Effect of different curing conditions on the degradation process

E. Toyomura[1], K. Aoyama[2] and T. Iyoda[3]
[1]*Graduate Student, School of Engineering, Shibaura Institute of Technology, Tokyo, Japan*
[2]*Undergraduate Student, School of Engineering, Shibaura Institute of Technology, Tokyo, Japan*
[3]*Associate Professor, Shibaura Institute of Technology, Tokyo, Japan*
[1]*E-mail*: me11067@shibaura-it.ac.jp

ABSTRACT: This study examined the effect of different curing methods and periods on the concrete degradation process using various cement types and water-cement ratios. Concrete specimens were tested using the accelerated carbonation test and chloride penetration test. For chloride penetration, test conditions include cyclic wet and dry conditions to simulate ocean tidal exposure as well as submerged conditions. The results of the carbonation test showed that the carbonation rate depended on the cement type and water-cement ratio, but the carbonation depth at early ages was strongly affected by the curing conditions. Based on this result, the method for estimating degradation focused on the early age so that the carbonation rate could be understood considering the curing conditions. The results of the chloride penetration test showed that the chloride penetration depth at early ages for Portland cement was different under the test conditions. However, as time passed, the chloride penetration depth became similar despite the different curing conditions. For Portland blast furnace slag cement, there was almost no difference between curing conditions due to the high bound chloride capability.

1. INTRODUCTION

Carbonation or salt attack may lead to the corrosion of reinforcing steel in reinforced concrete, so it is necessary to estimate the degradation progress. Currently, the durability of concrete against carbonation and salt attack is verified based on the cement type and water-cement ratio in the Japan Standard Specification for Concrete Structures [1]. This method assumes that the degradation rates of the surface and internal concrete are the same, but in reality the surface concrete quality is strongly affected by curing conditions [2], and it is widely know that proper curing can greatly increase the resistance against degradation factors. However, following the Japan Standard Specification for Concrete Structures, curing conditions only depend on cement type and ambient temperature around the construction site, so when the water-cement ratio is varied the quality of surface and internal concrete may be different even under the same curing conditions. Therefore, it is important to understand the effect of curing conditions and mix proportions on the degradation process.

This research aims to include curing conditions in evaluating the durability of concrete structures, and tries to understand the influence of proper or improper curing conditions.

2. EXPERIMENTAL OUTLINE

2.1 Fabrication of specimen

Concrete specimens were prepared using two types of cement: one was ordinary Portland cement and the other Blast-furnace slag cement with 50% replacement of cement with blast furnace slag. The unit water was constant at 175 kg/m^3. Three water-cement ratios of 30%, 45%, 60% were used. **Table 1** shows the concrete mix proportions. Mixing and casting were carried out at 20°C. The specimen size was 100×100×40 mm prismatic beams.

2.2 Curing conditions

Specimens were demolded the day after casting. These were turned 90 degrees and four surfaces including the casting surface were sealed. **Figure 1** illustrates this process.

Table 2 shows the curing conditions. The curing methods were drying, sealing and in water. The curing periods were 1, 3, 5, 7 and 28 days. For water curing, only W/C=45% specimens were tested.

2.3 Test method

2.3.1 Method of the accelerated carbonation test

This test is based on JIS A 1153:2003. **Table 3** shows the test conditions. After curing accelerated carbonation test was carried out under the conditions as Table 3.Specimen was cut with 40mm each

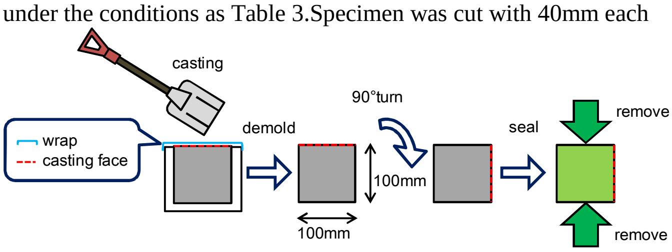

Figure 1 before curing

Table 2 Curing conditions

cement type	W/C (%)			curing method	curing period (day)				
OPC BB	30	45	60	drying	1	3	5	7	28
	30	45	60	sealing	1	3	5	7	28
		45		in water				7	28

