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# Effects of Elevated Temperature on Mechanical Properties of Steel Reinforcement Incorporating Threaded Mechanical Couplers

**Jongchai Jaitrong[1*], Chanachai Thongchom[1*], Boonsap Witchayangkoon[1]**

[1] *Department of Civil Engineering, Thammasat School of Engineering, Thammasat University, THAILAND.*
**Corresponding Author (Email: tchanach@ engr.tu.ac.th).*

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## Abstract

This paper presents an experimental study of the effects of the temperatures on the mechanical properties of hot-rolled steel reinforcement incorporating threaded mechanical couplers which are spliced with a parallel threaded coupling system. The experiment is conducted with a hot-rolled deformed bar with a diameter of 25mm, a quality class of SD40. The temperature is set to be at room temperature 500°C, 700°C, and 900°C with a heated duration of 120 minutes. The tensile loading is applied with a displacement rate of 4mm/min until failure. However, the results of this experiment are in the terms of yield strength and tensile strength. The result clearly shows that the mechanical properties change initially for the temperature of 500°C. Yield strength and tensile strength increased as the temperature reached 500°C, while they decreased with the increasing temperature to 700 and 900°C. Moreover, the comparison of the current experiment to those previous studies is provided.

**Discipline**: Civil Engineering.



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## 1 Introduction

Conflagrations are now a common occurrence that causes damage to build structures and result in severe loss of life and property (NFPA, 2020). Most reinforced concrete structures were not constructed or designed to withstand rising temperatures such as conflagration. For this reason, it is essential to investigate the structures' behavior under high-temperature conditions. Since the structure undergoes a rapid increase in temperature at the steel coupler which is the structure's weak point and the reinforcement at the steel coupler is insufficient, the primary structure such as beams and columns will generally be damaged, resulting in a reduction in strength and leading the structure to collapse.

In the traditional construction of reinforced concrete structures, the splicing of reinforced steel is widely employed for columns and beams. The reinforcement in concrete cannot be strengthened throughout the entire length of the structure due to the factory's manufactured restricted length of the reinforced steel. In comparison to lapped splice, splicing with a mechanical coupler is presently a more effective solution for reinforced concrete structures. This splicing method will lessen the amount of reinforcement steel needed (Eksin et al., 2022) and the density of reinforcement steel at the splicing site which reduces the construction costs compared to the lapped splice method (Hulshizer et. al., 1994). The reinforcing steel and mechanical coupler in reinforced concrete material such as beams and columns need to contact with high temperatures since a reinforced concrete structure accidentally experiences conflagration and the building's components directly into contact with fire. In the design of fire-resistant reinforced concrete structures, concrete is utilized as an insulator for the reinforcing steel with a sufficient covering distance to prevent the reinforcing steel from reaching the critical temperatures of 500°C (Unluoglu et. al., 2007). On the other hand, since the covering distance is inadequate the opportunity that the reinforced steel will be indirectly contacted with the fire is completely increased which affected the reinforced steel's strength and ductility. Continuous combustion might cause spalling in the damaged reinforced concrete structures due to the expansion of the concrete material and the vapor pressure inside the concrete causing the eruption of the concrete surface. Thus, the resisting temperature ability of the concrete is reduced. The effects of spalling will immediately expose the reinforced steel to fire which reduces the overall strength of the reinforced steel (Smith et. al., 1981). Therefore, the analysis of temperature effects on mechanical coupler behavior is critical for understanding the performance of reinforced steel splices with mechanical couplers in high-temperature situations.

In this paper, the effect of the temperature on the mechanical properties of reinforced steel splicing with a mechanical coupler under tensile strength after heating is investigated. The experiment is conducted with the following equipment including the hot rolled deformed bar with a diameter of 25 mm., quality class of SD40 and the parallel thread mechanical splicing (PTC). Moreover, the temperature is set to be at room temperature 500˚C, 700˚C and 900˚C with a heated duration of 120 minutes. The purpose of this paper is to examine the mechanical properties including 1.) Tensile yield strength, 2.) Ultimate tensile strength. The results of the current investigation are compared with the reinforced steel model with no splices after heating which was proposed by (Tao et. al. 2015).

