CHAPTER II
LITERATURE REVIEWS

2.1 Previous Studies on Recycled Concrete Aggregate (RCA)

The speedy increment of economic and social development results in an increasing tremendous number of needs in civil infrastructures. In the construction industry, there are two types of structure which are steel and concrete structure. Steel structure is not commonly used for normal structures because of its cost and difficulty of forming in shape that must be ordered from the manufacturer. In addition, steel components require hug truck for transportation which is the additional cost on it and the crane for lifting to assemble at construction site and need a professional labor to build, whereas concrete structure is globally used according to the price and the material that can be found all over the world. Similarly, concrete has advantages on casting into complexity shape, simple for transportation, compressive strength and especially cheaper than steel structure. Due to Behera et al. in 2014, 25 billion tons of concrete are manufactured worldwide. Concrete also has its own service life of approximately 50 years for reinforced concrete which means the unserviceable structures must be destroyed and disposed to the landfill site and resulted in not economically and environmentally sustainable. Moreover, extracting the natural coarse aggregate (NCA) from natural resources to utilize in concrete mixing causes the unbalance of ecological and generally pollutes the environment. Despite the convenience of concrete, there are waste management should be considered after out of life span. Therefore, waste concrete can be crushed to any size to reuse and namely as recycled concrete aggregate (RCA). The benefits of RCA are to lower in decreasing environmental pollution and require landfill. Instead of delivering NCA from explosive quarry, RCA can be found at cement plants and close to the city which can save transportation cost and the energy of crushing. According to Ponikiewski et al. in 2014, RCA has a problem with consistency which depends on the water to cement ratio and type of cement of the mixing. Correspondingly, RCA contains cement mortar attached to NCA which has high porosity and leads to higher water absorption compared to NCA.

2.2 Influence of Replacing RCA in Concrete as Coarse Aggregate

Safiuddin et al. in 2021 proposed a method to replace NCA with RCA in amount of 0, 30, 50, 70, and 100% of high workability of concrete and tested in compressive strength, split tensile strength, flexural strength, and modulus of elasticity to observe the behavior of sustainable concrete. The concrete mixing components have NCA from crushed granite stone and RCA from ready-mix plant as coarse aggregate with the maximum size of 20 mm, quartz river sand as fine aggregate, ordinary Portland cement with specific gravity of 3.12, tape water and a polycarboxylate based high-range water reducer (HRWR) of 1.06 specific gravity to ensure the workability. The gradation curve of coarse aggregate is shown in Figure 2.1 and the properties of coarse aggregate and fine aggregate in Table 2.1. The concrete was mixed in 3 differences water to cement ratios (0.50, 0.60, and 0.65) with the nixing proportion from Table 2.2 to observe the workability by using a rotary pan mixer and cast into 100 mm cubes for compression test, Ø 100 mm × 200 mm cylinder for split tensile test, and 100 mm × 100 mm × 200 mm prism for flexural strength test.

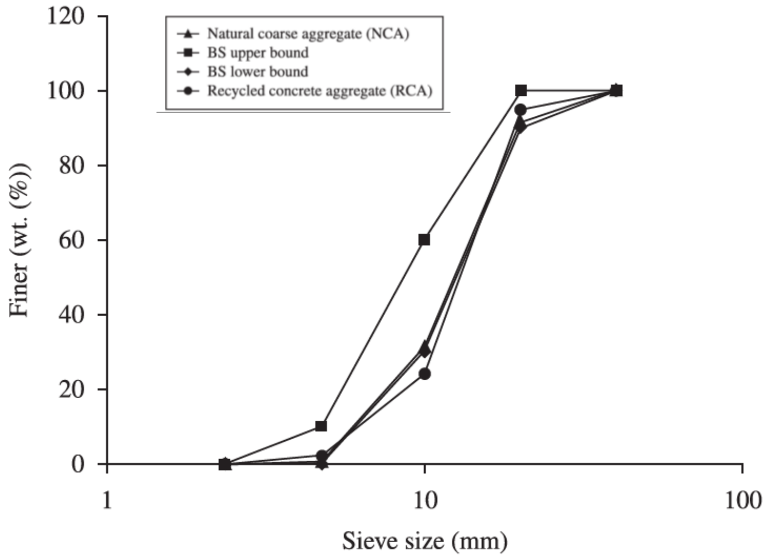

Figure 2.1 Gradation curve of natural coarse aggregate and recycled concrete aggregate (Safiuddin et al., 2011).

