Diyala Journal of Engineering Sciences Vol (13) No 4, 2020: 58-70

Diyala Journal of Engineering Sciences

Journal homepage: https://en.enginmag.uodiyala.edu.iq/

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Bonding Performance for Lightweight Concrete: A Review

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ARTICLE INFO

Article history:
Received 17 Aug. 2020
Accepted 9 Oct. 2020

Keywords:

Bond strength; Light weight concrete; Aerated concrete; Pull out test and Beam end test

ABSTRACT

Nowadays, lightweight concrete become popular among construction companies due to its physical characteristic such as sound and thermal insulation, lightweight, cost and environmental saving, self-levelling…etc., which make it an attractive choice as a building material. However, this concrete face many constructional obstacles due to the lack of adequate and sufficient constructional information about the nature of this concrete. This requires great caution when use it for structural purposes. Among these great constraints, for example, is the weak characteristic of the bond between this concrete and reinforcing steel. Therefore, in order to get rid of these defects of concrete and make it usable in various construction sectors, this paper summarizes researchers works concerning bond behavior between light weight concrete and reinforcing bars , the variable influencing bond behavior such as; concrete type, rebar type and diameter, W/C ratio, and adding fibres. And results collected from experimental work with most important conclusions.

1. Introduction

The bond between concrete and reinforcing bars is a very important structural feature through which it is possible to study the behavior of reinforced concrete when exposed to various stresses and assess the efficiency of reinforced concrete structural elements when subjected to seismic strikes , as well as it is worth noting that the weakness of this property leads to great deflections and affect the capability of the structural member to bear the loads on it because the loss of strain accessibility between concrete and reinforcing bars and thus failures to distribute stresses in reinforced concrete regularly Prince, M. J. R., & Singh, B. (2013) [26] Mo, K. H., Alengaram, U. J., & Jumaat, M. Z. (2016)[39]. The bonding process requires a chemical cling and mechanical response while the chemical cling is between the concrete and the reinforcement bar, If this process is used, the free end of the reinforcement bar keeps slipping and once the whole chemical cling has broken, the slip and friction occurs due to the high shear between the reinforce bar and the concrete, The transverse pressures increase the frictional shear, whereas the mechanical response produced by destroying and sliding the concrete between the reinforced bar ‘s ribs subsequently increases the bond stress until the splitting failure occurs in concrete or pulls out the failure in the reinforcing bar. (de Villiers, 2017)[42].

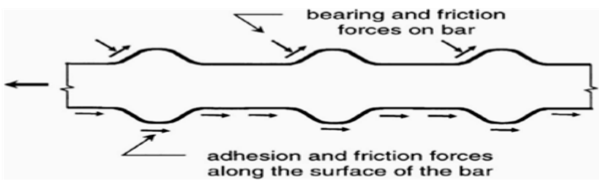

Fig.1 The mechanism of transfer force of bond (2003, ACI Committee 408)

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DOI: 10.24237/djes.2020.13408

The most common type of tests approved for studying the bond behavior between concrete and reinforcing bar is the mainly pull out test, followed by the beam end test. Both tests involve a concrete sample with a reinforcing bar protruding from both ends. One ends is called the loaded end and the other is called the free end. The loaded end is in which the reinforcing bar is subjected to a pulling force to simulate the tensile force that the rebar is subjected to in ideal reinforced concrete and at the same time (at the loaded end) the concrete sample is subjected to a compressive force. Continuously applying the tension to the reinforcing bar and compression to the concrete sample, until the bonding resistance between the two materials is exceeded at the area prone to bonding. While the other end (the free end) of the reinforcing bar, which is about 10-20mm, protrudes from the other face of the concrete.

The actual bonded length (embedded length) between the reinforcing bar and the concrete is exactly between the loaded end and free end, and is usually calculated as a percentage of the bar diameter, for example the bar has a diameter of 12mm, so the bonded length is calculated as $3d_b$ or $4d_b$..etc according to the required length.

The remainder of the bar length (unbonded length) is covered with an insulating material such as a plastic tube to ensure that there is no connection between that the reinforcing bar length and the concrete. (de Villiers, 2017)[42]