Table 1 Mix proportions

cement type	W/C (%)	s/a (%)	W (kg/m^3)	OPC (kg/m^3)	BFS (kg/m^3)	S (kg/m^3)	G (kg/m^3)	SL (cm)	Air (%)
OPC	30	47	172	573	-	752	867	22.0	5.3
	45	50		382	-	881	900	13.0	4.5
	60	51		287	-	939	923	10.5	3.6
BB	30	46	172	287	287	727	872	24.0	5.0
	45	49		191	191	856	911	10.5	4.5
	60	50		143	143	916	936	14.0	4.8

Table 3 Test conditions

test method	condition	test age (week)
carbonation	temperature 20±3℃	1 2 3 4 6 8 10 15
	humibity 60±6%	
	CO_2 5±0.3%	
salt water	temperature 20±3℃	
	salt water 3%	

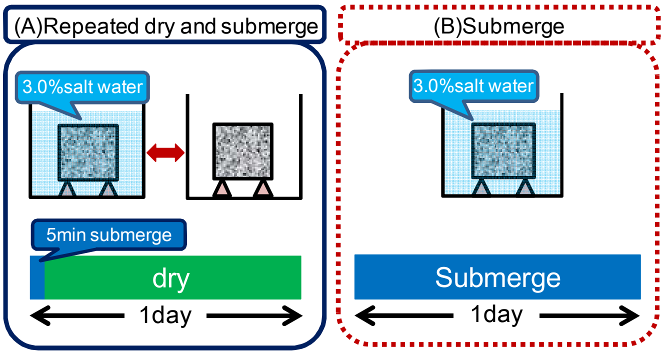

Figure 2 Method of supplying salt water

testing ages. Then it was sprayed with phenolphthalein solution on cross-sections. Carbonation depth was measured following JIS A 1152:2003.

2.3.2 Method of supplying salt water

The test conditions for supplying salt water are also shown in **Table 3**, and Figure 2 shows the method for supplying salt water. In this research, in order to vary the supply of salt water, drying and submerging test and submerging test were repeated. One cycle of repeated drying and submerging test was drying after 5 minutes of salt water submersion. The reason is to reduce effect of re-hydration on the concrete. Submerging test involved dipping the specimen for the entire time period. Fracture method, age and measurement of depth were the same as **2.3.1**, but silver nitrate reagent (0.1mol/l) was used on the fracture cross section.

3. RESULT AND DISCUSSIONS

3.1 Accelerated carbonation test

3.1.1 Effect of curing method on carbonation depth

Figure 3 shows the relationship between each cement type and carbonation depth for water-cement ratio 45%. The curing methods were dry, sealed and water, and the period was 7 days. Carbonation depth increases in the order of drying, sealed and water. In particular, the difference between dry and sealed is large. However, for each cement type, the slope (carbonation rate) is similar regardless of curing method. The cause of this, as illustrated in **Figure 4**, is that the degree of hydration is different by curing condition, so the state of the concrete surface is also different by curing condition. Areas that were insufficiently cured experienced faster progression of carbon dioxide [3]. Based on this reason it is believed that the carbonation depth of dry curing is the largest among the curing methods. Therefore, carbonation depth depends on the curing method and carbonation rate depends on the water-cement ratio.

3.1.2 Effect of curing period on carbonation depth

Figure 5 shows the relationship between each cement type and carbonation depth for water-cement ratio 45%. The curing periods were 1, 3, 5 and 7 days. The carbonation depth decreased as the curing period increases for each cement type. This is the same as

