CHAPTER VI

CONCLUSIONS

6.1 Summary:

The current study consists of two major parts. The first involves studying the effects of pozzolan (fly ash and rice husk ash) on the resistance of concrete structure to chloride ingress, which in turn the chloride diffusion coefficient. The second relates to the application of the proposed expressions of chloride diffusion coefficient. In order to fulfill these two tasks, the modified Nordtest NT Build 492 is employed. The reason why the test set up of Nordtest NT Build 492 has to modify is due to the occurring of leaking and short circuit. About total 123 concrete specimens are test at 28 days with different water binder ratio, percent of fly ash and percent of rice husk ash:

- Water binder ratio: 0.4, 0.5 and 0.6
- Ordinary Portland cement: 100%
- Partially replacement of Portland cement by fly ash: 15%, 25% and 35%
- Partially replacement of Portland cement by rice husk ash: 5%, 10% and 15%
- Ternary blend: 15% fly ash + 5% rice husk ash, 15% fly ash + 10% rice husk ash, 25% fly ash + 5% rice husk ash and 25% fly ash + 10% rice husk ash

In addition, four different expressions of chloride diffusion coefficient for each particular case are proposed as follows:

1) For ordinary Portland cement case:

$$D_{opc} = 25.28 - 71.98\times(w/b) + 172.5\times(w/b)^2$$

2) For case of adding fly ash:

$$D_{FA} = D_{opc} \times e^{\left(-3.02\times FA + 5.53\times FA^2 - 3.24\times FA^3\right)}$$

3) For case of adding rice husk ash:

$$D_{RHA} = D_{opc} \times e^{\left(-20.1\times RHA + 100.88\times RHA^2 - 127.54\times RHA^3\right)}$$

4) For case of triple blend:

$$D_{Triple} = D_{opc} \times k_{FA} \times k_{RHA} \times e^{\left(93.7\times RHA\times FA - 255.8\times RHA\times FA^2 - 550.6\times RHA^2\times FA + 1091.9\times RHA^2\times FA^2\right)}$$

Where:

D = Chloride diffusion coefficient.
w/b = Water binder ratio.
FA = Percent of partial replacement of Portland cement by fly ash.
RHA = Percent of partial replacement of Portland cement by rice husk ash.
k_{FA} = Factor that takes in account the influence of fly ash and sand content.

$$= e^{\left(-3.02\times FA + 5.53\times FA^2 - 3.24\times FA^3\right)}$$

k_{RHA} = Factor that takes in account the influence of rice husk ash and sand content.

$$= e^{\left(-20.1\times RHA + 100.88\times RHA^2 - 127.54\times RHA^3\right)}$$

Unintentionally, the factor k_{FA} and k_{RHA} also take in account the influence of sand content due to vary of sand content in mix proportion. However, because as it is said earlier, the objective of the current study is only about the impact of fly ash and rice husk ash, the effect of sand content in factor k_{FA} and k_{RHA} is not considered.

Finally, two study cases of concrete structure in Thailand and Vietnam environment are investigated and the results are presented as follows:

Case study	Water Binder ratio	Cover thickness (mm)	Rebar dimension (mm)	Initial time (year)	Propagation time (year)	Total service life (year)
Laem Phak Bia project, Thailand	0.42	50	32	43.6	1.66	45.30
Can Tho bridge, Vietnam	0.55	70	20	32.1	3.02	35.12

6.2 Conclusions:

Undoubtedly, chloride diffusion coefficient is the most important characteristic determining the long term durability of concrete exposed to sea water, especially to the chloride ingress. This coefficient strongly depends on water binder ratio. The smaller water binder ratio is, the lower chloride diffusion coefficient is, therefore the higher chloride resistance of concrete structure.

Furthermore, chloride diffusion coefficient also decreases with the large amount of partially replacement of Portland cement by pozzolan, especially by rice husk ash. The influence of rice husk ash on chloride resistance is very significant even though with small amount of rice husk ash, about 5 percent for instance. However, with large amount of rice husk ash, for example 15 percent in the current study, the chloride diffusion coefficient seems not to decrease much in compared with 10 percent, or sometimes even increase the chloride diffusion coefficient, for example with high water binder ratio 0.6. Therefore, it is recommended that 10 percent of replacement by rice husk ash is the optimal value.

Similarly, fly ash has huge impact on decrease chloride diffusion coefficient as well. For instance, increase fly ash from 15 percent to 25 percent will reduce chloride penetration about 25 percent. However, the influence of fly ash in compared with rice husk ash is not strong due to its low pozzolanic reactivity at the early age.