Table 2.1 Physical properties of fine and coarse aggregate (Safiuddin et al., 2021).

Physical Properties	RCA	NCA	FA
Maximum size aggregate (mm)	20	20	5
Fineness modulus	6.79	6.76	2.88
Bulk density (kg.m^{-3})	1250	1510	1620
Saturated surface dry specific gravity	2.53	2.62	2.69
Oven-dry based specific gravity	2.48	2.53	-
Open porosity (vol. (%))	5.03	1.55	-
Absorption (wt. (%))	2.03	0.60	1.32
Moisture content (wt. (%))	1.57	0.17	0.31
Angularity number	9.50	7.50	-
Aggregate impact value (wt. (%))	12.7	10.0	-

Table 2.2 Concrete mix proportions (Safiuddin et al., 2011).

Mix	NCA (kg.m^{-3})	RCA (%CA)	RCA (kg.m^{-3})	FA (kg.m^{-3})	OPC (kg.m^{-3})	W (kg.m^{-3})	HRWR (%C)
CRCA0	910	0	0	905	342	214	1.5
CRCA30	609	30	261	865	342	214	1.5
CRCA50	433	50	433	861	342	214	1.5
CRCA70	259	70	604	858	342	214	1.5
CRCA100	0	100	857	852	342	214	1.5

According to the test results in figure 2.2, the slump flow was reduced in a small amount by the percentage replacement respectively which can be maintained by using HRWR. Along with compressive strength from figure 2.3, at 7 and 28 days the strength was minor deducted but surprisingly for flexural strength had almost equally the strength at 100 percentage of replacement due to figure 2.4. Following with modulus of elasticity in figure 2.5, it had a significant reduction in substitution of RCA and similarly to flexural test, the splitting tensile test had a tiny decrease in 100 percentage by weight replacement in figure 2.6.

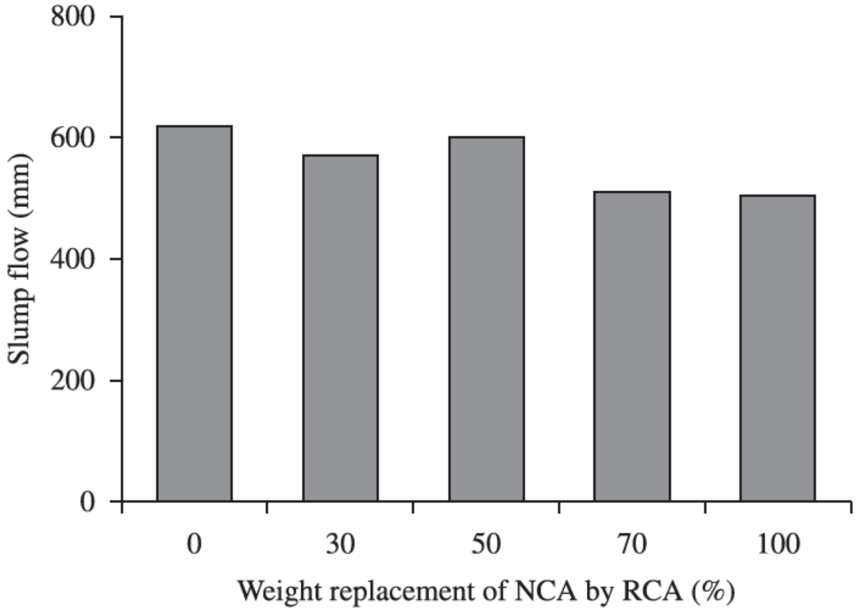

Figure 2.2 Replacement of RCA in concrete slump flow (Safiuddin et al., 2011).