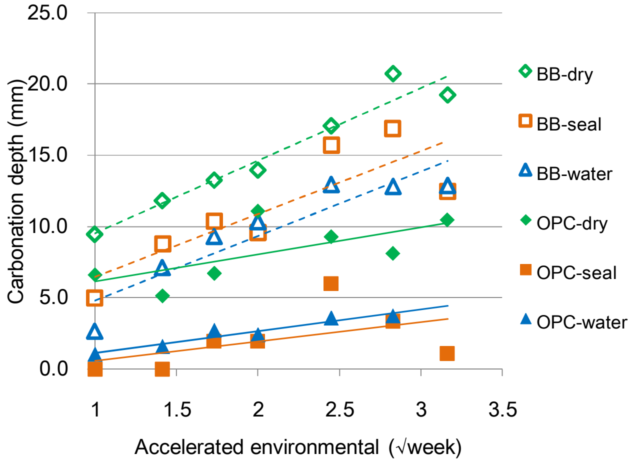

Figure 3 Relationship between carbonation depth and curing method

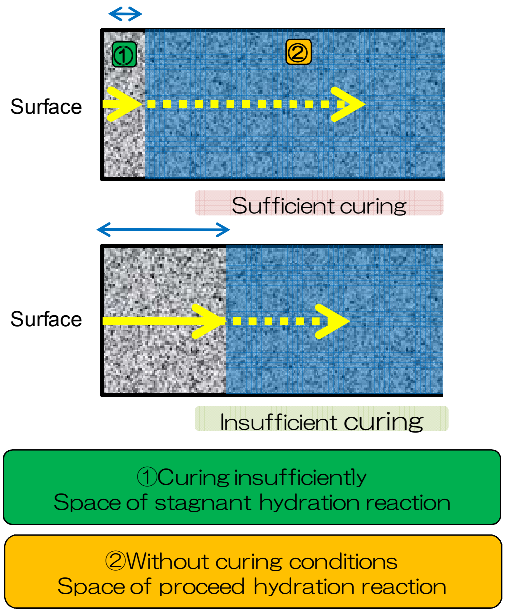

Figure 4 Different of hydration ratio on curing conditions

3.1.1, where insufficiently-cured areas were caused by the curing period, and the slope (carbonation rate) depended on the water-cement ratio

3.1.3 Effect of mix proportion on carbonation depth

Figure 6 shows the relationship between cement type and carbonation depth by water-cement ratio. Carbonation depth increased as water-cement ratio increased regardless of the cement type. The slope of BB (dashed line) is greater than OPC (solid line), and the slope increased with as the water-cement ratio increased.

3.1.4 Relationship between curing conditions and carbonation rate

The carbonation rate was more affected by water-cement ratio than by curing method or period, as discussed in **3.1.1** through **3.1.3**. On the other hand, carbonation depth is believed to greatly depend on curing conditions. Therefore we examine the following method for forecasting the progress of carbonation.

First, the carbonation rate equation was calculated using the standard curing of sealed for 28 day because, in this study, it is assumed that curing condition provided sufficient curing.

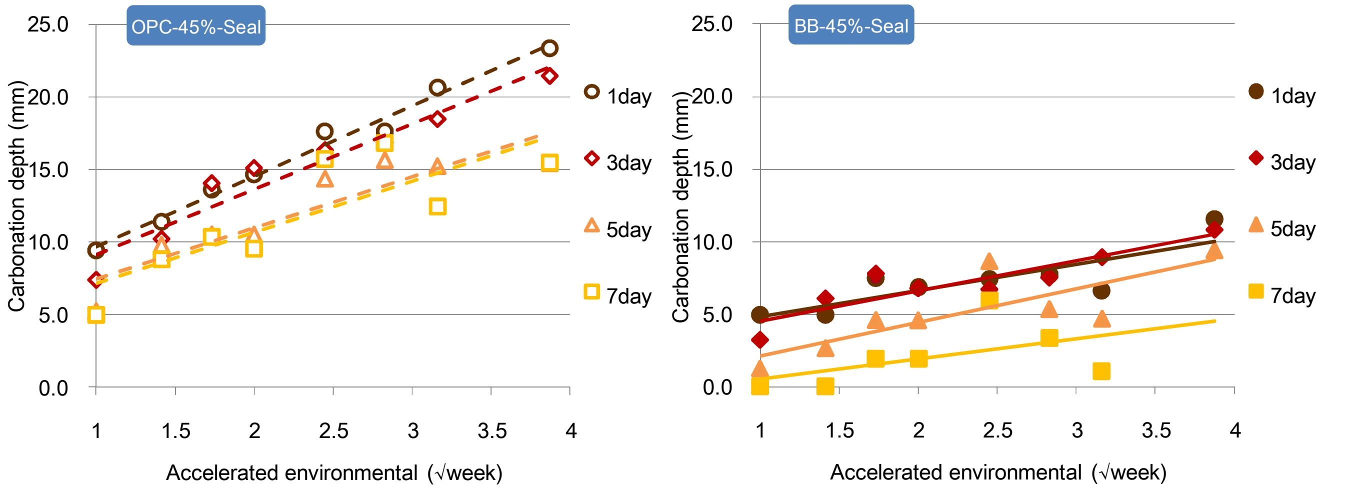

Figure 5 Relationship between carbonation depth and curing period (Left :OPC, Right :BB)

