Hardened properties of High Strength Lightweight Concrete

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Abstract

The current paper presents a comprehensive and detailed review of previous research on the performance hardened properties of high-strength lightweight concrete are discussed in this review. Lightweight concrete with a high strength is widely used in a variety of structural applications. The effects of new materials and mineral admixtures on performance and strength is not properly investigated. The strength of concrete mix is dependent on many parameters like cement type, mineral admixtures, fibers, Coarse aggregate and the interface between aggregate and mortar, the type of course aggregate used has a great influence on the strength and elasticity modulus of concrete. High strength lightweight concrete now uses silica fume, fly ash, and ground granulated blast-furnace slag in its mixed cements. These cementitious materials can contribute up to 25% of the total cement weight in most blends. Fly ash and slag cement contribute to a better finish, reduced permeability, and improved resistance to chemical attack, while silica fume adds to strength and durability. The effects of various mineral admixtures on the performance of high-strength concrete are discussed, including fly ash, silica fume, and slag. The effect of different types of coarse aggregate, mineral admixtures, and fibers on various properties of concrete mix, such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, toughness, and Poisson's ratio, is reviewed in this paper.

Keywords: High strength, lightweight concrete, modulus elasticity, density, Aggregate, Mineral admixture

1. INTRODUCTION

Recently, with the increasing construction of super high buildings, larger sized and longer span concrete structures, higher strength, lightweight, toughness, and other concrete performance standards have grown, the concrete industry is now the largest consumer of natural materials. It consumes 2.282 billion tons of cement annually, 10-12 billion tons of stones and rocks mixed, and 1 billion tons of mixing water **[1]**. Because of the high strength-to-unit-weight ratio that can be obtained, lightweight concrete is a famous alternative to normal concrete. This type of concrete has a unit weight that is at least 22% lower than a normal weight mix of equal strength. For several years **[2]**, lightweight aggregate concrete has been used economically in numerous reinforced and prestressed concrete structures all over the world. Multistory building frames, floors, shell roofs, curtain walls, folded plates, bridges, prestressed and precast elements of all types are among its applications , in concrete construction, self-weight represent a large portion of the overall load on the structure, and there are great advantages of decreasing concrete density. For the same strength level, a reduced density of concrete allows for a reduction in dead load for structural construction and foundation. As a result, more research on the properties of high-strength, lightweight concrete has been available in recent years and the best option for achieving an environmentally friendly and sustainable concrete industry is to use waste and by-product materials in concrete mixtures instead of raw materials **[3]**, Lightweight concrete (LWC) is an interesting field of study that has been used in structures since ancient. It has a range of benefits, including improved thermal insulation, sound absorption, fire and frost resistance, and seismic damping, the benefits of structural lightweight concrete over normal concrete are many well accepted. Lightweight aggregates produced from manufacturing by-products are used in the environmentally friendly. Since normal weight concrete has a low strength-to-weight ratio, it is expensive to use in structural members such as multi-story buildings, bridges, and floating structures. The most effective solution is to use high-strength lightweight concrete (HSLWC). By minimizing the cross sections of beams, columns, and foundations, it will also decrease the dead load of the buildings, In addition to becoming lighter weight, this type of concrete has strong thermal insulation and has a high durability **[4]**, Lightweight concrete is typically specified for structural concrete, concrete masonry units, or insulating purposes, depending on its unit weight and strength. The practical range of lightweight concrete 28-day dry unit weight is 300 to 1900 kg/m^3 **[3].** Many types of lightweight aggregates, such as foamed slag, volcanic cinders, diatomite, expanded clay, tuff, scoria, shale, granite, vermiculite, perlite, and industrial by-products such as sintered slate, pulverized-fuel ash, and expanded blast-furnace slag, have been used as building materials in recent years. The artificial light weight aggregate (LWA) were created using high temperatures and pressures, resulting in high fuel costs**,** As a result, waste materials are the perfect potential source for LWA, Which significantly reduces the construction costs as well as has many benefits in environmental issues **[4].**

The density of LWA varies with particle size, with fine and smaller particles having a higher density than coarse particles. The size of this difference is therefore determined by the aggregate manufacturing processes. As a result, changes in aggregate grain size can lead to changes in density. The properties of lightweight concrete, and hence LWA, can be used in a variety of ways, from construction applications to thermal insulation in structures. Furthermore, because of its lower thermal conductivity, lower coefficient of thermal expansion, and the inherent thermal stability of an aggregate heated to more than 1093°C, lightweight concrete is more fire resistant than ordinary concrete. **[5].**