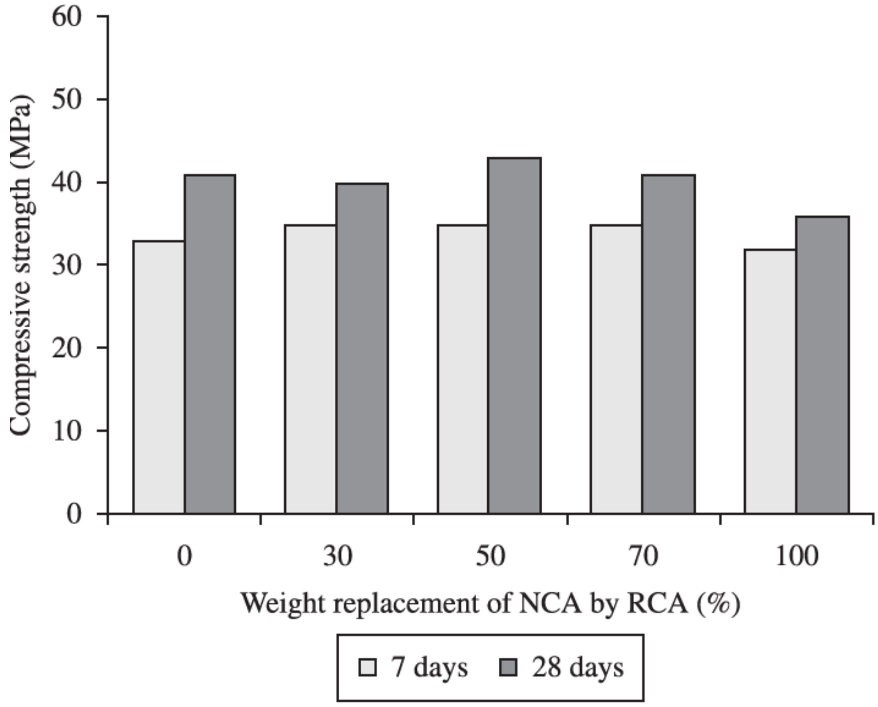

Figure 2.3 Replacement of RCA in compressive strength (Safiuddin et al., 2011).

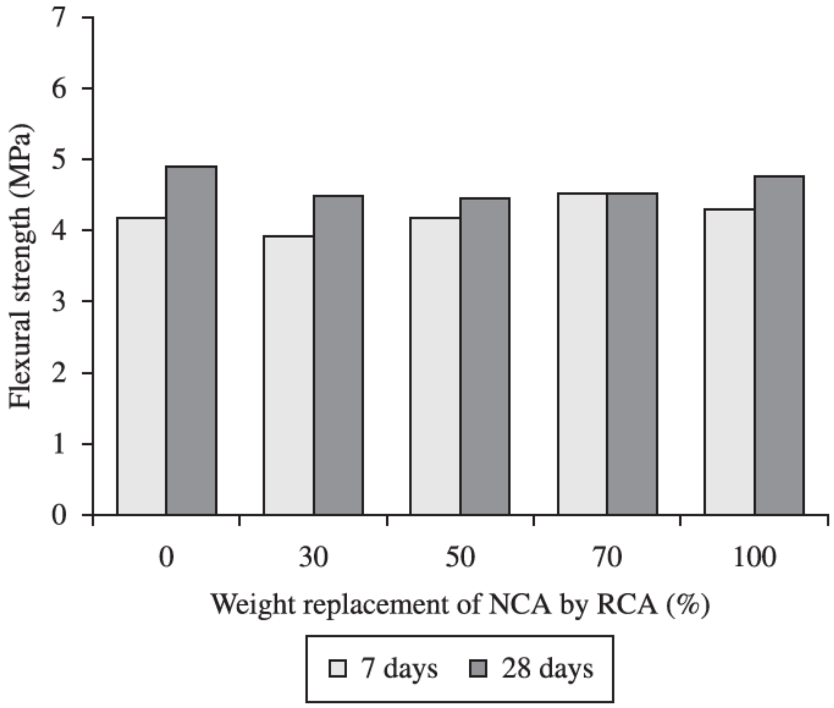

Figure 2.4 Replacement of RCA in flexural strength (Safiuddin et al., 2011).

