CHAPTER II

LITERATURE REVIEW

This chapter provides some content in order to support this thesis by reviewing the definition, concept, advantages and disadvantages of retrofitting and jacketing, basic concepts and advantages of using ultra-high performance concrete, and basic fundamentals of bond strength and the use of mechanical connectors.

2.1. **Definition and Purposes of Retrofitting**

The process of modifying the existing structure in order to get the good performance of a structure is called retrofitting. Retrofitting is needed if the structure isn't able to meet the desirable standard such as the loss of load carrying capacity or to add some additional loads. Tsonos (2008) stated that the mechanical properties of the concrete is arguable if it has already been damaged due to seismic activity or extreme loads. Pela and Benedetti (2011) stated that the structure and its components could be damaged due to environmental agents, service loads, poor construction technologies, seismic events, low cycle fatigue, freeze thaw cycles, corrosion, etc.

After the retrofitting process has been done, the structure must meet some of the criteria such as the retrofitting structure performance needs to be satisfied according to the standards, loads can be transferred to new or existing members and the act of new and existing members needs to meet the designer purposes. Retrofitting strategy is done in order to improve the performance of existing structure or to reduce the risk of the existing structure. Most common strategy to do the retrofitting is strengthening and stiffening the existing structure. Strengthening structure can be done by increasing the external forces from while stiffening structure can be done by reducing the displacement caused by the external forces. Usually strengthening and stiffening can be done by adding new load resisting moment (columns, shear walls and infill walls). The addition of external braced framing or bitterness also can be done. Failure of the structure can be categorized as material failures and stability failures. Limitation of modes of failure (prevent buckling, etc), limitation of allowable stress (achieve adequate design of strength), limitation of combined stress and ratio (if there is an interaction of actions) and retribution the loads to the other members can be done in order to prevent the failure of the structures. The types of failure are summarized in Table 2.1.

Table 2.1. Types of Material Failures and Stability Failures

Material Failures	**Stability Failures**
Direct tension failure	Axial – flexural buckling
Direct compression failure	Lateral buckling
Direct flexure failure	Lateral torsional buckling
Direct shear failure	Local buckling
Failure in shear due to tension failure	Crippling
Failure in shear due to compression failure	P - Δ effects
	Sliding
	Overturning
	Fatigue

	Bond, splice and anchorage failure
	Loss of prestress

Retrofitting can be classified as global retrofit, local retrofit or both global and local retrofit. The purpose of global retrofit is to increase the performance of the system by adding, removing or altering the members of the systems. While the purpose of local retrofit is to increase the performance of each member of the system in order to maintain the performance of the systems. Both local and global retrofit is considered to get the optimum way in order to choose global and local retrofit in the same times. The types of global retrofitting and local retrofitting are summarized in Table 2.2.

Table 2.2. Types of Global Retrofitting and Local Retrofitting

Retrofitting techniques	
Global retrofitting	**Local retrofitting**
Adding shear wall	Jacketing or encasing / stressing of beams
Adding infill wall	Jacketing or encasing of columns
Adding bracing	Strengthening of slab
Adding external frames	Jacketing of beam column jackets
Mass reduction	Wall thickening
Supplemental damping and base isolation	Strengthening individual footings

Some considerations is needed in order to do retrofitting such as avoiding strengthening weak member and strengthening the other members, avoiding strengthening the member which will increase the dead load of the member, strengthening the accessible member even though it is not a weak members because new loads will be distributed to members with higher stiffness and old loads will be resisted with plastic deformation, modifying the basic structural system if many members of the systems are defected and retesting the soil properties (considering the safety factor) if there is a foundation strengthening.

2.2. Jacketing Techniques

Repair the damaged part is the most chosen option to save more time and cost (Wu et al. 2014 ; Zhou et al. 2015 ; Panjehpour et al. 2016 ; Peled et al. 2007 ; Ilki et al. 2008). One of the techniques to maintain the ductility of the damaged member of the concrete is confinement (Gu et al. 2010 ; Iacobucci et al. 2003 ; Lehman et al. 2001 ; Stoppenhagen et al. 1995). Jacketing is a techniques which covering the weaker material with high strength material in order to strengthen or retrofit the cross section of the members. The main purpose of jacketing techniques are increasing the axial-flexural capacity, shear and tension of the cross section by adding thickness or new reinforcement, and enhancing concrete confinement by transverse reinforcement. There are several methods that has been commonly used in order to do the jacketing techniques such as concrete jacketing, steel jacketing and FRP jacketing.

2.2.1. Concrete Jacketing

Ma et al. (2017) stated that the first technique of jacketing is concrete jacketing. Concrete jacketing provides layer consists of reinforced concrete. Concrete jacketing is good for its monolithic behaviour of the composite element. The bond between substrate layer and overlay layer can be increased by the roughening of the concrete surface and the using of epoxy resin. Dowels bars can be replaced by steel connectors. The example of concrete jacketing is illustrated in Figure 2.1.