The disposal of old rubber tires has been a major environmental issue around the world. Millions of tires reach the end of their useful life per year, resulting in a significant volume of non-biodegradable solid waste in the environment. In the past, the building industry took on the task of substituting these materials for natural aggregates in concrete manufacturing, According to previous research on the properties of rubberized concrete (RBC), applying rubber to concrete decreases its workability and mechanical properties. Many procedures for enhancing the engineering characteristics of RBC have been presented in the literature to resolve this defect, including rubber pre-treatment with sodium hydroxide (NaOH) solvent, the inclusion of materials including silica fume and steel fiber, and pre-coating with limestone powder. The aim of this analysis was to monitor the negative effect of applying a large amount of rubber particles with a maximum size of 12 mm to concrete by using a NaOH pre-treatment process with the inclusion of both silica fume and steel fiber as well as to obtain an optimal strength and workability **[6,8].**

The type of aggregate used, as well as the moisture state of the aggregate, have a significant impact on the concrete's properties, only artificially developed LWA is ideal for the development of structural concretes, according to the relationship. One of these potential materials for making concrete lighter than standard aggregate concrete is sintered fly ash lightweight aggregate. One initiative to increase the structural strength of concrete is to reduce the self-weight of the concrete without reducing its strength. High-end pozzolanic materials such as metakaolin (MK) and silica fume (SF) must be used to create high-strength concrete. According to previous research, the optimal dosage of metakaolin and silica fume to improve the concrete's matured properties is 10 to 15 % replacement amounts, a stronger paste can be created inside the concrete matrix by using a lower water-binder ratio and a good pozzolanic content. to create a more effective approach for developing high strength, high performance lightweight concrete using sintered fly ash aggregate, as well as to investigate the effects of metakaolin and silica fume on the mechanical and durability properties of the formed concretes **[9,10].**

It is very popular to use silica fume (SF) in the production of high-performance concretes. Many systematic studies conducted by many research groups around the world have shown that using silica fume in concrete improves concrete strength, modulus of elasticity, chemical and abrasion resistance, as well as improving toughness, corrosion resistance, and mechanical properties. However, despite the fact that some researchers have identified different replacement ratios, there is no simple, unique conclusion about the optimum silica fume replacement percentages, it is very popular to use silica fume (SF) in the production of high-performance concretes. Many systematic studies conducted by many research groups around the world have shown that using silica fume in concrete improves concrete strength, modulus of elasticity, chemical and abrasion resistance, as well as improving toughness, corrosion resistance, and mechanical properties. However, despite the fact that some researchers have identified different replacement ratios, there is no clear, specific conclusion about the optimum silica fume replacement percentages. **[11].**

The use of lightweight aggregate in concrete has a number of benefits such as Reduce the amount of dead load that's lead to reduce the footing sizes and gets lighter and smaller upper structure, and Low transportation costs due to lighter weight and smaller precast components, and Beams, columns, and slabs have been reduced in size and dimension, and the flat area has been increased, and High thermal efficiency, and Resistance to fire has improved. The production and usage of LWA have many benefits such as FA can be recycled effectively, and Natural materials (sand and coarse aggregate) are rare in nature and should be protected, and protects the riverbed and beaches from the damage caused by aggregate production, and reduces the greenhouse gas emissions and specific energy consumption rates by reducing the need for the vast amount of cement which contributes majorly to carbon dioxide emissions. As compared to other conventional pozzolanic materials, Nanosilica is very effective at increasing the strength, durability, and microstructure of cement paste. The benefits of incorporating nanotechnology into cement and mortar are many. It increases cement manufacturing, improves the properties of construction, revolutionizes efficiency monitoring, and has the ability to reduce permeability, The FA has low initial activity, but after using small amounts of Nanosilica, the pozzolanic activity significantly increased, and Nano-particles react with calcium hydroxide crystals to create C-S-H gel, which is arrayed in the Interfacial transition zone between hardened cement paste and aggregate. **[12]**.

In the production of lightweight concrete, agricultural waste such as oil palm shell (OPS), palm oil clinker (POC), and coconut shell has been used as a replacement aggregate instead of conventional crushed gravel aggregate. The use of OPS as a lightweight coarse aggregate in the construction of lightweight aggregate concrete has a long history of research, but POC is a relatively new renewable material in the production of lightweight concrete, POC boulders range in size from 100 to 300 mm in diameter. These boulders are then crushed to the appropriate size for lightweight concrete development. The aim of this waste material is to improve the mechanical properties of HSLWC by mixing waste POC into new lightweight concrete. As a replacement for OPS coarse aggregate, different percentages of POC were tested. Compressive strength, stress-strain behavior, and HSLWC modulus of elasticity are among the mechanical properties investigated. **[13].**

Short fibers have been used to strengthen brittle materials like cement and masonry bricks for centuries. Steel, glass, industrial materials (polypropylene, cement, nylon, etc.) and some natural fibers are now available for commercial use in a variety of fiber forms. There have been several laboratory studies on the use of polypropylene fibers in concrete. For this use, volume percentages of polypropylene fibers ranged from 0.1 % to 0.5 % in most cases. The effect of various fibers on the mechanical properties of concrete containing fly ash has been shown by a number of researchers. They showed that fiber reinforced fly ash concrete can be used in precast infrastructure components due to the fibers' ability to improve mechanical properties and the beneficial effect of fly ash on other concrete properties **[14].**

2- Objective

In this paper, the effects of various types of strength materials and coarse aggregate on the various properties of concrete are reviewed. Based on a number of papers on the subject, an attempt to determine the effect of the type of strength material and aggregate on mechanical properties such as compressive strength, modulus of elasticity, tensile strength, flexural strength, splitting strength, toughness, and poissons ratio.