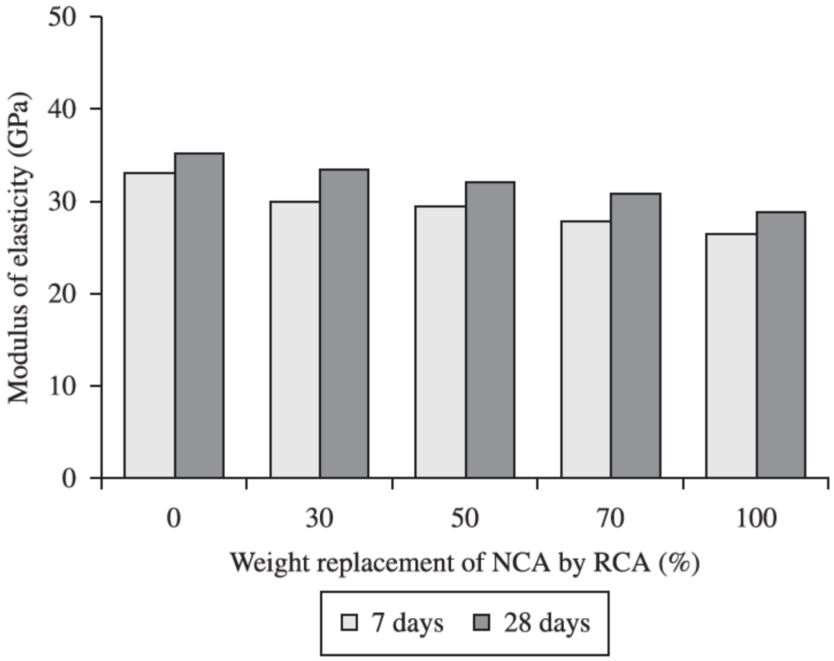

Figure 2.5 Replacement of RCA in modulus of elasticity (Safiuddin et al., 2011).

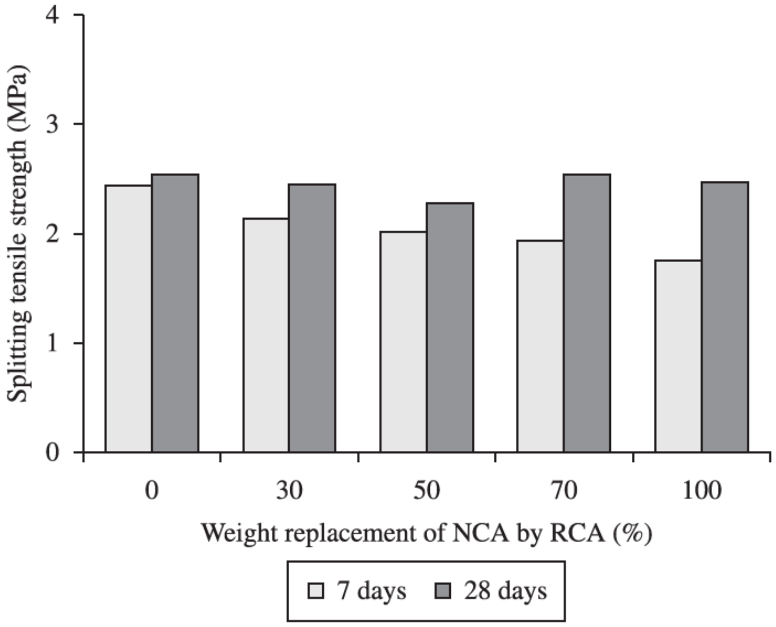

Figure 2.6 Replacement of RCA in splitting tensile strength (Safiuddin et al., 2011).

Therefore, RCA can be considered as an alternative material to replace NCA for concrete application as several studies has been investigated in the same result of reducing a minor amount of compressive strength, compressive strength, and split tensile strength (Nagataki et al., 2000; Shayan et al., 2003).