The effectiveness of the concrete jacketing is shown by Bett investigation. Bett el al. (1988) investigated repaired column retrofitted by concrete jacketing is applied by lateral load and constant axial load. The experiment resulted in higher stiffness and lateral load capacity. Ersoy et al. (1993) tested that the column jacketed by concrete has a better performance compared with the unjacketed concrete if the specimen is applied by uniaxial load and the combination of uniaxial load and cyclic lateral load. Rodriguez and Park (1994) stated that square concrete column jacketed by the concrete has higher ductility and strength due to the seismic loading.

Ma et al. (2016) stated that the disadvantages of using concrete jacketing is due to its high cost of cleaning and roughening the concrete surface. The adding of dowels bars or connectors may increase the dimensions of the columns so that it may reduce the space in construction. The reinforced concrete jacket thickness is usually larger than 100 mm. Because of that, it consumes lot of spaces and adds the dead load (Rodriguez and Park 1994 ; Priestley et al. 1996).

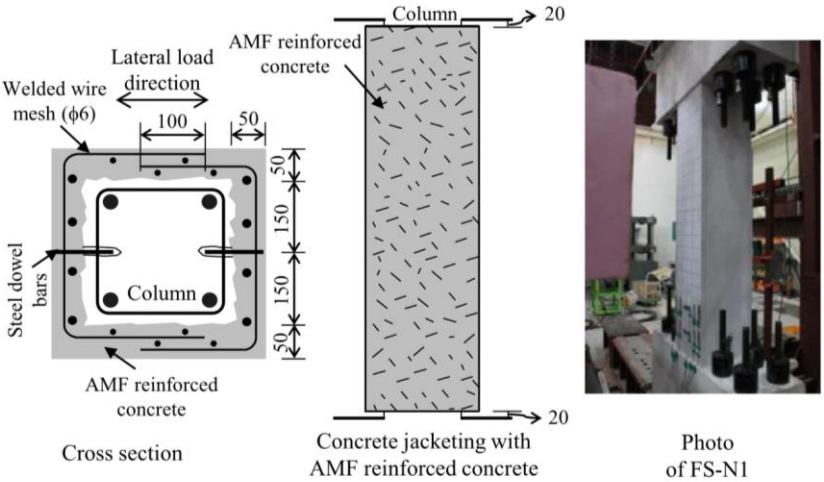

Figure 2.1. Concrete Jacketing

2.2.2. <u>Steel Jacketing</u>

Steel jackets is often used to increase the basic strength of the reinforced concrete. The reinforced concrete is confined by the steel jackets. Hesham (2011) stated that steel jackets is often used to strengthen the non-ductile column. The advantages of using steel jackets is compared with using concrete jackets. Steel jackets provides thinner layers, lighter weight. Steel jackets also increase the shear strength, confinement, ductility, stiffness and load bearing capacity of the columns. Steel jackets is believed to improve the flexural strength, shear capacity, ductility and stiffness of concrete columns (Engindeniz et al. 2005 ; Vandoros et al. 2008 ; and Li et al. 2009). The example of steel jacketing is illustrated in Figure 2.2.

Xiao and Wu (2003) stated that the increasing of the ductility of the damaged columns can be done by steel jacketing. Hesham (2011) stated that the larger area covered by steel jackets results in increasing of the load carrying capacity of the column. The use of straps in steel jackets doesn't have much impacts on the load carrying capacity of the column. R.K.L. Su and Wang (2012) stated that pre-loaded rectangular concrete columns with pre-cambered steel plates increase the strength, deformation and ductility of the columns. Usama (1999) investigated that the use of the welded stirrups increases the load carrying capacity of the column by 87 – 91 % of the original column. Nader (2009) investigated that the use of pre tensioned steel jackets in RC columns increased the load carrying capacity of the column. Shaban and Abdel (2014) tested the concrete retrofitted by steel jacketing with using external ties and steel angles. It is said that the clear spacing of the external ties must not be less than 150 mm, the increasing of thickness of external plates, in order to give a good strain behaviour and column capacity. The ultimate load and overall behaviour of the strengthened column can be increased by increasing the number of ties and the height of using steel angles. The thickness of using steel plates must be more than 3 mm in order to strengthen the columns. Khair Al Deen Isam Bsisu (2009) tested the square concrete column retrofitted with steel jackets which the tests were under concentric axial loading results in higher compressive strength and confinement of the concrete columns with steel jackets increased the ductility of the concrete column itself. Ghobarah et al. (1997) stated that the improvement the shear strength and ductility of the laterally loaded column can be done by using corrugated steel jackets. Wu et al. (2006) stated that the ductility of the columns on the rectangular reinforced concrete (RC) can be improved by using steel platen as jacket. Sarno et al. (2006) stated that the stainless-steel jacket to retrofit seismically loaded frame concrete structure resulted in higher plastic deformations and energy absorption capacity. Local buckling in steel members also can be avoided by the strain hardening properties of stainless steel. Ma et al. (2016) stated that steel jacketing can increase the shear strength of the concrete members compared with concrete jacketing. He also stated that the use of right angle of square or rectangular cross section is not effective in enhancing the flexural stiffness and results in no increasing of the deformability of the columns. The bonding between steel plates also plays and important role in the effectiveness of the steel jacketing.