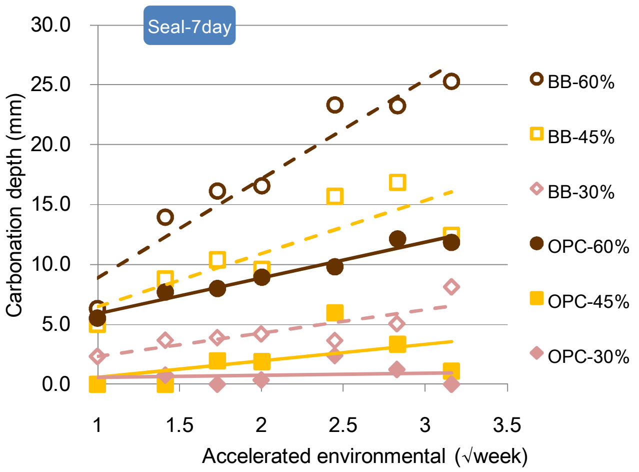

Figure 6 Relationship between carbonation depth and mix proportion

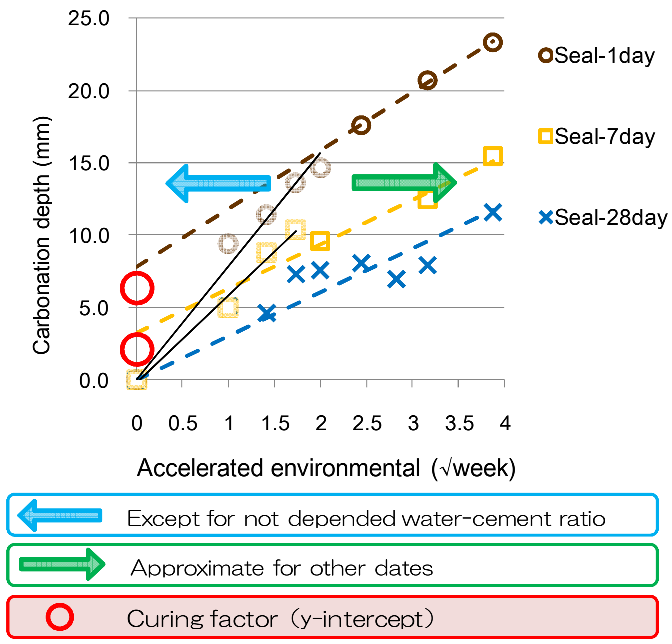

Figure 7 Method of calculating curing factor

Next, there are porous areas in surface of concrete due to different curing condition by lack of water. We considered that carbonation coefficient has same with standard curing condition and internal concrete excepting these areas of affected curing. So, it was approximated by using a coefficient of carbonation rate of standard curing using data excepting for the data in that area. The y-intercept was then defined as a curing factor which varied with curing conditions in carbonation ratio equation. **Figure 7** shows the method of calculating the curing factor, and this factor was added in Eq (1) to the carbonation depth ($\sqrt{}$ t law). This may allow the forecasting of carbonation depth considering curing conditions.

$$y=a\sqrt{t}+b \tag{1}$$

where, y: carbonation depth (mm), a: carbonation rate factor (mm/ $\sqrt{}$ year), t: carbonation age (year), b: curing factor (mm)

Figure 8 shows the relationship between the curing factor and curing period. The curing coefficient decreased with an increase in curing period regardless of the cement type.

The slope of BB (dashed line) is greater than OPC (solid line), and that slope increased with an increase in the water-cement ratio. For BB to have the same curing factor as OPC, 3 to 4 days of extra curing are necessary.