2. Bond strength of lightweight aggregate concrete

In the new millennium, considering the significance of sustainable development to replace natural aggregates in concrete, alternative materials such as lightweight aggregates must be used. It is necessary to know the applicability of this type of concrete in construction applications by studying the behavior of the bond between lightweight aggregates concrete and reinforcing bar a significant difference in bond strength from one investigator to another can be noted when using light weight aggregates instead of normal aggregates known. Some researchers used light weight aggregates as replacement of coarse aggregate For example, Nadir, Y., & Sujatha, A. (2018),[47] replaced normal aggregate with coconut shell aggregate with density 650 kg/m^3 at level 25%, 50%, 75%, 100% when studying the bond behavior of coconut shell aggregate concrete and deformed steel bars(12mm and 16mm) using pull out test and found that decrease bond strength with increasing the percentage of replacement and diameter of bar, where the decreasing of bond strength when using 12mm diameter bar was (4.93%, 10.71%,11.27%,15.92%) and it was (1.84%,2.86%, 4.69%, 7.76%)when using 16mm diameter bar for percentage of replacement 25%,50%,75% and 100% respectively. In 2013 the researcher (Wu, 2013)[27]discovered that elevated bond strength of light weight aggregate concrete compared to normal concrete using expanded shale aggregate concretef_c'52.1 MPa, bond length 80 mm and dia. of bar 16mm, and discovered that the strength of bond was 18.5 MPa accessed using pullout test And it was greater than that of other scientists using the same concrete and same method of test (pull out test) such as (Karahan, 2012)[22]who found that the bond strength of lightweight expanded shale aggregate concrete is lower than that of standard concrete using 40.1 MPa and 1985kg/m^3 unit weight's concrete , bar dia. 15 mm, bond length 150 mm, and 3.2 MPa was found to be the bond strength and (Mor, 1993)[6]adopted pull out test to investigate the bond strength of expanded shale aggregate concrete of f_c' of 66.5 MPa and bar dia. 19mm discovered that LWAC has gained bond strength greater than standard concrete, the bond strength was 13.1 MPa. Of 150mm, the length of bond of reinforcing bar, in addition to (Xi Liu, Yang Liu, Tao Wu , Hui Wei ,2020)[49]who replaced crushed gravel normal weight aggregate by shale ceramsite lightweight aggregate to investigate the bond-slip properties using PO (pull out) test ,between LWAC with strength grade (39.4MPa, 48.7MPa, 62.7MPa, 83.2MPa), oven dry density (1824-1871Kg/m^3) and ribbed rebar with dia. of (12,16,20mm) ,embedded length of (50,80mm)an found that LWAC have better bond strength than that NWC[49]**.**Another researchers studying the bond behavior of expanded clay aggregate concrete like; (Carmo, 2014)[32], using expanded clay aggregate concrete of f_c' 70.4 MPa , design density 1900kg/m^3 and dia. of bar was 12mm and discovered that the bond strength of this concrete by using pull out test method was lesser than standard concrete but the bond strength gains by using bond length of 150mm was 32.8 MPa which was the higher bond strength of this type of concrete comparing to others investigators who used the same concrete such as (Bogas, 2014)[33]who used expanded clay aggregate concrete of f_c' 61.1MPa, fresh density 1933kg/m^3 ,dry density 1840kg/m^3 , dia. of bar 12mm and bond length was 100mm and noted that the bond strength was 19.822.1MPa which was greater than the strength of bond of normal concrete, the researcher adopted pull out test in his work and (Alduaij, 1999)[10] discovered that the bond strength reduced by using this type of concrete rather than standard concrete when used concrete of cylinder compressive strength 22MPa, dry unit weight 1520kg/m^3 , bond length 60mm and dia. of bar was 12mm which was the less bond strength (4.1 MPa) comparing with others researchers. on the other side In 1993, (Clarke, 1993)[7], investigated the bond strength by using two types of test (pull put and beam end tests) of light weight concrete made from Pelletized blast furnace slag as coarse aggregates replacement, the concrete used has compressive strength (23.2 MPa and 41.7 MPa with density 2025kg/m^3 and 2050kg/m^3 respectively)and using reinforcing bar with diameter of (10mm & 16mm) with length of bond was (100mm&150mm) and found that the bond strength ranging from 10.3MPa to 15.8 MPa ,this was attributed to decreasing bar diameter and length of bond leads to increasing bond strength also when compressive strength of concrete increase, the strength of bond increased too. Mo, K. H., Yeap, K. W., Alengaram, U. J., Jumaat, M. Z., & Bashar, I. I. (2018)[45] researcher study two types of lightweight concrete (cement-base lightweight concrete with 27.5MPa compressive strength and 1953kg/m^3 oven dry density and geopolymer- base lightweight concrete with28.4MPa compressive strength and 1902kg/m^{3}oven dry density) both containing oil palm shell as replacement of coarse aggregate at level 30% the results gained explained that ultimate bond strength (10.38-15.58MPa) was higher for cement base lightweight concrete compared to ultimate bond strength of geopolymer lightweight concrete (10.04-11.34MPa) when using direct pull out test. In 2019 researchers (Aamer, Lina, Yaqoob,2019)[48]adopted pull out test to investigate the bond strength of LWC contains porcelanite with dry loose unit weight 717kg/m^3as coarse aggregates replacement, pull-out test conducted on six cubes specimens of this LWAC with compressive strength (20.8MPa) , bond length (200mm&300mm), dia. of rebar was (10mm&16mm) and concrete cover (92mm&117mm) and noted that the values of bond strength between(1.1MPa and 1.49MPa)for LWAC which was lower than that obtained from conventional concrete of (2.84MPa-3.8MPa) bond strength and attributed that to The weakness of lightweight aggregates concrete in resisting shear strength, which led to the ease of shattering the concrete under the reinforcing steel ribs, in addition to the formation of capillary cracks at the interface between the concrete and the reinforcing steel ribs. On the other side, (Mingshuang, Xiaoyan , Kai , Teng, Shunbo , 2018)[46]investigated bond strength (using pull out test) on a new type of LWAC that is made with expanded shale agg. In it's fine and coarse state in 100% ratio by using the pull-out test technique to measure the various slips at the end corresponding to the loading direction and free-end adopted various variables such as W/C ratio of the mix , bond length, rebar diameter.