2.3 Hemp Fiber Treatment

Fiber reinforced concrete has been used in civil engineering for several years to improve the ductility and reduction of the volume of concrete. Synthetic fibers such as carbon, glass or aramid fiber are used in some applications because of the high cost. Of course, synthetic fibers provide higher tensile strength and modulus of elasticity but exchange with the energy consumption and environmental pollutions. Thus, the natural fibers such as hemp, jute and sisal have been a focus point for the alternative which several studies stated that natural fibers had low density, great tensile strength and modulus of elasticity according to cellulose contains and can be considered as reinforcer of polymeric matrix (Bledzki and Gassan, 1999). Due to affordable price and eco-friendly, the are some disadvantages that come with interaction of fiber surface to concrete matrix and the impurity attached to the surface. So, the treatment process has instigated which sodium hydroxide (NaOH) is found to be effective and cheap. NaOH has roles to wash the surface and improve the mechanical properties, modulus of elasticity and tensile strength (Sharifa and Ansell, 2004). To activate the alkaline treatment, 6% of NaOH solution was prepared and maintained at room temperature and saturated for 48 hours and cleaned with distill water then air-dry. The samples were investigated with scanning electron microscope (SEM) to see the surface of the fiber by 500 times zoom in from Poletanovic et al. in figure 2.7.

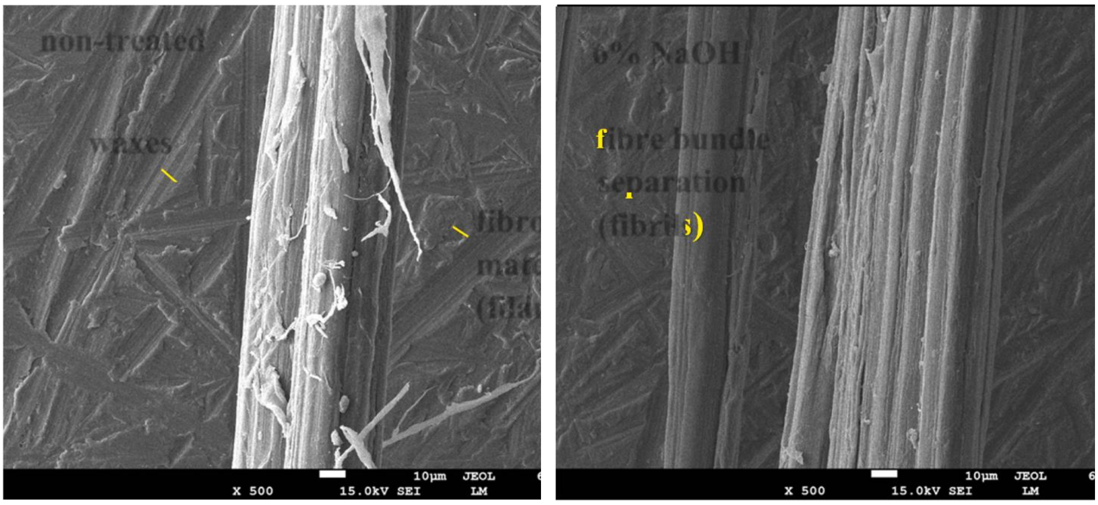

Figure 2.7 SEM of untreated hemp fiber and 6% NaOH treatment hemp fiber (Peletanovic et al. 2021).

Without treatment, the surface of hemp fiber attached with waxes and dusts which made the hemp fiber in form of smooth surface contact, whereas after treatment the waxes and filaments were removed. Thus, the hemp fiber was left without interruption and resulted remain with pure fiber.

2.4 Previous Studies on Hemp Fiber Reinforced Concrete

Different types of fibers such as steel, glass, natural and synthetic fibers have been used to study to reinforced with concrete in the last decades to improve the cracking performance on stress transferred (Quan and Stroeven, 2000; Akay and Tasdemir, 2012; Ponikiewski and Katzer, 2014; Su and Lin, 2017) but adding fibers to concrete resulted in effecting the compressive strength, flexural strength and mode of failure against its brittleness (Barros et al., 2005; Usman et al., 2020). Krishna and Rao in 2021 conducted an experiment by using polyester fiber reinforced concrete as a rigid pavement and resulted in improvement of compressive strength, flexural strength and splitting tensile strength by adding 0.3% fiber content and assisted to reduced 20 % of thickness of pavement.