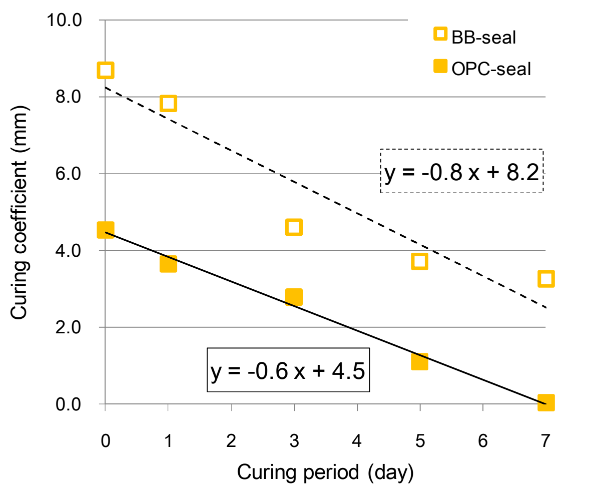

Figure 8 Relationship between curing factor and curing period

3.2 Salt water supply test

3.2.1 Effect of cement type on salt penetration depth

Figure 9 shows the result for repeated drying and submersion test (A) and submersion test (B) as the relationship between salt penetration depth and cement type for 7 days of sealed curing. The salt penetration depth of OPC differed depending on the method of salt water supply. The salt penetration depth by submersion was greater than for the dry and submersion test, possibly due to the difference in volume of salt provided. On the other hand, the salt penetration depth for BB did not differ by test condition, so it may be considered that BB possesses greater immobilization capability against intrusion regardless of environment.

3.2.2 Effect of curing method salt penetration depth

Figures 10 and **11** show the relationship between salt penetration depth and curing method for 7 days curing of OPC and BB. The salt penetration depth of OPC decreases in order of dry curing, sealed and water when salt water was provided for one week. For submersion test, sealed had the smallest depth 2 weeks later, and the decreasing order became sealed, water and dry by 13 weeks. For the repeated dry and submersion test, the intrusion depth in descending order was dry, sealed, and water for the whole period. In submerge condition, the depth of penetrated chloride ion on drying curing condition was smaller than it on sealed curing condition. The results for BB were different by curing condition at early time points, but the difference in depth decreased and the penetration depth for all curing conditions and supply methods became similar by the 13th week.

3.2.3 Effect of curing period on salt penetration depth

Figure 12 shows the relationship between salt penetration depth and curing method for OPC. The salt penetration depth grew smaller as the sealed curing period increased, regardless of the method of salt water supply. This may be caused by an increase in the surface density of the concrete under sealed conditions. In concrete using BB, salt penetration depth was almost same regardless on different methods of supplying salt ion and curing conditions.

3.2.4 Assessment of curing effect

Table 4 shows the assessment values of the curing effect on each cement type on a scale of large, medium and low. Salt penetration depth in OPC was affected by curing method and period in both environments. On the other hand, salt penetration depth in BB was about the same in both environments. Therefore, BB is considered to be less affect by curing condition than OPC.

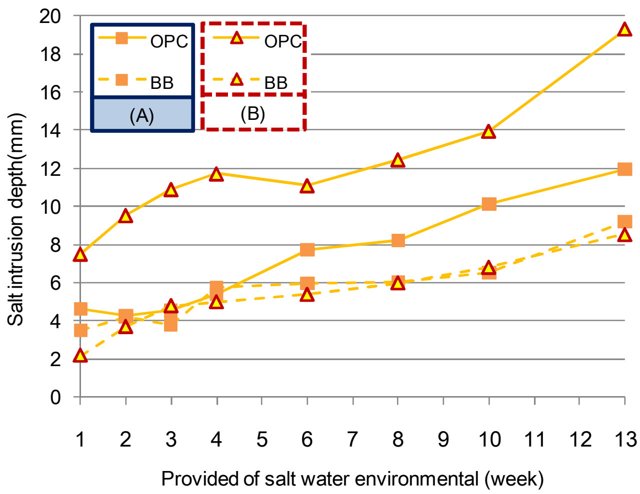

Figure 9 Relationship between salt penetration depth and cement type

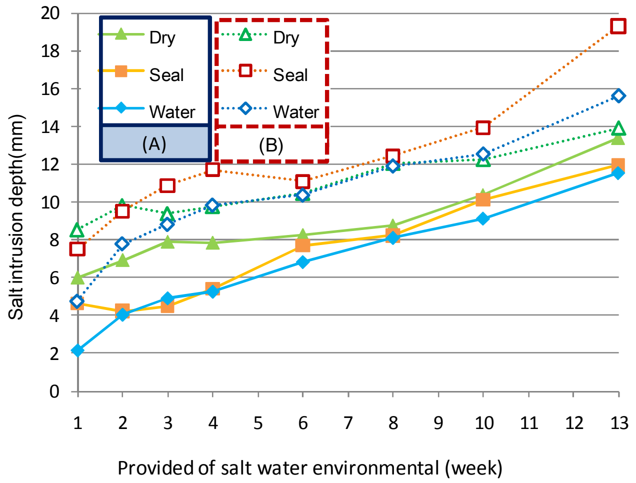

Figure 10 Relationship between salt penetration depth and curing method (N)