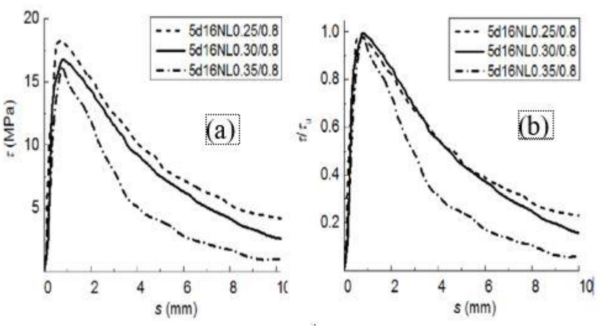

Fig.2 (a)The effect of W/C ratio on bond stress-slip curve; (b)the effect of W/C ratio on normalized bond stress-slip curve[46]

From preview figure above we can note that increasing compressive strength of concrete by decreasing w/c ratio led to enhance the bond performance between deformed steel rebar and steel fiber reinforced lightweight concrete, where; (5d is bond length, 16 is bar diameter, N is expanded shale with bulk density 800kg/m^3 and cylinder compressive strength 5MPa , L is lightweight expanded shale sand with bulk density 946kg/m^3 and fineness modulus of 3.56 , [0.25-0.30-0.35] is w/c ratio , 0.8 is the ratio of SP.,($\tau_u$is the maximum value of bond stress, τ is bond stress).

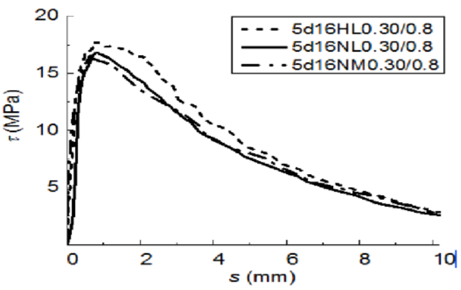

Fig 3. The effect of fine and coarse agg. On bond stress-slip curve [46]

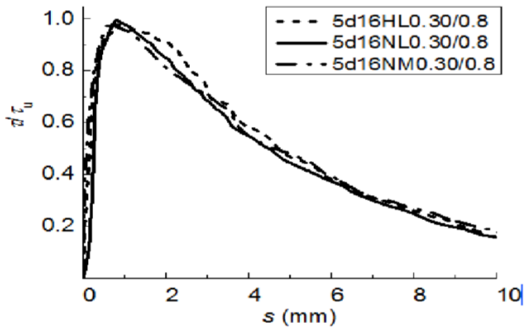

Fig 4. The effect of fine and coarse agg. On normalized bond stress-slip curve [46]

From figure above can observed Higher bond strength and fullness of bond stress-slip curve of (HL0.30/0.8)for steel fiber reinforced LWC made with (H; expanded shale as coarse agg. of 6.2 MPa cylinder compressive strength and 917kg/m^3bulk density)[46] . This showed that the strength of expanded shales contributed in the resistance to the challenging action under shear and compression. While (NM0.30/0.8) steel fiber reinforced LWC made with (M; manufactured sand 2.5 fineness modulus and 1930kg/m^3bulk density) had higher compressive strength and relatively lower strength in tensile compared with (NL0.30/0.8) that leads to equal of both bond strength and bond stress-slip curve[46]. However, the strength of coarse expanded shale affected the bond strength significantly, While the impact of finely expanded shale replaced with manufactured sand may be excluded[46].

Other investigators investigated the bond strength by using lightweight aggregates as replacement partially of fine aggregate such as In 2009, (Lachemi, 2009)[16] using lightweight concrete 1894kg/m^3 *made* with blast furnace slag aggregates as fine aggregates replacement and noted that the bond strength was reduced 15% by adopting pull out test. Also, in 2014, (Bogas, 2014)[33] studied the bond behavior of lightweight concrete1840kg/m^3 by replacement normal sand with expanded clay and found that the reduction of bond strength was 33%. On the other hand there are some researchers who used high level of lightweight aggregate as replacement of fine aggregates for example, in 2009, (Yang, 2009)[18], investigated the bond strength of lightweight concrete with density 1153.2kg/m^3 containing expanded clay as fine aggregates replacement at level more than 50% and discovered the decrease of bond strength was higher than 30% the method of test adopted was pull out test. And In 1995, (Khanbilvardi, 1995)[8] , who replaced fine aggregates by sludge ash at level more than 30% and noted decreased of bond strength by 33% by using beam test .We note from the above that all the researchers have reached the same result is a significant reduction in the strength of the bond when using lightweight aggregates as an alternative to fine aggregates.

3. Bond strength of lightweight concrete by using different admixtures

Many researchers have tried through previous studies to improve the strength of the bond between the reinforcing bar and lightweight concrete, some of them used different chemical additives like, super plastisizer and some of them used mineral additives such as, slag, fly ash, silica fume and metakaolin while others tried to improved bond strength by using fibers such as, Polypropylene and steel fibers. These researchers are M.