## 2 Materials and Methods

### 2.1 Materials

This experiment employed a parallel thread mechanical splicing )PTC) with a diameter of 39mm. and a length of 66mm. for a spliced with a deformed bar with a diameter of 25mm, quality class of SD40, and tensile yield strength specified of 4,000 kg/cm$^2$ (TIS., 2016) as shown in Figure 1. The design and manufacture are approved by the national standard ISO 9001 and follows the requirement of ACI 318, IBC 2006, BS 8110, Eurocode 2, DIN 1045, CalTrans, ASME sec lll Div2 which classify as the mechanical coupler division 2 (Dextra Group-Bartec, 2017). The experimental testing is performed separately with the considered temperature of room temperature, 500$^\circ$C, 700$^\circ$C and 900$^\circ$C. This experiment utilized 3 samples for each temperature, over all of 12 samples with a sample length of 1 meter.

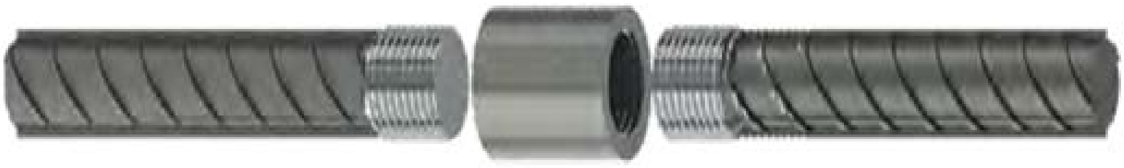

**Figure 1**: Parallel thread mechanical splicing (PTC). (Dextra Group-Bartec, 2017)

### 2.2 Equipment

The experiment furnace is a closed-system device that heated the test sample. This furnace can control the temperature by increasing the rate of temperature in terms of degree celsius per minute with a maximum rate of 20°C/min, a maximum temperature of 1,000°C and a heated duration as the researcher required. The furnace's outer part has a dimension of 530 x530 x 300mm (width x length x height) while the furnace's inner part has a dimension of 200 x 200 x 200mm with a top and bottom hole which has a diameter of 50mm as seen in Figure 2.

**Figure 2**: The experimental furnace.

## 2.3 Methods

Prepare and install the sample in the experiment furnace to heat the sample at the rate of 20°C/min until it reaches the considered temperature (Hibbeler, 2018). Then remain the temperature constant for 120 minutes. As a consequence, let the sample rest to cooling down until room temperature of 25°C (Virendra et. al., 2013) as shown in Figure 3. Testing the sample with the Universal Testing Machine (UTM), by employing the Extensometer as a stress gauge during the tensile test. The Extensometer is placed in a specific location as shown in Figures 4 and 5 and controlled the applied load with the displacement rate of 4mm/mins until failure. Therefore, the mechanical properties of reinforced steel splicing with parallel thread mechanical splicing consisting of tensile yield strength and ultimate tensile strength are examined. The failure surface and mechanism are recorded along with the comparison of the mechanical properties of reinforced steel splicing with parallel thread mechanical splicing to the reinforced steel model with no splices after heating which was proposed by Tao et. al. (2015).