Like two previous cases, ternary blend have also significant effect on reducing chloride diffusion coefficient. With maximum 35 percent of replacement of fly ash and 15 percent of replacement of rice husk ash and with water binder ratio 0.4, the minimum chloride diffusion coefficient can be achieved. In addition, due to the flexibility in adjusting the amount of fly ash and rice husk ash in ternary blend in order to obtain the same chloride diffusion coefficient, different mix proportion can be introduced when consider another phenomenon besides chloride ingress. For example, when consider the freezing and thawing attack besides the chloride ingress, the amount of fly ash should be reduced as much as possible if the carbon content in fly ash is high. Similarly, the amount of fly ash should be adjusted at reasonable level when include the sulfate attack due to the high amount of aluminum oxide content. Conversely, if strength is also one of the important criteria, the amount of rice husk ash should not be more than 10 percent.

In addition, in ternary blend case, it can also concluded that at the early age 28 days, the decrease of chloride diffusion coefficient is only due to the effect of rice husk ash and fly ash has no significant influence. However, at the later age 91 days for instance, both fly ash and rice husk ash affect the reduce of chloride diffusion coefficient.

Regarding to the proposed expressions, we should pay attention when applying the expression in fly ash case with high water binder ratio of 0.6 and high partially replaced amount of fly ash of up to 25% and 35%. And in ternary blend case, we should also be careful when using the expression with high water binder ratio of 0.6.

Finally, from the results of application of proposed expression of chloride diffusion coefficient for two case studies in Thailand and Vietnam, obviously the local marine environment, particularly the chloride concentration in sea water has significant influence on the service life of concrete structures. Generally speaking, concrete structures submerged in Vietnam marine environment has the shorter service life than that with the same design properties submerged in Thailand marine environment due to the higher chloride concentration in sea water.

6.3 Limitations:

Due to the time restraint of the current work and the complicated mechanism of chloride diffusion process, there are some limitations in the proposed expressions as well as their application.

First of all, the current experiment is conducted only at the early age 28 days which does not show the effect of fly ash on chloride diffusion coefficient significantly.

Secondly, the chloride binding isotherm is skipped which in turn ignoring the cement content parameter.

Thirdly, the proposed expressions of chloride diffusion coefficient for pozzolan case are only applied with the case of partially replacement of Portland cement by equivalent mass of pozzolan (fly ash and rice husk in the current study), not the case of adding pozzolan to Portland cement.

Next, unintentionally, the factor k_{FA} and k_{RHA} also take in account the influence of sand content due to vary of sand content in mix proportion. However, because as it is said earlier, the objective of the current study is only about the impact of fly ash, the effect of sand content in factor k_{FA} will not be considered and investigated in the proposed expressions of chloride diffusion coefficient.

Finally, regarding the application, the proposed expressions of chloride diffusion coefficient is only valid for concrete structure submerged in marine environment. If the structure is investigated in the other zone, the chloride diffusion coefficient may be lower than in submerged zone because in completely saturated condition, the chloride ions can move easier and faster than in unsaturated condition. Therefore, in that case, an adjust factor is required.

6.4 Recommendations:

Based on the application of the proposed expressions of chloride diffusion coefficient, some recommendations can be drawn out for a certain concrete structures in local environment. First of all, if the service life of a certain concrete structures submerged completely in Thailand marine environment is expected 50 years, the water binder ratio should not be more than 0.41 with the cover thickness 50 mm and without partially replacement by pozzolan. Similarly, the water binder ratio should not be more than 0.38 for a certain concrete structure with the same design properties submerged in Vietnam marine environment.

In addition, because the current work only investigated the effect of fly ash and rice husk ash on chloride diffusion coefficient at the early age 28 days, it is not sufficient for consider the application of the proposed expressions in long term, for example after 91 days. Therefore, another study conducted with the same approach but after 91 days is necessary in order to fulfill the whole application of proposed expressions of chloride diffusion coefficient in practice.

Finally, due to the limitations described earlier, the proposed expressions of chloride diffusion coefficient as well as the application need more developments in the future, particularly taking in account the chloride binding isotherm or the cement content. Moreover, the current study also recommends a separate investigation of sand content and percent of partial replacement of ordinary Portland cement by pozzolan in proposed expressions of chloride diffusion coefficient. Furthermore, chloride ingress governed by the diffusion process is a complex phenomenon which is related to many parameters. It means that more parameters such as humidity, the volume and shape of aggregate, the temperature or the execution of concrete structure should be considered in order to understand fully about the chloride diffusion mechanism and to achieve the complete expression for predicting chloride diffusion coefficient.