Some researchers retrofitted the concrete columns with 6 mm thickness of steel jackets installed with 25 mm diameter of anchor bolts. It resulted in the improvement of the lateral load carrying capacity and energy dissipation capacity of the concrete columns. It also changes the brittle behaviour of the concrete column to a ductile behaviour of the concrete column (Aboutaha and Jirsa 1996 ; Belal et al. 2015 ; McLean and Bernards 1992). Eunsoo Choi et al. (2012) demonstrated the use of steel wrapping jacketing in order to increase the strength of the concrete. The steel wrapping jacket shows the improvement of the bond strength of the concrete. In this research, the steel wrapping jacket transfer the splitting bond failure to pull out bond failure. Because of the increasing of the bond strength, the flexural strength of the concrete also increases. It is said that the circular columns with circular steel jackets is more effective compared with rectangular columns with rectangular steel jackets. Priestley et al. (1996) stated that the retrofitting of members by using steel jacketing isn’t suitable for members with rectangular cross section. In that case, stiffeners can be used for rectangular columns.

Steel jacketing has a good performance in resisting seismic behaviour for the RC columns. But steel jacketing has problems such as grouting (Priestley et al. 1996 ; Pantelides et al. 2004 ; Pantelides et al. 2007). Bracci et al. (1995) stated that the grouting of the steel bonds the steel to the concrete surface which leads to a large cross-sectional area. Although it enhances the flexural stiffness of the concrete, but it leads to shortening natural period which will cause more seismic inertia force. Steel jacketing has low resistance due to corrosion and sometimes it may cause excessive capacity, resulting in buckling or brittle failure when it reaches the ultimate strength (Engindeniz et al. 2005 ; Vandoros and Dritsos 2008 ; Li et al. 2009).

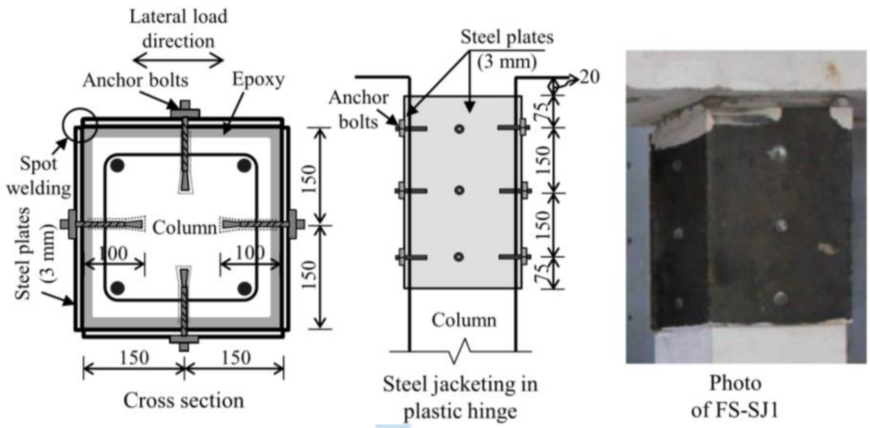

Figure 2.2. Steel Jacketing

2.2.3. <u>Fibre Reinforced Polymer Jacketing</u>

Fibre Reinforced Polymer (FRP) jacketing is a technique which wrapping the members of the structure by using high strength carbon fibre. The advantages of using FRP jacketing are improving the seismic capacity, higher modulus of elasticity, lighter weight and free to rust. The example of FRP jacketing is illustrated in Figure 2.3.