Collepardi, M. Corradi, in 1979,[3] added SP to the lightweight concrete mix and noted that the bond strength increased this attributed to the reduction of water and water to binder ratio so compressive strength of concrete increased , A. Mor, In 1993,[6] investigated the bond strength of lightweight concrete by partially replacement of cement by silica fume and found that the bond strength improved by two times more than lightweight concrete without silica fume, In 2011, E. Sancak, O. Simsek, A.C. Apay,[20] studied the effect of additive silica fume with superplasticizer (5% and 2% respectively)(10% and 2% respectively) and silica fume only(5%)(10%) in lightweight concrete with density 23% lower than that of normal weight concrete and observed that increased bond strength in case of both SP and silica fume were presented while the decrease obvious in bond strength when silica fume used only without superplasticizer, results of bond strength were obtained using the pull test.

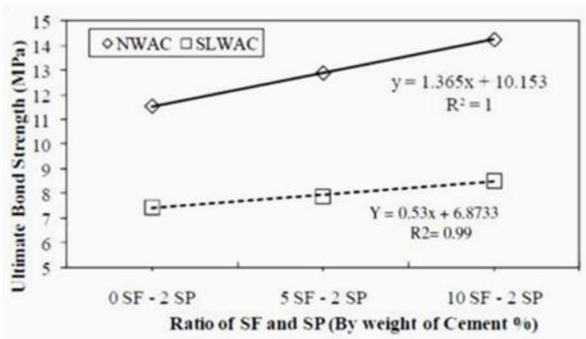

Fig 5. The effect of adding both silica fume and superplastisizer on bond strength of lightweight aggregates concrete [20]

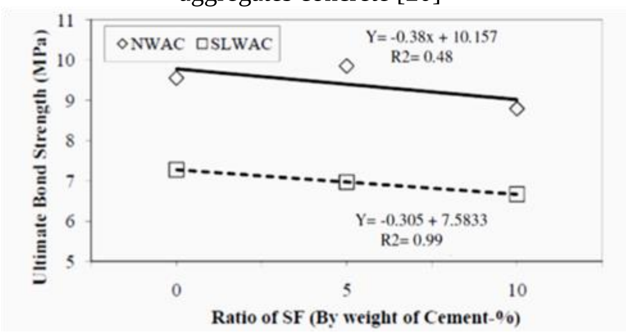

Fig 6. The effect of adding silica fume on bond strength of lightweight aggregates concrete[20]

Another researcher In 2009, H. Tanyildizi,[17] replaced cement by 10% of silica fume and observed an increase in bond strength (using pull out test) of lightweight concrete containing scoria aggregate (its oven dry density $1074 kg/m^3$) was 30%. But some researchers a proved that a clear decline in bond strength of LWC when using mineral admixture like silica fume and fly ash those investigators was J.A. Bogas, M.G. Gomes, S. Real in 2014,[33] who used silica fume as additive in lightweight concrete and observed an reduction of bond strength by 9%. He attributed the minor effect of silica fume on the lightweight concrete's bonding strength to its impact on the chemical and physical adhesion component. Also, H. Tanyildizi, in 2009[17] , reached the same result with low bond strength by replacement of cement with fly ash at level 15% in lightweight concrete made from scoria aggregate compared to concrete containing silica fume which it's strength to bond increased . On the other side, K.H. Mo, U.J. Alengaram, M.Z. Jumaat, S.P. Yap, in 2015,[38] replaced cement with ground granulated blast.furnace slag at high level more than 60% and found a decrease in the strength of bond (using pull out test) of lightweight concrete($1880 kg/m^3$) made from oil palm shell aggregates. Other researcher approved that the distinction in bond strength of lightweight concrete containing expanded shale aggregates was not gigantic when using metakaolin as an additive. O. Karahan, K.M.A. Hossain, E. Ozbay, M. Lachemi, E. Sancak, in 2012[22]. In addition, some researchers have considered the effect of adding fiber in lightweight concrete to the bonding behavior of this concrete such as, A. Ali, S. Iqbal, K. Holschemacher, T.A. Bier in 2016,[40] carried out an experimental to investigate the effect of adding steel fiber with aspect ratio of 70 on bond strength of lightweight concrete by using pull out test and found that adding steel fibers with ratio of 0.5% increase the strength of bond more than 28% while decreasing the ratio of steel fibers to 0.25% Has no significant effect on bond strength , J.A. Rahim, S.H. Hamzah, H.M. Saman in 2014,[34] adding steel fibers with ratio of 0.5% to lightweight concrete containing expanded polystyrene and noted decrease the bond strength because of the steel fiber holding in combination, voids arose, results of bond strength were obtained using the pull test.