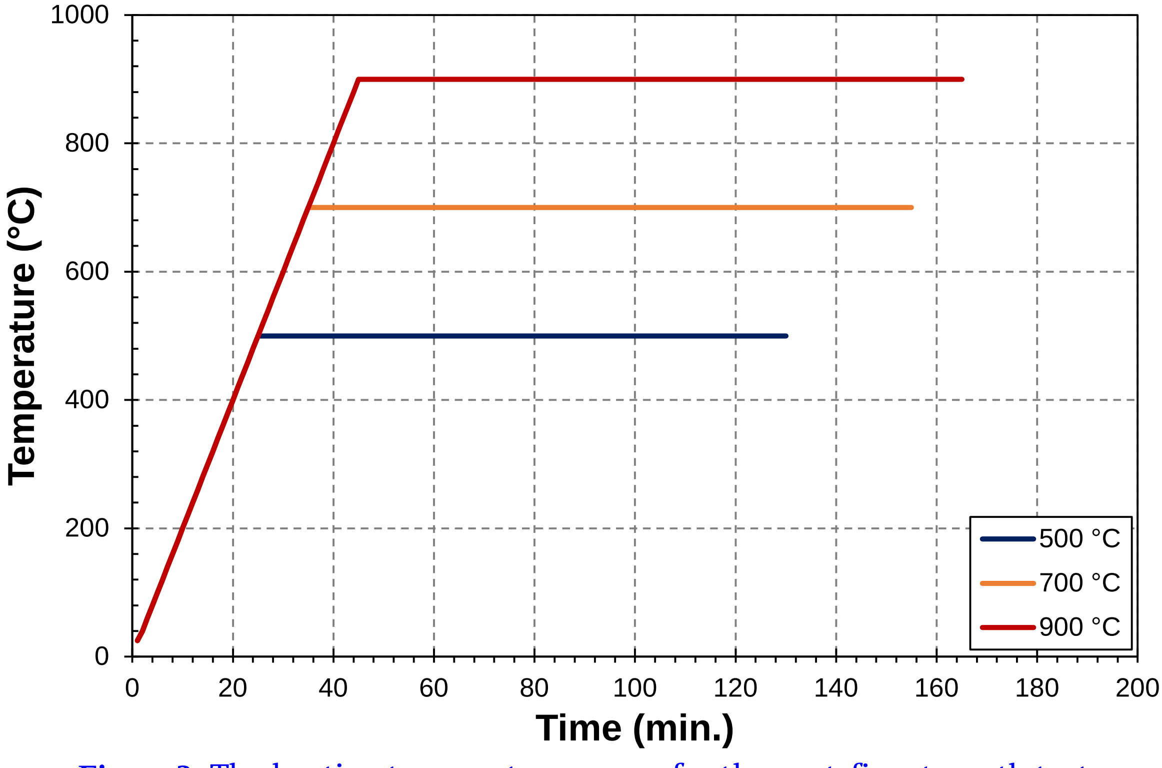


**Figure 3**: The heating temperature curves for the post-fire strength test.

**Figure 4**: Monotonic tensile strength testing.

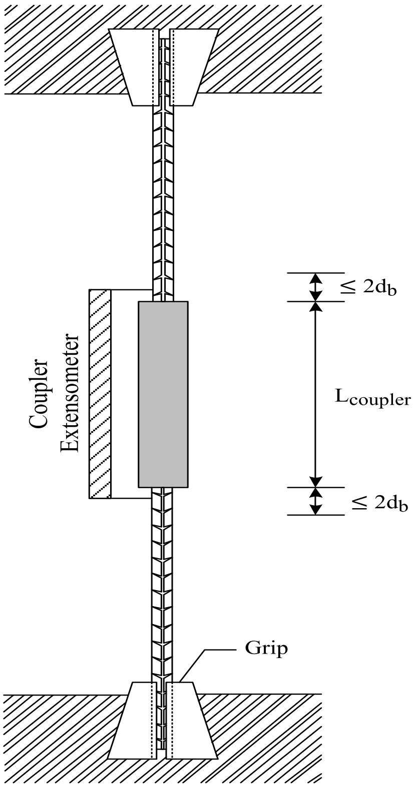


**Figure 5**: Detail of extensometer installation

# 3 Result and Discussion

The experimental results of the reinforced steel with parallel thread mechanical splicing )PTC( after heated at room temperature, 500°C, 700°C and 900°C and mechanical properties experiment under tension including the tensile yield strength and ultimate tensile strength. The comparison of the present study resulted in those proposed by Tao et. al. )2015( as well as the failure surface and mechanism is also described in this section as follows.

## 3.1 Yield Strength

According to Table 1, the reinforced steel or deformed bar samples DB25 with parallel thread mechanical splicing (PTC) after heated at room temperature, 500°C, 700°C and 900°C. The tensile yield strength results at room temperature are 472, 592, 356 and 306MPa, respectively. Note that, it can be defined as the ratio of tensile yield strength to room temperature of 1.000, 1.254, 0.754 and 0.647, respectively. The tensile yield strength of the reinforced steel with parallel thread mechanical splicing (PTC) that heated at 500°C is increased by 25.4%, decreased by 24.6% at 700°C and suddenly decreases to 35.3% at 900°C.

