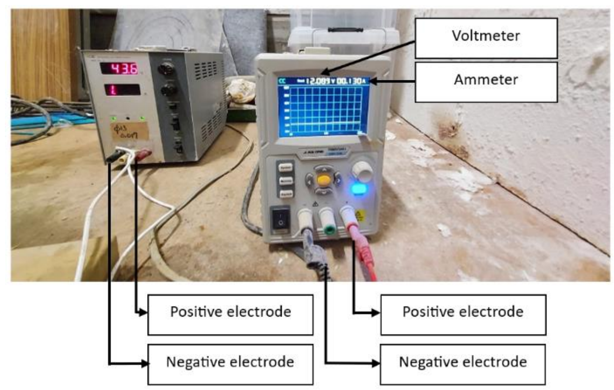



**Fig. 3.** DC power

2.2.3. Cutting specimens and immeresed with solution

Each specimen was crushed to enable the removal of the rebar following the completion of both tests. To decompose the corrosion on the iron, the rebar is weighed before being immersed in a diammonium hydrogen citrate solution. The rebar was then weighed again after 8 hours of immersion. This test attempts to ascertain the extent to which corrosion affects the weight of the rebar after the specimen has undergone the EACC method.

## 3. Result

3.1. Hammering test and EACC method

Specimen 20-1 and 40-1 would act as example of the result because it had the largest cracks among other.

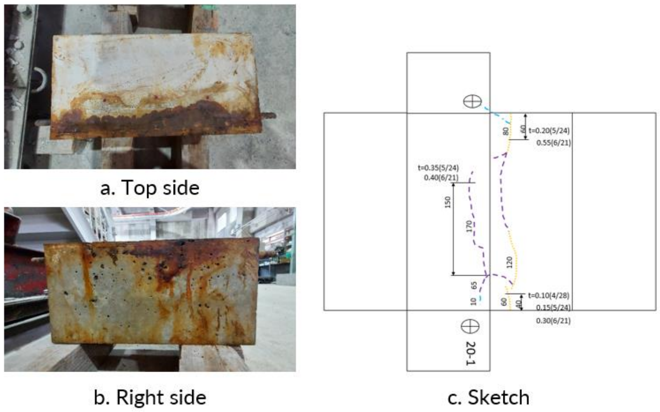



**Fig. 4.** Condition of specimen 20-1 after completed immersion

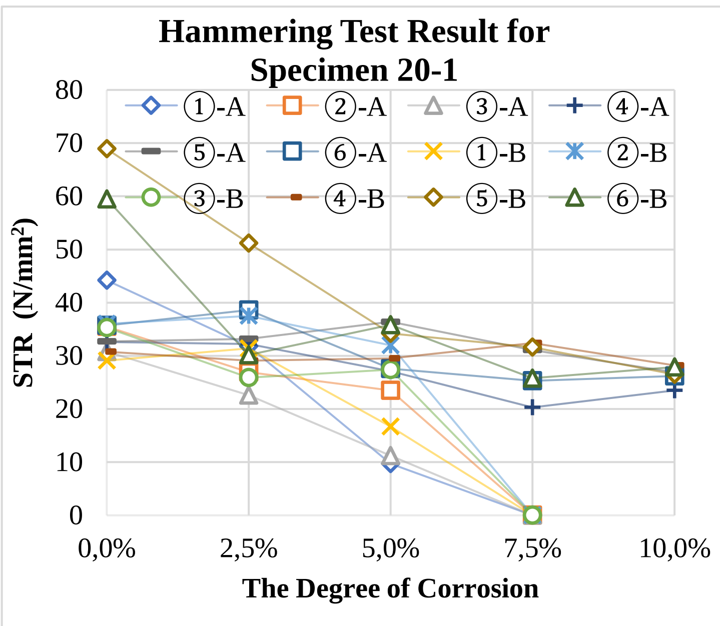



**Fig. 5.** Hammering test result of specimen 20-1

Fig 4. depicts the specimen 20-1's overall state. There were no apparent cracks after the initial soaking. Only after the second immersion did cracks emerge, which were noted on the specimen's top side by a yellow line. The cracks developed in lengths of 60, 80 and 120 mm. On the 80 mm line, the greatest crack was visible, with a width of 0,20 mm at the third immersion and growing to 0,55 mm at the fourth.

The biggest cracks were close to points 3-A and 2-B. The STR values at point 3-A were 22,60 N/mm$^2$ and 11,20 N/mm$^2$ before (degree of corrosion 2,5%) and after (degree of corrosion 5%) a crack appeared. Whereas, at point 2-B, the STR values were 32,00 N/mm$^2$ and 0,00 N/mm$^2$ respectively before (degree of corrosion 5%) and after (degree of corrosion 7,5%) the cracking occurred (Fig. 5.).