From ACI 440.2R-17 (2017), it is stated that FRP wrapping can be applied to RC column with damaged surface because it depends on lateral confinement pressure. FRP jacketing has higher corrosion resistance, higher strength to weight ratio, no or ignoring shear deformation and no slip interface between FRP and concrete surface (Choi et al. 2013 ; Rousakis et al. 2016 ; Rousakis et al. 2018 ; Engindeniz et al. 2005 ; Parvin et al. 2014 ; Bisby et al. 2005 ; Hadi 2009). Wu et al. (2006) also stated that the effectiveness of using FRP wrapping on square and rectangular columns depends on the corner radius of the cross section. Panjehpour et al. (2016) stated that the damaged High Strength Concrete (HSC) cylinders retrofitted by CFRP jacketing can resist the axial deformation of the cylinders when subjected under uniaxial compression. He also stated that this test also stated that the CFRP jacketing has three times bigger in energy absorption compared with the unjacketing by using CFRP. Some researches stated that the use of FRP wrapping can reduce the cost of the construction and easily shape in needs to our demands. (Yamamoto 1992 ; Kono et al. 2008). Ozcan et al. (2010) stated that the concrete column retrofitted by CFRP sheets and fixed with CFRP anchors shows higher deformation capacity and load-carrying capacity. Ma et al. (2016) stated that FRP method become the most effective method because it can restore 3 times of the original strength of the damaged concrete.

The disadvantages of using FRP jacketing is the cost. The cost of using FRP techniques tends to be higher compared to concrete and steel jacketing. The increasing of diameter of concrete column results in decreasing of confinement effect. It makes that it needs more FRP wrapping. In this case, the cost of using FRP wrapping tends to be higher and it will also reduce the bond strength (Hadi 2004 ; Hadi et al. 2013 ; Lam and Teng 2003). Han et al. (2009) said that the bond of FRP jackets by using adhesive epoxy may lead to a problems such as wrinkles in the FRP surface which inhibit the confining action on the concrete and the use of FRP jacketing will be less effective. Hadi et al. (2009) stated that using FRP in columns isn't effective enough because it has only increased the lateral stiffness of the column. Mirmiran et al. (1998) stated that the disadvantages of using FRP jacketing is the lack of fibre pretension which causes the limited using of FRP.

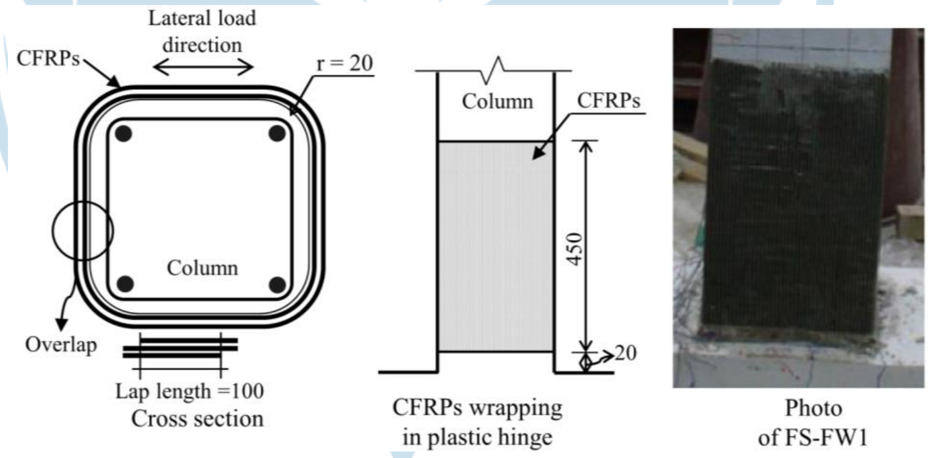

Figure 2.3. FRP Jacketing

The advantages and disadvantages of concrete jacketing, steel jacketing and FRP jacketing are summarized as the Table 2.3.

Table 2.3. The Outcome of Concrete, Steel and FRP Jacketing

Jacketing Techniques	Advantages	Disadvantages
Concrete Jacketing	- Higher stiffness and lateral load - Increase ductility and strength - Good monolithic behaviour - Restoring original strength of the concrete	- High cost of preparation - Increasing the dead load of the structure
Steel Jacketing	- Light weight - Increase ductility, shear strength, flexural strength, confinement, flexural strength and stiffness - Good performance in resisting seismic performance - Restoring original strength of the concrete	- Grouting problem - Low resistance to corrosion - Cause brittle and buckle failure when it reaches the ultimate strength

FRP Jacketing	- Light weight - Improve seismic capacity and high modulus capacity - High resistance to corrosion, energy absorption, deformation capacity and load carrying capacity - No slip interface between concrete and FRP - Easily to be shaped - Restoring original strength of the concrete	- High cost of using FRP - The excessive use of FRP may cause the decreasing of bond strength - Wrinkles in FRP jacketing is possible - Lack of fibre pretension - Only increase the lateral stiffness of the column

2.3. Ultra-High Performance Concrete

UHPC has a better performance compared with the normal concrete. Concrete has a very low tensile strength around 8% -15 % of the compressive strength and strain capacity so that steel bars or fibre acting as reinforcement is needed to improve the tensile and the ductility of the concrete (Shah et al. (1995) ; Banthia and Sappakittipakorn 2007). Camacho (2013) stated that UHPC also can be defined as the combination of Self-Compacting Concrete (SCC), Fibre Reinforced Concrete (FRC) and High-Performance Concrete (HPC) as illustrated in Figure 2.4.