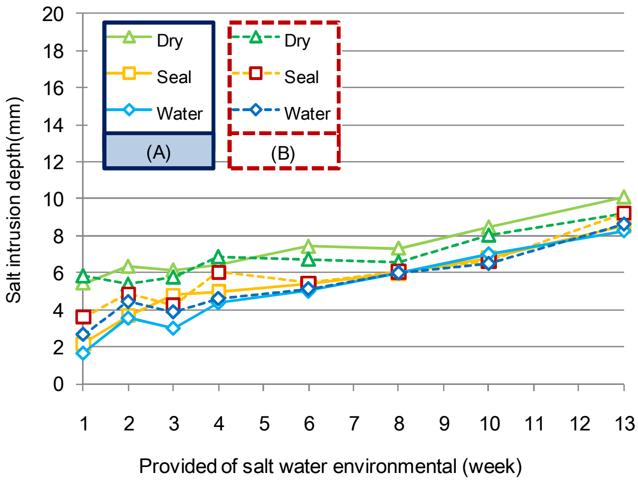

Figure 11 Relationship between salt penetration depth and curing method (BB)

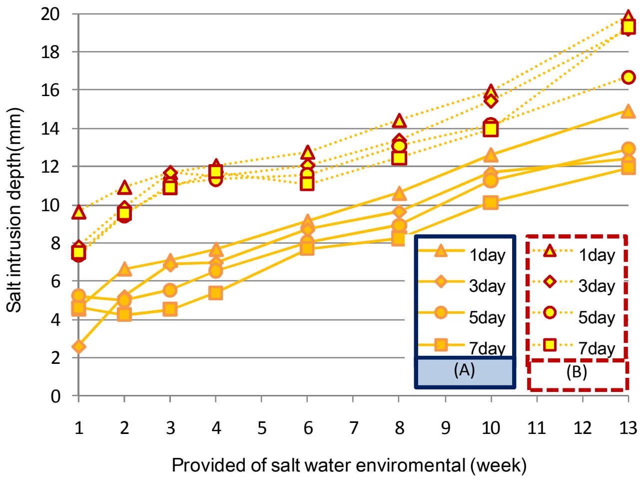

Figure 12 Relationship between salt penetration depth and curing method (N)

Table 4 Assessment for curing effect of concrete

Cement type	Curing conditio	(A) Early	(A) Long	(B) Early	(B) Long
OPC	method	○	△	○	×
	perood	○	○	○	○
BB	method	△	×	△	×
	period	×	×	×	×

○=Effective,△=Littele effective,×=No effective

4. CONCLUSION

This research aimed to evaluate the effect of different curing conditions on the degradation process. The conclusions of this study are as follows.

4.1 Accelerated carbonation test

1) The carbonation rates of each cement type were confirmed to be dependent on the water-cement ratio, but the degree of hydration of the surface concrete progresses different depending on the curing conditions, resulting in different carbonation depths.
2) When the y-intercept of the carbonation equation was defined as the curing factor, the possibility of curing conditions on the carbonation rate can be taken into account in forecasting carbonation depth.

4.2 Salt water supply test

1) Salt penetration depth in OPC was affected by curing method and period. Under the submerged environment, salt intrusion depth in OPC by sealed curing is smaller than dry curing.
2) Compared with OPC, BB is not affected by curing condition under salt water supply.

5. REFERENCES

[1] JSCE,Standard Specofocation for concrete Structures,2007
[2] Okazaki, S. , Yagi,T., Kishi, and T., Yajima, T .," Difference of sensitivity due to curing condition on strengeth and permeability" Cement Science and concrete Techonogy,No.60,2006 (*in Japanese*)
[3] Ishii,Y., Ring,S., Nakarai,K., and Taitou, H., "Effect of hydration behaviour and permeability on cement " JSCE Kanto,Ⅴ-058. (*in Japanese*)