Other researcher used pull out test observed that the improved in bond strength was lower (7%-22%) and (18%-39%) when investigated the bond behavior of lightweight concrete includes expanded clay in addition to steel fibers have aspect ratio of 60 in the ratio of (1%-2%) ,respectively G. Campione, C. Cucchiara, L. La Mendola, M. Papia in 2005[11]. One researcher found that bond strength of coldbonded fly ash lightweight self-compacting concrete with very low weight (1631.52kg/m^3) increased from 45% to 70% when adding steel fibers more than 1% while increase this ratio to 1.5% will increase the strength of bond for the same type of concrete from 60% to 80 % adopting PO (pull out test) E. Guneyisi, M. Gesoglu, S. Ipek in 2013[25]. As will as the researchers (Aamer, Lina, Yaqoob,2019)[48] studied the effect of steel fibers in lightweight porcelanite agg. concrete on bond strength by using three frictional volume of steel fiber (0.5% , 1% , 1.5%) and found the improvement in bond strength was (43% ,55.82% ,63.57%) respectively , compared with base LWAC without fibers. Moreover, in 2017 the researcher Mo, K. H., Goh, S. H., Alengaram, U. J., Visintin, P., & Jumaat, M. Z. (2017)[43] conducted a pull out test to study the bond strength behavior of lightweight concrete having 32.20Mpa compressive strength, 1890kg/m^3 oven dry density and containing oil palm shell aggregates and found through experience that Include the concrete mixture with steel fibers at a rate up to 1% improve both bond and tensile strength of that lightweight concrete. On the other hand**,** by using another type of fibers and the direct test method for bonding strength (pull out test) by M. El Zareef, M. Schlaich in 2008,[13] who used polypropylene fibers as an additive to ultra-light weight concrete (Dry density 0.760 g/cm3) made from expanded clay aggregates and discovered that this fibers with 6mm length reduced the bond strength of LWC but by using glass FRP bar the decreased in bond strength was higher compared to utilize normal steel reinforcing bar, also observed that utilizing PP fiber of 20 mm length , increased the bond strength higher than 5% by using glass FRP & 25% when utilize steel reinforcing bar. And Doostmohamadi, A., Karamloo, M., & Afzali-Naniz, O. (2020)[50] discover that using polyolefin macro fibers with two friction volume (0.3% and 0.5%) by volume of self-compacting lightweight concrete improved the bond strength between GFRP bars coated with sand (8mm diameter) and self-compacting lightweight concrete (36MPa and 40MPa) and stated that the use of fibers restricts the longitudinal parallel cracks to the bar and splitting failure will not observed in concrete specimens in the present of fibers within concrete mixes.

4. The effect of rebar variables on the bond strength of lightweight concrete

a-Reinforcing type

Many researchers carried out an experimental works to investigate the bond behavior of lightweight concrete using deferent types of reinforcing bars, generally most of them found that using deformed bars give high bond strength comparing with the use of plain bars and contributed that to the present of ribs in deformed bars which enhancing both of frictional and mechanical force between concrete and reinforcing bar and so bond strength will increase[14][2][12][23][39]**,** other researchers using (square twisted steel bars, bamboo bars, plain and deformed glass FRP bars, mild steel bars as plain , elliptic plain glass FRP bars) as deferent types of reinforcing bars , on the other side , some researchers coating the surface of reinforcing bars with deferent layers to improve the bond strength of lightweight concrete these layers including (epoxy resin, sand, zinc) (Kim Hung Mo, U. Johnson Alengaram , Mohd Zamin Jumaat, 2016)[39] .These researchers are (C.O. Orangun, 1967)[2] who studied the bond behavior of lightweight concrete containing Lytag aggregates and adopted two methods of test, (pull out & beam test) and the bar used was *square twisted bars , mild steel and Tentor bars* and gets the best results of bond strength by using square twisted bars comparing to tentor bars or mild steel bars .(1995, K. Ghavami)[9] used beam test to investigate the bond strength of lightweight concrete made from expanded clay aggregates reinforcing with bamboo and compared the results with the same concrete but reinforced with normal steel bar and has been demonstrated that the strength of bond of expanded clay aggregates concrete reinforced with bamboo could be enhanced by applying water repell ent therapy and internal bamboo wiring up to 90 percent. (2008, K.M.A. Hossain)[14] investigated the bond strength of pumic volcanic aggregate concrete1805kg/m^3 air dry density with 28.8 MPa compressive strength reinforced with plain steel bar have 10mm diameter & 125mm bond length as well as deformed steel bars and found that better results of bond strength obtained by using deformed steel bars by adopted pull out test in his experimental work. (2014, J. Zhou, H. Liu, S. Ma, J. Li, H. Hou)[37] Also using bamboo as well as normal steel bars to reinforcing lightweight concrete including shale ceramist (the performance density is 1650kg/m3), and conducted pull out test to investigate the bond strength of this concrete, finally found that bond strength increased by using steel bars. While Li, S., & Song, C. (2020)[51] study the bond anchorage of 1850 grade steel strands and lightweight aggregate concrete(45.8MPa compressive strength) adopting thickness of cover and anchorage length as parameters and found that improving bond strength by using pull out test with greater thickness of cover and increase the length of anchorage.