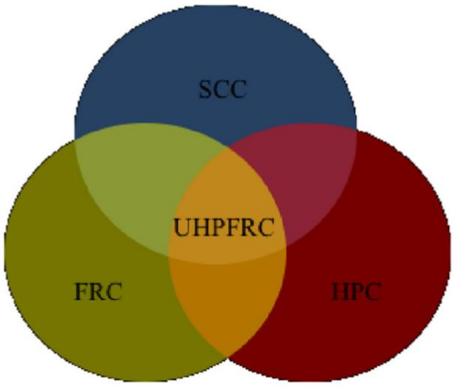

Figure 2.4. The Combination of UHPC

2.3.1. Purposes of Using Ultra-High Performance Concrete

Unlike the origin concrete, the purposes of UHPC have been conducted by some researchers such as follow :

- Minimizing composite porosity by optimizing the granular mixture through a wide distribution of powder size classes and reducing the W/B.
- Enhancement of the microstructure by the post set heat treatment to speed up the pozzolanic reaction of SF and to increase mechanical properties.
- Improvement of homogeneity by eliminating the coarse aggregate resulting in a decrease in the mechanical effects of heterogeneity.
- Increase in ductile behaviour by adding adequate volume fraction of small steel fibers.

Those four purposes will produce a very high compressive strength of concrete and improvement of tensile strength and ductility by adding steel fibre (Schmidt and Fehling 2005 ; Richard and Cheyrezy 1995 ; Spasojevic 2008 ; Hassan et al. 2012 ; Tayeh et al. 2013 ; Rossi 2013 ; Yu et al. 2014).

2.3.2. Material and Mechanical Properties of Ultra-High Performance Concrete

UHPC has a compressive strength of at least 120 MPa, specified tensile ductility, toughness requirement and slump flow between 200 – 250 mm. The materials of steel, carbon, glass and synthetic fibre are the main factors of the enhancing the tensile/ flexural strength and toughness. (ACI 239 (2012) ; C1856/C1856M 17 (2017) ; Willie and Naaman 2012 ; Wu and Khayat 2018 ; Reda et al. 1999 ; Zohrevand et al. 2011 ; Missemer et al. 2019 ; and Kang et al. 2016). Association Francaise de Genie Civil (2002) stated that a lower strength UHPC is a concrete with the range of compressive strength of 130 – 150 MPa strengthened with steel or fibre. UHPC also can be described as fibre reinforced, superplasticizer, silica fume-cement mixture with very low water cement ratio, and the presence of a very fine quartz sand ranging from 0.15 – 0.60 mm replacing the aggregate. Resplendino (2008) stated that the compressive strength of UHPC is 130 MPa with the tensile strength of 12 MPa. FWA-HRT-11-038 (2011) said that the lower water cement ratio lower than 0.25 is needed to obtain a high strength of UHPC. UHPC provides good mechanical properties such as high tensile strength, impermeability, flowability and energy absorption. (Wille et al. 2011 ; Russell et al. 2013 ; Hassan et al. 2012 ; Graybeal 2006 ; Shafieifar et al. 2017 ; Farzad et al. 2019b).

Richard and Cheyrezy (1995) conducted the mixture of UHPC with the use of high binder content and high cement content. The pressence of silica fume, quartz powder, quartz sand, superplasticizer and low water content ratio is a must.

The steel fibre that been used is generally in length of 12.5 mm and in diameter of 180 μm. The pressence of coarse agreggate needs to be eliminated in order to fulfill the homogeneity enhancement of the matrix. Then, Richard et al. summarized the standards of the UHPC in the Table 2.4.

Table 2.4. Mixture and Mechanical Properties of UHPC

Materials (kg / m^3)	**Recommended Value**
Portland cement	1000
Fine sand (150 – 600 μm)	500
Ground quartz (d_{50} = 10 μm)	390
Silica fume	230
Superplasticizer (Polyacrylate)	19
Steel fibre	630
Total water	190
Compacting pressure	50
Heat treatment	250 – 400 °C
Compressive strength (MPa)	490 – 680
Flexural strength (MPa)	45 – 102

According to NF P 18-470 (2016), since UHPC has a low water to binder ratio, then some UHPC material requirements must be satisfied and it is listed in Table 2.5.