**Table 1**: Tensile yield strength

| T (°C) | fy (MPa) | | | | | fyT/fy,25°C |
|---|---|---|---|---|---|---|
| | S-1 | S-2 | S-3 | Mean | SD | |
| RT | 473 | 448 | 496 | 472 | ±23.97 | 1.000 |
| 500 | 619 | 589 | 569 | 592 | ±24.91 | 1.254 |
| 700 | 345 | 366 | 357 | 356 | ±10.54 | 0.754 |
| 900 | 303 | 323 | 306 | 306 | ±17.46 | 0.647 |

Figure 6 shows the relationship between temperature and the tensile yield strength ratio. Note that the tensile yield strength ratio refers to the ratio of tensile yield strength at various temperatures to the tensile yield strength at room temperature. In Figure 6, a linear decreasing relationship can be observed at the temperature of 700°C and still decreasing until it reached the temperature of 900°C. Nevertheless, at the temperature of 500°C the tensile yield strength of the reinforced steel with parallel thread mechanical splicing (PTC ) increases by 25.4% when compared to the reinforced steel DB25 with no splices model proposed by Tao et. al. )2015( in which there is only slight change in tensile yield strength.

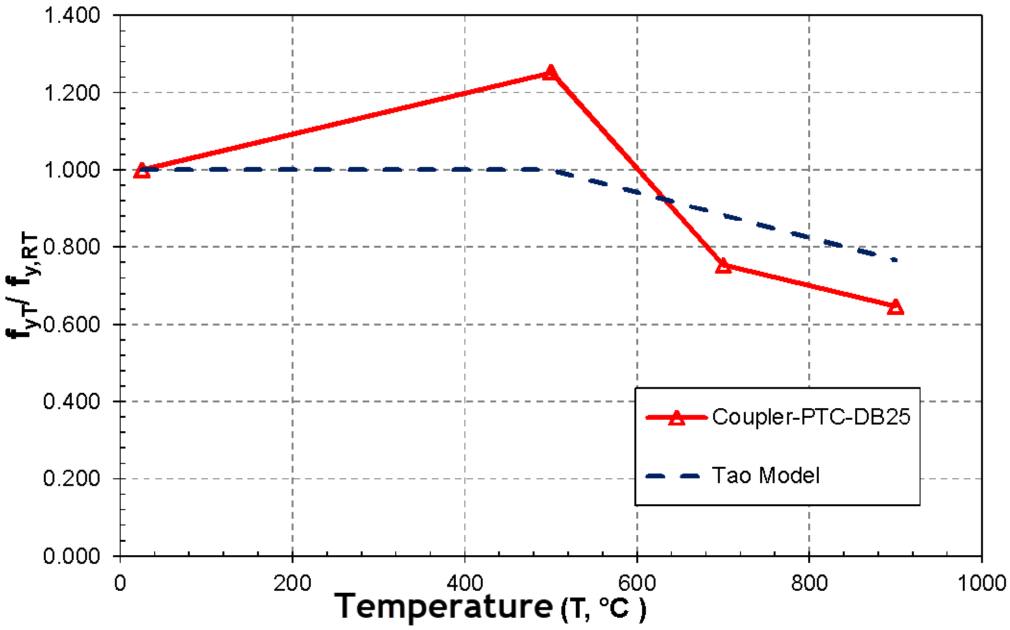


**Figure 6**: The effects of temperature on the tensile yield strength ratio

## 3.2 Tensile Strength

According to Table 2, the reinforced steel or deformed bar samples DB25 with parallel thread mechanical splicing (PTC) after heated at room temperature, 500°C, 700°C and 900°C. The ultimate tensile strength result has a value of 602, 608, 528 and 514MPa, respectively. Note that, it can define the ultimate tensile strength to the room temperature as the ultimate tensile strength ratio of 1.000, 1.010, 0.877 and 0.853 respectively. The ultimate tensile strength of the reinforced steel with parallel thread mechanical splicing (PTC) that was heated at 500°C has only slight changes while decreasing by 12.3% at 700°C and suddenly decreasing to 14.7% at 900°C.

**Table 2**: Ultimate tensile strength

| T (°C) | $f_u$ (MPa) | | | | | $f_{uT}/f_{u,25°C}$ |
|---|---|---|---|---|---|---|
| | S-1 | S-2 | S-3 | Mean | SD | |
| RT | 615 | 591 | 599 | 472 | ±12.50 | 1.000 |
| 500 | 629 | 596 | 598 | 592 | ±18.67 | 1.010 |
| 700 | 519 | 538 | 526 | 356 | ±9.42 | 0.877 |
| 900 | 526 | 522 | 492 | 306 | ±18.68 | 0.853 |