(1965, J.R. Van Liere)[1] used lightweight concrete made from expanded shale aggregates and two types of reinforcing bar (plain & deformed) steel bars to study the strength of bond also, adopted epoxy resin as coating layer of reinforcing bars surface, the epoxy resin is used by three methods;

1. Coating just before concrete is casted
2. Coating, sand rolling and drying before the concrete is cast,
3. Coating and sand rolling without dry oven before concrete casting

and observed that an improvement in bond strength by using plain steel as reinforcing bars when adopted all previous methods while only method (3) produced the best results for bond strength when using deformed steel bars. (2008, W.C. Tang, T.Y. Lo, R.V. Balendran)[15] used deferent shape of plain glass FRP bars (rounded and elliptical) with lightweight concrete made from polystyrene as an aggregate to study the bond behavior of this concrete through pull out test and found that clear declined in bond strength by using rounded shape of bars while an improvement in the strength of bond up to 40 percentage when used an elliptical shape of bars, on the other side used glass FRP bars and coated them with two types of coating layers(sand and zinc) as a way to improve the bonding strength of this concrete and reinforcing bars, and obtained best results when using sand as an coating layer whilst the strength of bond enhanced by up to 350 percent compared to glass FRP plain bars and by up to 140 percent compared to steel mild bars. It can be seen from previous studies that the coating of the plain reinforcing bar surface significantly improves the bonding strength compared to the deformed bar regardless of the type of coating used.

b-diameter of bar

Previous trials carried out by many scientists have shown that the bond property reduce by the reinforcing bar increase in diameter , for example; K. Gunasekaran, R. Annadurai, P.S. Kumar in 2012[23] investigated different diameters of bars included (8mm,10mm,12mm,16mm) with lightweight concrete (having air dry density 1970 Kg/m^3) made from shell coconut as aggregate to study the bond behavior of this concrete using pull out test, the reinforcing bars used in this work was plain steel bars and observed that increasing bar diameter leads to decrease the strength of bond by 43%. Also, in 2013, X. Wu, Z. Wu, J. Zheng, X. Zhang,[27] found that clear decline in the strength of bond up to 40% by increasing the diameter of bond from 12 to 22 mm when used self-compacted LWC .in addition to D.C.L. Teo, M.A. Mannan, V.J. Kurian, C. Ganapathy,in 2007[12] used light weight oil palm shale concrete with28-day air density of 1960 kg/m^3 reinforced with plain reinforcing bar includes different diameters bars (10mm,12mm,16mm) to study the effect of these bar diameter on bond strength of LWAC and concluded that bond strength reduced by 23% -34% as dia. of bars increased when used pull out test to performance his experimental work. Also In 2010, S. Pul,[19] got the same results when used the same method of test (pull out test) to investigate bond strength of LWC and noted that decreased by up to 7% as increasing diameters of bars from 8mm to 14mm. moreover, Al-Shannag, M. J., & Charif, A. (2017)[44]study various diameters of bar (∅12, ∅14, ∅16, ∅20, ∅25) in his experimental work on bond strength between steel bars and lightweight concrete containing natural lightweight aggregates and two ratios of cement 350kg/m^3 and 500kg/m^3 with 34MPa and 48MPa compressive strength respectively and 1860kg/m^3 and 1925kg/m^3 oven dry unit weight respectively, And reached to fact that a decrease in the bonding strength, with an increase in the diameter of the bar and a decrease in the compressive strength. While Hoque, M. M., Islam, M. N., Islam, M., & Kader, M. A. (2020[52] investigate the bond strength between crushed clay bricks aggregate (1046kg/m^3) concrete (30Mpa, 25Mpa, 20Mpa $f_{c'}$) and steel bars (12mm, 16mm, 20mm diameters) and discovered that the minimum(2.75mm) and maximum (6mm) slips were noted by using 12 mm and 6 mm diameter bar respectively. And stated that higher slips for larger diameter bars compared with lower diameters bars. on the other side there were some investigators have proved counterproductive to the above like, D. Zhang, W. Yang in 2014[36] used pull out test to investigate the strength of bond of lightweight shale ceramsite aggregates (having apparent density1,250kg/m^3) concrete reinforced in two groups , the first with plain reinforced bar 6mm diameter and the second with deformed bars includes different diameters (16mm, 20mm,25mm) and Noted the obvious increase in the bond strength as dia. of bar increased. Another researcher was T. Uygunoglu, W. Brostow, O. Gencel, I.B. Topcu, In 2013[31] also used pull out test to investigate the bond strength of polymer lightweight aggregate concrete with densities (1346kg/m^3, 1469kg/m^3,1464kg/m^3)according to the fiber content(0%,0.5%,1%) respectively, reinforced with steel bars ∅12,∅14,∅16 embedded in cubic molds and observed that an increasing in the bond strength when increase the diameter of bars.

