CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This research study evaluated the importance of using hemp fiber for improving the mechanical strength of concrete, which also examined for both aggregate natural coarse aggregate (NCA) and recycled concrete aggregate (RCA). Also, replacing concrete aggregates by using waste polymer such as PET and crumb rubber blended with natural rubber latex to utilize as an alternative method to drive concrete industries to be environmentally friendly. The mechanical properties of hemp fiber reinforced concrete (HFRC) and waste polymer concrete were tested to follow the requirement of Department of Highway, Thailand to be used in as a sustainable pavement material. Both NCA and RCA had different behaviors during adding various hemp fiber percentage in 0.0% (control sample), 0.5%, 0.75%, and 1.0% with a constant water to cement ratio of 0.5. Whereas waste polymer concrete replaced the aggregate of PET and crumb rubber in 10, 20, and 30% mixing with natural rubber latex. To be considered as pavement material, two parameters such as compressive and flexural strength was a must to meet minimum requirement, thereafter, number of repetitions of HRFC samples to be lastly tested in flexural fatigue test in between stress ratio of 60%, 70%, and 80% of flexural strength to observe concrete behavior. The following significant findings was found and summarized from this study below:

I. For all samples, NCA produces a better quality compared to RCA in compressive strength, flexural strength, density, modulus of elasticity, compressive toughness, flexural toughness but fatigue test provides similar number of repetitions.

II. For control samples using NCA provides higher value of compressive, and strength compared to RCA, but RCA reduced a small amount of strength compared to NCA which showed the importance of controlling materials in grading of all aggregate. For both RCA and NCA material with addition higher percentage results in reduction in compressive strength but improves to obtain higher compressive strain which valuable in compressive toughness.

III. A proper amount of hemp fiber addition in concrete produces higher flexural strength with higher deformation of concrete, for example reinforced with 0.5% of volume for NCA and RCA. To obtain a higher deformation more percentage of hemp fiber should be presented but trade-off with reduction in flexural strength, for example reinforced with 0.75% and 1.00% of volume for NCA and RCA.

IV. Compressive toughness is examined in area under maximum resistance and illustrates that putting 0.5% of hemp fiber gives a higher energy absorption to samples while adding 0.75%, and 1.00% reduces compressive toughness compared to control samples for both RCA and NCA. Even the compressive strain increases but compressive strength largely reduces and brings this into lower toughness.

V. Flexural toughness is produced in the area between the flexural strength and deformation. A higher deformation and flexural strength for 0.5% hemp fiber sample turns out to be maximum for NCA and RCA. Whereas control sample produces minimum toughness due to the low flexibility causes to rapidly fail the sample. 0.75% and 1.00% assists flexural toughness to higher than control because of large yielding in deformation.

VI. According to higher energy absorption, HFRCs provides less cracking to samples in compressive and flexural which will solve cracking problem for traditional rigid pavement.

VII. Density of HFRC samples decrease in higher percentage adding of hemp fiber which are caused by lower specific gravity of hemp fiber involvement. In the same trending, modulus of elasticity decreases simultaneously according to reduction of compressive strength on stress-strain curve.

VIII. With the addition of NRL additive, the compressive strength of the NRL-modified concrete was lower than the normal concrete. At the age of 28 days, the compressive strength of NRL10WP, NRL20WP, and NRL30WP was about 8.3%, 15%, and 28.5% lower than that NRL-modified concrete. However, the 28-day compressive strength of NRL-modified concrete and NRL10WP was 34.25 MPa and 32.54 MPa and met the minimum compressive requirement (fc ≥ 32 MPa) for concrete pavement specified by DOH, Thailand.

IX. The flexural strength of NRL-modified concrete was approximately 3.3% higher than normal concrete. Similar to the compressive strength behavior, the flexural strength of NRL-modified concrete with PET and crumb rubber aggregate replacement decreased with increasing replacement ratios. However, the flexural strength of NRL10WP was found to meet the minimum flexural strength requirement ($f_f \geq 4.2$ MPa), for rigid pavement specified by DOH, Thailand. In terms of mechanical strength properties, it is confirmed that 10% of waste PET and crumb rubber aggregate replacement can be used in concrete mix for rigid pavement design.

X. Microstructural analysis indicated that the addition of NRL additive generated the film network to prevent the development of hydration products and resulted in com-pressive strength reduction. However, this film network acts as a bridge mechanism to enhance the adhesion or bonding between the aggregates in the concrete matrix, leading to improved flexural strength. PET and crumb rubber are hydrophobic and non-polar materials, hence increasing the amount of these materials in the concrete mix can affect their microstructure by creating weaker interfaces between aggregates and cement pasted. As such, the mechanical strength dropped. However, the NRL-modified concrete with PET and crumb rubber aggregate replacement can help the concrete's ability to absorb energy and improving its toughness and resistance to impact and dynamic loads.

XI. Optimum reinforcement percentage of hemp fiber is at 0.5% which exhibits a higher number of repetitions compared to control sample. Moreover, the relationship between deformation and number of cycles showed that less stress ratio delivers higher deformation which related to resistance of hemp fiber in concrete materials. Number of repetitions is the most important in pavement design parameter to decide for thickness of the pavement that can influence cost of pavement construction which HFRCs provided more than 5% better compared to traditional PCA 1984 curve.

XII. The research demonstrates that integrating waste PET and crumb rubber in concrete mix is a sustainable practice. The output of this research can be used as a guideline for pavement researchers, engineers, designers, and end-users understanding the crucial microstructural and macro-characteristics of NRL-modified concrete with waste aggregates and can adjust the mix design to meet the specification requirements of the concrete for rigid pavement applications.

5.2 Recommendation

Despite good results, there were many errors in testing along the way. To get the best and accuracy outcome of hemp fiber reinforced concrete, there are some suggestions as follow:

I. Sand, crushed stone, and RCA must be tested and meet the requirement of Department of Highway, Thailand or follow ASTM standards to know the material properties for mix design which could affect the strength of concrete.

II. Sieving coarse aggregates in an appropriate percentage mixing of sizes could produce an accurate slump flow and density of the concrete.

III. Hemp fiber must be treated with 6% of sodium hydroxide (NaoH) to activate alkali in concrete which cleans the impurity and breaks down bundles to small individual fiber that can produce a better bonding in concrete.

IV. Water reduction admixture plays an important role to maintain the flow of concrete which recommended to mix as normal concrete to obtain a good mixture and follow adding hemp fiber in the last stage.

V. Water to cement ratio less than 0.45 is not recommended according to water absorption in hemp fiber could affect the water reactions in normal concrete and resulted in lower slump less than requirement.

VI. During mixing, avoid mixing at temperature higher than 30 degrees Celsius which affects the flow of the concrete. In addition, during casting in the mold, 3 layers of compaction must be followed to guarantee distribution greatly of hemp fibers in the samples.

VII. Before using PET and crumb rubber in mixing, cleaning the aggregate is a must to extract the dusty soil and unwanted waste particles.

VIII. Rubber latex must know the sources and check the property before using in the concrete.