Table 2.5. UHPC Requirements

Properties	**Recommended Value**
Maximum aggregate size	≤ 100 mm
Concrete density	2200 – 2800 kg / m^3

Tensile strength at 28 days	≥ 6 MPa
Water porosity at 90 days	≤ 9 %
Diffusion coefficient of chloride ions at 90 days	≤ 0.5 x 10^{-12} m^2 / s
Apparent gas permeability at 90 days	≤ 9.0 x 10^{-19} m^2

2.3.3. Applications of Using Ultra-High Performance Concrete

The use of UHPC in construction have proven to reduce complication and inconsistencies and it is been used widely for construction repair because of its good flowability to shape into various geometry, early high strength to prevent construction delays, good durability due to moisture, freeze-thaw and abrasion, high tensile strength to reduce cracking and good fatigue resistance (Classen et al. 2016; Feldmann et al. 2011; Grünberg et al. 2008; Shaheen and Shrive 2008). Voo et al. 2017 stated that the application of using the UHPC varies from building and infrastructures components, repair and rehabilitation, overlay materials, etc. Schmidt and Fehling (2005) also stated that UHPC (Ultra High Performance Concrete) becomes the most used solutions to improve the sustainability of the buildings and its structural terms because of its high strength and good durability. The application of UHPC can be seen in protective structures as non-penetrable coverings and in elements that must durable against aggressive environments and severe loadings such as earthquakes, impacts or blasts. It is due to its durability, low permeability and energy absorption. (Ahlborn et al. 2008 ; Bruhwiler and Denarie 2008 ; Tayeh et al. 2012 ; Graybeal and Baby 2013 ; Adhikary et al. 2013

; Habel and Gauvreau 2008 ; Mao et al. 2015 ; Yi et al. 2012). Bruhwiler and Denarie (2008) stated that UHPC also can be as a tools of retrofitting and repairing the existing reinforced concrete members. The UHPC development can be used for cast in-situ or precast applications using conventional concreting equipment. UHPC is a great solution to increase the speed of construction because it can gain strength quickly about 68 MPa in just five days of ambient air curing (Graybeal 2006 ; Farzad et al. 2018).

2.3.4. <u>Case Studies of Using Ultra-High Performance Concrete</u>

UHPC jacketing brings some advantages such as protective jackets against outside elements, prevention of spalling of the concrete cover of steel reinforcements, less or no cost maintenance due to its durability, good interface bond between UHPC and concrete columns, and good workability in order to do various shapes (Wu et al. 2018 ; Jose et al. 2018).

Yin et al. (2017) stated that UHPC which is acting as rehabilitate material or patch material for repair and rehabilitation of structural damage shows an excellent energy absorption capacity with extensive deflection hardening and ductility although there is no improvement in the ultimate strength in the projects of strengthened slabs. Meanwhile, the UHPC which is used as retrofit material in overlays shows an improvement the overall stiffness of the slabs and delays the development of shear cracks.

Some findings stated that a thickness of 32 – 102 mm of UHPC overlays over the existing reinforced concrete increases element stiffness, decrease crack width and spacing, and increase load-carrying capacity of the element prior to failure. (Habel et al. 2007 ; Noshiravani et al. 2013).

Some researches stated that UHPC overlays of RC members is strengthened when it is subjected to bending. It means that UHPC enhance the ultimate loads, stiffness and cracking behaviours. (Noshiravani and Bruhwiler 2013 ; Oesterleeet 2010 ; Habel et al. 2007).

Xie et al. (2019) tested the stub concrete column retrofitted with UHPC jacket with different thickness and different shape of stub concrete column. The increasing thickness of the UHPC jackets results in higher compressive resistance and displacement at ultimate resistance. Cylinder stub columns retrofitted by UHPC jackets shows better ductility compared with square stub columns retrofitted by UHPC jackets. There is no improvement on the initial stiffness of concrete columns even retrofitting by using UHPC jackets has been applied.

Farzad et al. (2019) retrofitted the damaged columns in the bridge pier with UHPC jackets as a repair material. He stated that the retrofitted concrete column by using UHPC shows an improvement in lateral strength, deformation, energy dissipation capacity and stiffness. The UHPC jacketing which contains steel fibre performs a good performance by transforming spalling cover to gradual mechanism. It is caused by the steel fibre to bring the greater material to large strains.

2.4. Concrete-to-concrete bond

In order to do the retrofitting process, the bonding between the overlay concrete and substrate concrete needs to be put in a concern. The illustration of the bond strength between concrete and concrete are shown in Figure 2.5.The bond strength at the interface (contact layer) of the overlay concrete and substrate concrete is important to ensure the monolithic behaviour and load transfer between members. If the bond strength is assured, then the life of the structure members will be extended because of the absence of crack that allow the inflow of the water and chloride to the interface of the overlay and substrate concrete (Graybeal et al. 2017).