Figure 7 shows the relationship between the temperature to the ultimate tensile strength ratio. Note that the ultimate tensile strength ratio refers to the ratio of ultimate tensile strength at various temperatures to the ultimate tensile strength at room temperature. In Figure 7, a linear decreasing relationship can be observed at the temperature of 700°C in the cases of the reinforced steel with parallel thread mechanical splicing (PTC) as well as the reinforced steel with no splices. It is typically decreasing gradually until the temperature of 900 °C. Nevertheless, at the temperature of 500°C the ultimate tensile strength of the reinforced steel with parallel thread mechanical splicing (PTC) has only a slight change as well as the reinforced steel DB25 with no splices model proposed by Tao et al. (2015)

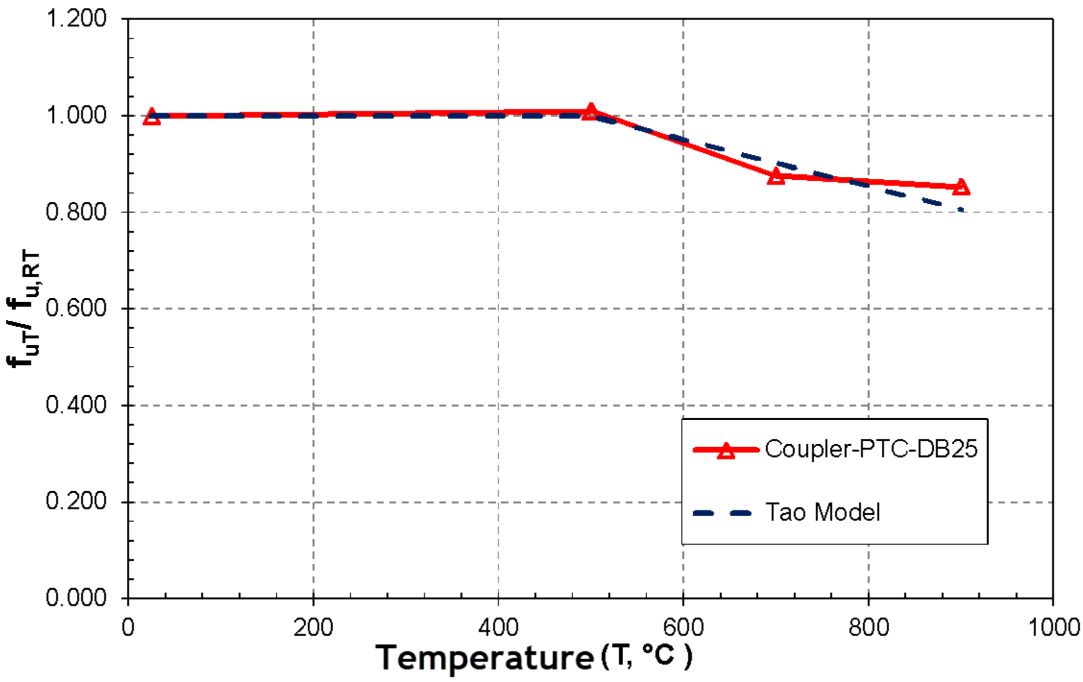


**Figure 7**: The effects of temperature on the ultimate tensile strength ratio

## 3.3 Texture and Failure

The characteristics of the samples surface of reinforced steel or deformed bar samples DB25 with parallel thread mechanical splicing )PTC( after heated at room temperature, 500°C, 700°C and 900°C are shown in Figure 8. Since the sample is heated at 500°C, a slight change can be observed for the reinforced steel while the darker surface can be observed for the mechanical coupler. However, the characteristics of the samples' surface have not changed much once the dark skin was peeled off. For the cases heated at 700°C, the darker surface can be observed for the reinforced steel while an umber color embedded in the mechanical coupler surface is founded. For the temperature of 900°C, it was found that the reinforced steel and the mechanical coupler are burnt and a white flaky peeling can be observed. Furthermore, the failure mechanism under tension at the temperature of 500°C and 900°C, an outer part failure of the mechanical coupler is observed. Whereas, the middle part failure of the mechanical coupler is founded at the temperature of 700°C as shown in Figure 9.