c-bond length

Its observed from many previews studies that the strength of bond of LWC decrease as length of bond of reinforcing bar increase that is occur as a result of illegal-uniform spread of the stresses of bond around the bond length(W. Yang, J. Yu, Y. Wang, in 2012[24] & K.M.A. Hossain, in 2008[14]). When used pull out test by D. Kim, M.S. Kim, G.Y. Yun, Y.H. Lee, In 2013[29] , to investigate the bond strength of light-weight concrete and deformed steel reinforcing bars of different bond length 40mm, 80mm, 120mm, 150mm embedded in light weight concrete includes bottom ash aggregate concrete some specimens with density 1880 kg/m^3 and others with 1650kg/m^3 and found that by increasing the length of bond an obvious reduction was noted in the bond strength. Also, In 2012 and 2008, approved the same results by W. Yang, J. Yu, Y. Wang[24] and W.C. Tang, T.Y. Lo, R.V. Balendran[15], respectively when the first researcher used steel reinforced bars with length of bond ranging from 60mm to 120mm and lightweight concrete made from shale ceramic as aggregates then observed that the reduction in the bond strength by using pull out test was up to 29%. And the second researcher used bond length of reinforcing bar varied from 50mm to 90mm embedded in the polystyrene LWC (450kg/m^3 density). In 2008, K.M.A. Hossain,[14] utilized plain steel bar with 125mm bond length and deformed steel with 75mm and 175m bond length embedded in the same type of concrete includes lightweight pumice aggregate concrete(1805kg/m^3 density) and noted the decreased was 26% of the strength of bond as the bond length increased .another researcher In 2014, J. Zhou, H. Liu, S. Ma, J. Li, H. Hou,[37] used another type of reinforced bar it was bamboo bars and observed a reduction in the bond strength as the bond length increased when the length of bond used was varied from 25mm to 150mm and the type of concrete was lightweight concrete containing ceramsite with performance density was 1650 kg/m^3.

5. The bond strength of lightweight aerated concrete

This type of lightweight concrete is free from coarse aggregate and contains only cement, fine aggregates (sand) , water, and at least 20% of air by the volume and the air is introduced into this concrete either by using an air entraining agent and concrete resulting in this way called aerated concrete or by the use of foam in this way, concrete is called foamed concrete. The density of this concrete ranging from 400 $Kg/m^3$to 1800 Kg/m^3 (Van Rooyen, Algurnon Steve (2013)[30] . Low densities of this concrete can not be used structurally, but only used for thermal and acoustic insulation. High densities have wide structural applications, for example, this concrete is very suitable for use with high-altitude buildings and those characterized by high temperature changes in addition to reducing the use of reinforcing bars with this type of concrete due to the low density of this concrete as well as faster construction and cost savings when using aerated concrete. The previous studies of the bonding strength for these type of concrete are limited for example; In 2014, A.F. Maree, K.H. Riad[35] approved that as a result of water to binder ratio used in light weight aerated concrete is low, the bond strength of this concrete increased by using stirrups and bars with small diameter comparing with normal concrete also, the slippage increased compared to normal concrete because of the high strength of bond and low modulus of elasticity for aerated concrete. on the other side both P.E. Regan in 1979[4] and H. Weigler, S. Karl in 1980[5] Proved the opposite of the above, whereas H. Weigler, S. Karl,1980[5] found clear decline in the bond strength with increasing the air contain in concrete when used pull out test to pull reinforcing bar from foamed concrete and P.E. Regan,1979[4] also used pull out test to investigate the strength of bond of aerated concrete the reinforcing bar utilized in this experimental work was 8mm diameter and 450mm bond length and noted that the bond strength was 1.17–1.34 MPa which was lower than conventional concrete and mentioned that the used of stirrups helped to make the bond strength increase due to spread loads through concrete. In 2011, B.I.N. Ayudhya, Y. Ungkoon [21] , used FRP bars (carbon FRP, aramid FRP & fiberglass) embedded into autoclaved aerated concrete and noted the bond strength of steel deformed bars was higher and the mode of failure was splitting failure of foamed concrete while the use of FRP bars leads to lower bond strength and the mode of failure was pull out failure .as well as found that lower bond strength of aramid fibers than carbon fibers and when used layer of sand to covered the bar surface noted an obvious increase in the strength of bond of autoclaved aerated concrete. Another researcher in 2013, M. Ramezani, J. Vilches, T. Neitzert[28] got satisfactory results of bond strength when pulled out steel strip with large diameter holes. The most recently studies was in 2016 and 2017 , by Nindyawati and Baiq, S. U. (2016)[41] explored the effectiveness of bamboo in lightweight foamed concrete as reinforcement. The research concentrated mainly on the effectiveness of bamboo bonding in foamed concrete with average f_c' of 12.7MPa, the strength of PO was between 0.33-0.48MPa. premised on bond pullout test with direct tension. and by Johannes P. de Villiers | Gideon P.A.G. van Zijl | Algurnon S. van Rooyen,2017[42] , who utilized the two type of test (pull out and beam end tests) to investigate the strength of bond of foamed concrete and found that the increased in the bond strength with increase the density of foamed concrete when used beam end test was lower also the specimens of beams showed early and sharp crack compared to normal concrete while clear increased in bond strength when used pull out test as the density of this concrete increased too.