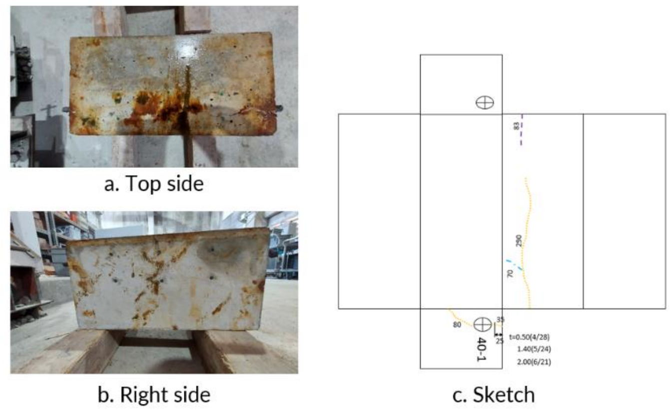



**Fig. 6.** Condition of specimen 40-1 after completed immersion

Concrete cracks are indicated by this STR value. The STR value is high when there are no cracks. The STR value began to drop as little cracks began to show. The STR value dramatically decreased as the crack grows in size.

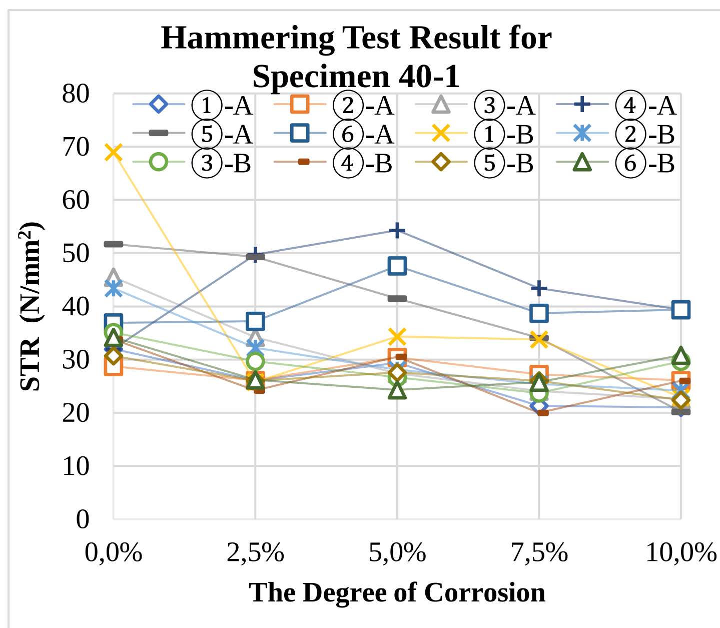



**Fig. 7.** Hammering test result of specimen 20-1

Fig. 6. shows the specimen 40-1's state. After the second immersion, the specimen's top and

front started to show signs of cracking. The specimen's front had the largest crack, which was 0,50 mm wide.
The crack extended from the rebar's front to the top of the specimen. It was near points 1-A and 1-B. As the third and fourth immersion processes proceeded, the crack grew larger to 1,40 mm and 2,00 mm, respectively.
When the immersion process was not conducted yet, the STR value for point 1-A and 1-B were 32,00 $N/mm^2$ and 69,00 $N/mm^2$. When the degree of corrosion reached 2,5%, the STR value decreased to 26,10 $N/mm^2$ and 25,80 $N/mm^2$. Point 1-B had the greatest deviation in STR values, measuring 43,20 $N/mm^2$ (Fig. 7.).

3.2. Cutting and immersion result
The starting weight of the rebar from specimen 20-1 was 331,459 grams. While the rebar from specimen 40-1 weighed 346,705 grams at first. The corrosion had degraded after immersion in diammonium hydrogen citrate solution, reducing the weight of the entire rebar.
Specimens 20-1 and 40-1 both had the final rebar weights of 318,163 grams and 334,147 grams, respectively. Therefore, the weight of the rebar differed by 13,296 grams from specimen 20-1. The weight of the rebar reduced by 4,01%. In contrast, the difference in the specimen 40-1 indicated a value of 12,558 grams. There was a 3,62% weight reduction in this rebar.

## 4. Conclusion

The following main conclusions are taken from the results:

a. Corrosion occurs when reinforcing steel within the concrete structure comes into contact with moisture and oxygen, leading to the formation of rust. As rust occupies a larger volume than the steel it forms from, it exerts expansive pressure on the surrounding concrete. This pressure causes the concrete to crack, resulting in visible cracks on the surface or within the structure.
b. Corrosion cracks can dramatically reduce the strength of concrete. Corrosion of the reinforcing steel reduces its ability to provide tensile strength to the concrete.
c. As the immersion operation is carried out, the hammering test results reveal a decreasing value. Corrosion reduces the value of STR as a concrete strength indicator and also the weight of the rebar, making it more vulnerable.
d. The larger the cover depth, the greater the minimum concrete strength attained. The average STR value difference is 17,53 N/mm2 (square). This value can be used as an indicator or a minimum limit to determine when cracks are most likely to occur. Thus, as a structure's strength degrades, it can be predicted by doing repairs before the structure's strength drops to 17,53 N/mm2.
e. The method of hitting with a hammer during the hammering test, as well as the human error aspect, can influence STR value.

## 5. References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