There are some factors that need to be considered which are affecting the bond strength between overlay concrete and substrate concrete. Some researches stated that the concrete-to-concrete bond is influenced by some factors such as substrate surface condition, compaction method, curing process, mechanical properties of the material, use of bonding agents and the age of the chemical bonds (Bissonnette et al. 2012 ; Beushausen 2010 ; Momayez et al. 2004). The other researches also pointed out the same factors which are affecting the bond strength such as surface treatment (cleaning, removing laitance layer, and roughening), compaction method and curing process (Garbacz et al. 2005 ; Courard et al. 2006 ; Santos and Julio 2007). The tensile bond strength to access bond strength between substrate concrete and overlay concrete can be influenced by substrate surface condition, the use of bonding agents and the mechanical properties of both materials (Wall and Shrive 1998 ; Momayez et al. 2005 ; Silfwerbrand and Beuhausen 2005).

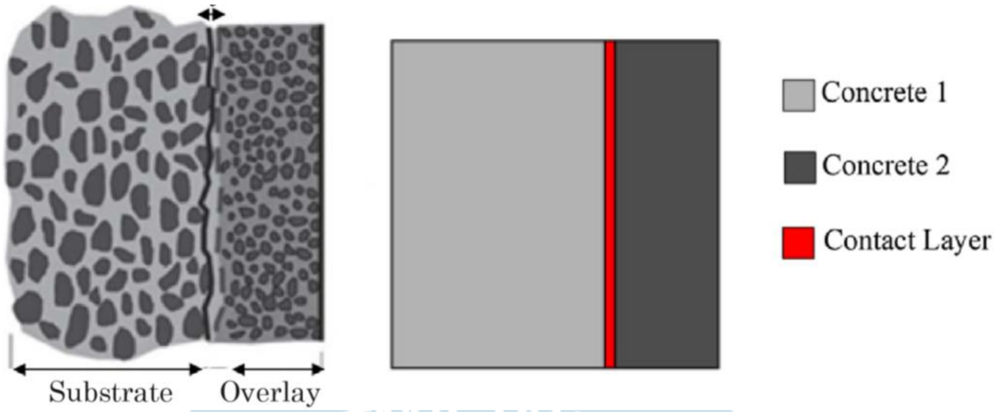

Figure 2.5. Illustration of the Bond Strength at the Interface between Concrete and Concrete

2.4.1. <u>Surface Treatment</u>

The surface treatment of the substrate concrete before casting the overlay concrete can be done by cleaning the surface, removing the laitance layer and roughening the surface. The surface of the substrate concrete also plays an important role to obtain the good bond strength (Warner et al. 1998 ; Carter et al. 2002). Haber et al. (2018) stated that the result of the bond strength won't be the same if the treatment of the substrate concrete is different. Roughening the substrate surface is considered to be done in order to enhance the mechanical interlocking between substrate concrete and overlay concrete (Courard and Garbacz 2006 ; Courard 2002 ; Courard 2000). Cleaning the substrate surface is done by removing debris or dust before casting the overlay concrete. The laitance in the substrate surface needs to be removed in order to achieve the bond strength at the interface of overlay-substrate concrete (Wall and Shrive 1998 ; Pandey 2012 ; Austin et al.

1999 ; Courard et al. 2014). The types and method of surface preparation and its result will be investigated in Chapter 3.1.1 and Chapter 4.1.

Beside the surface roughening, the condition of moisture substrate condition is likely to affect the performance of the bond strength. Pigeon et al. stated that the moisture condition doesn't give an improvement to the bond strength, opposite with the statement of Monuz et al. (2014) which stated that the moisture condition do affect the performance of the bond strength. This parameter also will be investigated in Chapter 3.1.1 and Chapter 4.1.

2.4.2. Curing Condition

According to Safritt (2015), the curing is done in order to control the temperature of the cement, increase the hydration of the cement, and control the movement of the moisture into the concrete. By doing the curing, the compressive strength and resistance to scrapes of the concrete will be increased and the surface of the concrete will be free from dust. Ramezanianpour and Malhotra (1995) stated that the curing process needs to be done if the concrete surfaces is too dry or hot during the early age. Curing condition is the most important factor because the cement hydration influenced by the adequate moisture content and temperature will provide a good mechanical properties of the concrete (Sharon Huo and Won Ling Ung 2006 ; Nawy 2008 ; ACI 308R-01 2001). The research about the types of curing and its results will be investigated in Chapter 3.1.2 and Chapter 4.2.

2.4.3. Mechanical Properties of the Material

The properties used in overlay concrete and substrate concrete also plays an important role in order to achieve a desired bond strength. Behfarnia et al. (2005) stated that the good bond strength can be provided if the strength of the concrete is increased. It is likely that the bond strength mostly fails in the substrate concrete because the substrate concrete has lower strength compared with the UHPC as the overlay concrete (De la Varga et al. 2016). The further research will be investigated in Chapter 3.1.3 and Chapter 4.3.