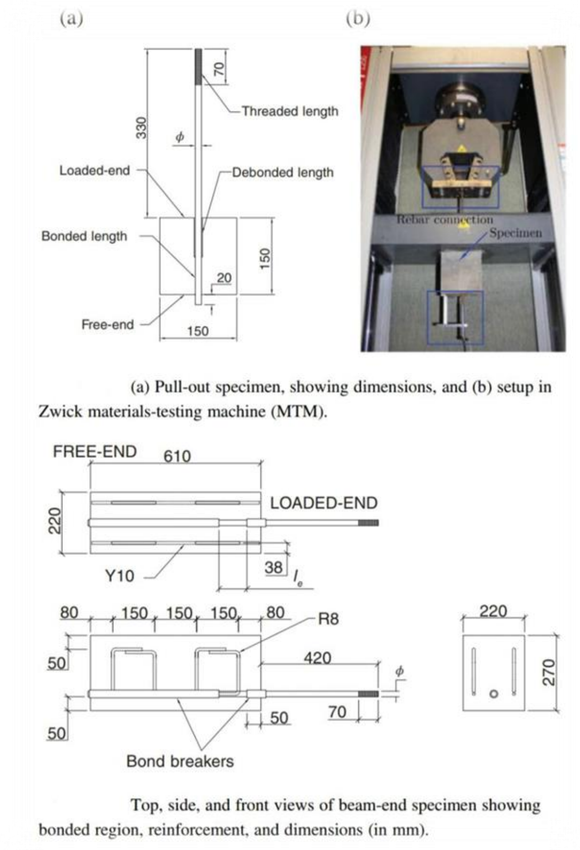

Fig 7. Details regarding the pull-out test and the Beam end test [42]

6. Conclusion

Most researchers have found paradoxical results from their studies and researches on the bonding properties of lightweight concrete. The reason for this is due to the different examination methods used by one researcher to another**,** some of them relied on the use of pull out tests and others relied on the use of the beam ends test while others adopted the both tests. Through review of previous studies, the bonding properties of lightweight concrete can be summarized as follows:

1. Increase the percentage of normal weight aggregates replacement from (25%-100%) by lightweight aggregate leads to reduce bond strength between (4.93%-15.92%) by using small diameter of bars, while the percentage of reduction between (1.48%-7.76%) when using large bars diameters
2. About 50% of the researchers agreed to increase the lightweight aggregate concrete bonding strength compared to normal weight concrete, as the results of the bond test ranged between (13.1Mpa-19.822Mpa) for lightweight aggregate concrete
3. Bond strength of cement-base lightweight aggregate concrete was (10.3MPa-15.58Mpa) higher than that for geopolymer-base lightweight aggregate concrete which was (10.04Mpa-11.34Mpa)
4. All researchers determined the use of lightweight aggregate as an alternative to fine aggregate in the production of lightweight concrete, resulting in decreased bonding resistance by (15%-33%) between concrete and reinforcing bars. This depends on the approved replacement percentage, as it varies from one researcher to another
5. Added both of silica fume at rate up to 10% by cement weight and SP. Up to 2% can enhance the bond strength of structural lightweight aggregate concrete by 60% compared to normal weight aggregate concrete
6. Some additives lead to decrease bond strength such as fly ash and GGBS when added at level 15% and 60% respectively. While, other additive such as metakaolin has no significant effect on bond strength.
7. Previews researchers used different friction volume of steel fibers (0.25%, 0.5%, 1%, 1.5%, 2%) in their experimental works,the rates of improvement in bond strength varied from one researcher to another because of the difference in other adopted variables from one researcher to another. As the improvement in bond strength when used percentage 0.5% was 28% and 43%, the percentage 1% was 15%, 25%, 55.82% , the percentage 1.5% was 20%, 63.57%, and 2% was 21% while, 0.25% has no significant effect on bond property.
8. The effect of polypropylene fibers on bonding resistance depends on the lengths of fibers, as short lengths (6mm) have a negative effect on bonding resistance compared to large lengths (20mm) which improve the bond strength up to 5% and 25% when using GFRP and steel bars respectively.
9. All researchers reached the same result when using different types of reinforcing

bars for the purpose of studying the strength of the bond between them and lightweight concrete، and they designed that the use of deformed steel bars gave the best bonding results where the bond strength ranged between (7.06MPa-12.5MPa) as the bond resistance is affected by other factors that differ From one researcher to another، such as concrete strength, bonding length and bar diameter.

10. Covering the surface of the plain bars with a different layers adopted by previews researchers (sand, epoxy resin, zinc, Negrolin-sand-wire) could significantly improve the bonding performance of these bars embedded into Lightweight concrete. By up to 90% for bamboo bars, 350% for GFRP bars compared to plain one, 140% for GFRP compared to mild steel.
11. 80% of the researchers concluded a clear decrease in the results of the bond strength ranging between (7%-43%) when using bars of large diameters. Where different bars diameters ranging from ($\emptyset 8\ to\ \emptyset 25$) were studied.
12. Different bonding lengths ranging from (25mm to 175mm) were used during the study of the bonding property between reinforcing bars and lightweight concrete, and the same result was reached by all researchers. Which is the decrease in the bonding resistance by about 26% to 29% when increasing the bonding length.
13. The bonding resistance of Lightweight aerated Concrete is much less compared to normal concrete and has been improved during previous studies by using certain techniques such as the use of stirrups, where the bonding strength improved by 4%, in addition it is recommended to use high densities for this concrete in order to enhance the bonding strength, where the previous densities used of this concrete ranged from ($700Kg/m^3$ to $1850Kg/m^3$) as an entrained air contributes to reduce the density by 20-25%.

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