**Figure 8**: The reinforced steel with parallel thread mechanical splicing (PTC) failure surface after being heated with various temperature


**Figure 9**: The reinforced steel with parallel thread mechanical splicing (PTC) failure mechanism after being heated with various temperature

# 4 Conclusion

This study focused on temperature effects on the mechanical properties of the reinforced steel splicing with a mechanical coupler. The tensile yield strength of the reinforced steel samples DB25 with parallel thread mechanical splicing )PTC( initially varies after being heated at the temperature of 500°C. The tensile yield strength starts to increase and decrease at the temperature of 700°C and 900°C. In contrast, the ultimate tensile strength decreases as the temperature increases.

The comparison of the current study results including the tensile yield strength and the ultimate tensile strength to those proposed by Tao et. al. )2015( seems to have an excellent agreement. However, both tensile yield strength and ultimate tensile strength have a downward trend since the samples are heated at a temperature over 500°C. Therefore, the higher the temperature, the lower the tensile yield strength and the ultimate tensile strength.

# 5 Availability of Data and Material

All information is included in this report.

# 6 Acknowledgement

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# 7 References

Bangi, J.O., Maranga, S.M., Ng'ang'a, S.P., and Mutuli, S.M. (2014). Effect of heat on mechanical properties and microstructure of reinforcing steel bars made from scrap. *Journal of Research in Engineering*, 1(2), 20-26.

Dextra Group-Bartec (2017) "PTC (Parallel threaded coupler)" https://www.dextra-group.com/downloads-bim?folder=1.+Construction+solutions%2FRebar+splicing%-2F**b**artec.

Eksin, V., Thongchom, C., and Witchayangkoon, B. (2022). Experimental Investigation on Bond Behavior between Geopolymer Concrete and Steel Rebar. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13(10), 13A10B, 1-10. http://tuengr.com/V13/13A10B.pdf DOI: 10.14456/ITJEMAST.2022.191

Hibbeler R.C. (2018). *Mechanics of Materials*. Tenth Edition in SI Units. Pearson Education, Inc. United Kingdom.

Hulshizer, A.J., Ucciferro, J.J., and Gray, G.E. (1994). Mechanical reinforcement couplings meet demands of strength and constructi-bility. *Concrete International*, 16(12), 47-52.

Kumar, V., Sharma, U., Singh, B., & Bhargava, P. (2013). Effect of temperature on mechanical properties of pre-damaged steel reinforcing bars. *Construction And Building Materials*, *46*, 19-27. DOI: 10.1016/j.conbuildmat.2013.03.051

National Fire Protection Association – NFPA (2020), *Fire Loss in the United States During 2019*., USA, 2020.

Smith, C.I., Kirby, B.R., Lapwood, D.G., Cole, K.J., Cunningham, A.P., and Preston, R.R. (1981). The reinstatement of fire damaged steel framed structures. *Fire Safety Journal*, 4(1), 21-62

Tao, Z., Wang, X., & Uy, B. (2013). Stress-Strain Curves of Structural and Reinforcing Steels after Exposure to Elevated Temperatures. *Journal of Materials In Civil Engineering*, *25*(9), 1306-1316. DOI: 10.1061/(asce)mt.1943 5533.0000676

TIS. (2016), Steel Bars for Reinforced Concrete: Deformed Bars, TIS.24-2559 (2016), *Thai Industrial Standards Institute (TISI) under the Ministry of Industry*.

Unluoglu, E., Topcu, I.B., and Yalaman, B. (2007). Concrete cover effect on reinforced concrete bars exposed to high temperatures. *Construction and Building Materials*, 21(6), 1155-1160.

**Jongchai Jaitrong** is a Master's degree student at the Department of Civil Engineering, Faculty of Engineering, Thammasat University, Thailand. He got a Bachelor's degree in Civil Engineering from Thammasat University, Thailand. His research focuses on Building Structures in Civil Engineering.

**Dr.Chanachai Thongchom** is an Assistant Professor at the Department of Civil Engineering at Thammasat University, Thailand. He received his B.Eng. from Thammasat University with Honors. He got his PhD degree in Civil Engineering from Chulalongkorn University, Thailand. His research focuses on strengthening the concrete structure.

**Dr. Boonsap Witchayangkoon** is an Associate Professor of the Department of Civil Engineering at Thammasat University. He received his B.Eng. from King Mongkut's University of Technology Thonburi with Honors. He earned his PhD from The University of Maine, USA in Spatial Information Science & Engineering. Dr. Witchayangkoon's interests involve Applications of Emerging Technologies to Engineering.