Besides the strength of the concrete, some researches conducted a parameter such as concrete age (such as UHPC) to the bond strength (Zhang et al. 2019 ; Haber et al. 2018 ; Jafarinejad et al. 2019). The reason is UHPC has gain an impressive strength at the early ages and the investigation is done to see whether the strength will be higher in the increasing of UHPC age. The detail and results will be discussed in Chapter 3.1.3 and Chapter 4.3.

2.4.4. Use of Chemical Bond

The use of bonding agent also may affect the bond strength at the interface between the overlay concrete and substrate concrete. Epoxy-based resins is one of the epoxy commonly used by the researches. Julio et al. (2005) stated that the use of epoxy-based resins is usually used together with the substrate preparation in order to roughening the substrate surface. The use of bonding agent is also know to create a bond between the substrate concrete and overlay concrete (Julio et al. 2003 ; Garbacz et al. 2005). But the use of the bonding agent may have some issues such as decreasing or failure in bond strength compared without using the bonding agent (Emmons 1994 ; Austin et al. 1995 ; Cleland and Long 1997). The use of epoxy needs to be considered in order to be used to get a desired bond strength. The further research will be investigated in Chapter 3.1.4 and Chapter 4.4.

2.4.5. Types of Failure in Bond Strength

After the test to investigate the bond strength between concrete, several types of failure are observed. According to ASTM C1583 2013, there are four types of failures in direct tension bond test in order to measure the bond strength which is summarized as below.

i. Cohesive failure = the failure occurs at the substrate or overlay concrete, then the bond strength is higher than the tensile strength of the concrete.

ii. Adhesive failure = the failure occurs at the interface between the substrate and overlay concrete, then it is the value of the bond strength at the interface between substrate and overlay concrete.

iii. Mixed failure = the failure occurs at both bond line between the concrete and at the overlay or substrate concrete.

iv. If the failure occurs at the interface between the machine specimen and the substrate concrete, then the result is neglected.

The illustration of the type of failures can be seen in Figure 2.6. This type of failure can be used in other test setup specimens. Usually specimens with adhesive failure shows a lower bond strength compared with specimens with cohesive failure. In order to have a high bond strength, it is better for specimens to have a cohesive failure.

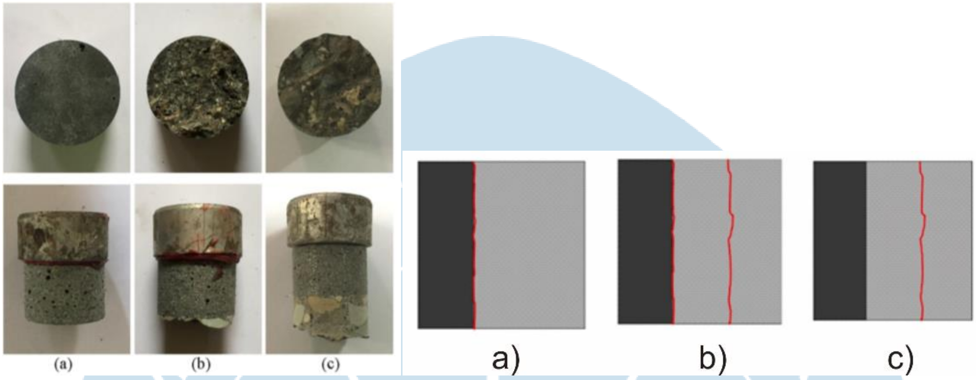

Figure 2.6. The Illustration of Type of Failure : a) Adhesive , b) Mixed , and c) Cohesive

2.5. Mechanical Connectors

Ertas et al. (2006) stated that the connections in a building structure can minimize the damage caused by the structure itself or seismic events. To ensure that the connectors is doing well, then the use and strength of the connector and concrete need to be ensured. If the strength of the connectors and strength of the concrete are adequate, then it will enhance the behaviour of the connectors (Lam and El-Lobody 2005). Raval and Dave (2013) did some researches about retrofitting reinforced concrete members and one of them are using mechanical connectors such as dowel connectors. They stated that the use of the mechanical connectors mostly can be found in jacketing techniques and it can be seen that the use of the mechanical connectors improves the structural properties of the structural members such as load carrying capacity and displacement at higher loads. Julio and Branco (2008) added the use of mechanical connections to the column added by the jacketing and it results in increasing of the compressive strength of the column. The shear strength of the strengthening structural members by adding steel connectors is also increased (Julio ES 2001 ; Julio et al. 2001). Enuica et al. stated that the use of mechanical connectors in jacketing technique is seen to improve the bond strength between the overlay concrete and substrate concrete.