Hemp concretes were interested by several researchers and studied to save natural resources. Lightweight hemp concrete was used in walls, slabs and plasters for timber buildings and repaired work in France since 1990 (Allin, 2005). Gencel et al. (2021) observed the behavior of hemp fibers reinforced with foam and fly ash which gave an increment of compressive strength when using higher foam content and for long term strength was improved when mixing with low foam content and 30% of fly ash. Furthermore, hemp fiber with 10 % of fly ash can strengthen the flexural strength of foam concrete. Comak et al. (2018) tested various length of short hemp fiber with different hemp fiber content for investigated the characteristic of cement-based mortar. In addition, mixing with 2-3% of 12 mm hemp fiber length improved compressive strength, flexural strength, and splitting tensile strength. The resulted was tested by Sedan et al.(2008) showed that treated hemp fiber with NaOH increased surface roughness and hemp FRC increase the flexural strength at acceptable amount and in contrast to modulus of elasticity that decreased. Another study case proposed by using 0.5% of hemp fiber content by weight of concrete and found that 25 % of flexural strength was improved compared to normal concrete (Ramadevi and Shri, 2004). However, Li et al. (2004) stated that at optimum hemp fiber content increased 4% of compressive strength, 9% of flexural strength, and 114 % of flexural toughness compared to normal concrete. Significantly, length of the hemp fiber did not have much effect to the concrete properties but alkali presented on hemp fiber produced good results for HFRC but exchanged with reduction of compressive strength and modulus of elasticity where modulus of rupture and tensile strength were increased notably (Awwad et al., 2012; Awwad et al., 2013).

2.5 Knowledge Gap and Proposed Research on Hemp Fiber

Sedan et al. (2018) stated that during testing the flexural strength, fiber pullout was the problems which effected the load transferred process. Therefore, previous studies revealed that the difference of HFRC strength were based on mix design.

Reinforced concrete with hemp fiber can result in ductile behavior and produce great energy absorption but applications of HFRC have been applied to beam and column which required modulus of elasticity, compressive strength, and flexural strength. One of the most important infrastructures like pavement requires to observe a long-term post-crack behavior which relates to flexural strength, flexural toughness, and toughness index that have positive contribution to have a long service life. Pavement is designed to support dynamic loads which flexural fatigue test will require for hemp FRC. Natural resources of coarse aggregate such as limestone is not eco-friendly to environmental which to maintain the sustainability pavement, recycled concrete aggregate will use to replace limestone to study with hemp fiber.

The primary parameter of concrete pavement design is based on the fatigue resistance which causes the distress to pavement. Large number of cyclic loads as induced by traffic can reduce the performance of concrete propagation cracks, deteriorating the elastic properties , increasing the fatigue fracture toughness (Perdikaris et al., 1986; Matsumoto, 1998; Lee and Barr, 2004) and eventually leading to the brittle failure of the material. The internal progressive damage of plain concrete occurs under repeated loads to form crack and ultimately fail due to flexural fatigue (Maitra et al., 2014). In design progression, fiber can resist the crack propagation which will increase the endurance life of the materials and contribute to a more ductile behavior (Chang and Chai, 1995; Rossi and Parant, 2008). According to the American Association for State Highway and Transportation Officials (AASHTO) was developed the performance prediction of concrete pavement in late 1950s which studied on the behavior and several tested data to create the empirical methods but did not include the fatigue performance that can cause the failure to the pavement. Therefore, the traditional design methods are mostly over-designing the strength to ensure the durability of pavement but did not address the failure of fatigue (Sabih and Tarefder, 2018). Thus, the mechanistic-empirical pavement design guide (MEPDG) was introduced in 2004 by AASHTO in cooperation with the National Cooperative Highway Research Program (NCHRP) and the Federal Highway Administration (FHWA). Since the MEPDG is based on the behavior and materials properties, this will have a potential to reduce the degree of uncertainty in the design steps which combined with realistic criteria for design the level of distress. For this reason, there will have more certainty of design and materials which significantly leads to reduce the maintenance process and rehabilitation activities (Ceylan et al., 2008). That being the case for this research to evaluate the fatigue performance and develop MEPDG method of hemp fiber reinforced concrete pavement with RCA.