3. Materials and Method

A wide range of experimental data of different mechanical properties of high strength lightweight concrete (HSLWC) in this study. These data are collected from 14 published papers in journals, Table 1 shows the sources of data and some general information about the collected data. The number of mixtures for LWC , curing methods, type and maximum size of the natural and lightweight course and fine aggregates, maximum size additional chemical admixtures including the Super Plasticizer (SP), High Range Water Reducing Admixture (HRWRA) and Air-Entraining Agent (AEA) are illustrated in the table. In addition, the types of fiber used in some experimental studies are given, the most common method of producing HSC is by optimizing the combination of cementitious material, aggregates, water, and admixtures. Typically, fly ash or silica fumes substituted for part of Portland cement is an effective method to increase long-term strength. Low w/c ratios also increase concrete strength and the coarse aggregates are partly or completely replaced by natural or artificial lightweight aggregate, and the proportions of the mixture can be varied to produce HSLWC. In this study, the density and mechanical properties of HSLWC are evaluated as the most effective parameters.

Table 1. Source of collected data for HSLWC

Curing Condition	Cementitious Material		Coarse aggregate		Fine aggregate		Lightweight aggregate		Chemical admixture			Fiber	
	cement	Others	Type	Max, size (mm)	Type	Max, size (mm)	Type	Max, size (mm)	S.P	HRWRA	Others	Type	Range
Water	OPC-I	S.F			Sand	Medium Graded	Expanded clay	15	Naphthalene			Steel Fiber	0 - 2%
Fog Room	OPC-I	S.F	Crushed granite		River sand		Sintered fly ash	13	Naphthalene			polypropylene fiber	0.28 - 1.7%
Moist and Air	OPC-I						Tuff	19		F-Plastocrete 163	Air Entrained agent		
Water	OPC-I		Oil palm shell		Sand	4.75	Oil palm boiler clincker		Type G with density 1.09±0.02kg/m3				
Water	OPC-III	S.F	Expanded clay	25	Natural Sand		Clay and Shale LWA	9.5	sulfonated melamine				
Water	OPC-I	S.F	Crushed limestone		Crushed limestone		Coarse rubber particle	12	GLENUIM	Polycarboxylic		Steel Fiber	
Water	OPC-I	S.F			Sand		High-performance shale ceramic		poly-carboxylic type		water reducing agent		
Water	OPC-I	S.F	Crushed limestone	10	Crushed stone	5	Coarse and fine rubber particle	size distribution	GLENIUM 27	Polycarboxylic ether-based		Hooked SF	1%
water and Chloride water	OPC-I	S.F and M.K			River sand		Sintered fly ash	12	S.P				
Water and Air	OPC-II	S.F	Lime stone		River sand		Leca aggregate	4	S.P				
Water	OPC-I	S.F	Coarse aggregate		Sand				S.P				
Water	OPC-I	FA - F	River Gravel		River sand		Light weight coarswe aggregate		Nano silica	Glenium 51			
Water	OPC-I		oil palm shell	12.5	Sand	4.75	Palm oil clincker			Sika ViscoCrete®-2199			
Watwer and curing heating	OPC-I	S.F					Crushed pumice	16				polypropylene fiber	0 - 2%

W/c	References
0.28	[1]
0.25	[2]
0.4	[3[
0.29 and 0.36	[4]
0.31 and 0.26	[5]
0.14	[6]
0.28, 0.32, 0.36 and 0.40	[7]
0.14	[8]
0.25 and 0.35	[9]
0.28 - 0.40	[10]
0.26 - 0.42	[11]
0.35	[12]
0.353	[13]
0.77	[14]

4. Result and Discussion:

Effect of mineral admixture and lightweight coarse aggregate on the hardened properties of concrete are illustrated in table 2

4.1 Compressive strength:

The compressive strength increases with increasing fiber volume fraction and aspect ratio. However, it shows a relatively lower rate of increase shown in the fig.1 [1], Table 2 shows the strength values. As previously said, the presence of fibers in the LWCs had no significant effect on the compressive strength of the concrete that was tested [2], Using lightweight tuff aggregates, and normal techniques, it was possible to produce high strength concrete with a cube compressive strength of 55-60 MPa at 90 days, the strengths under air curing were less that those under moist curing by about 18% for compressive strength shown in the fig.2 [3]. The 28-day compressive strength of the oil palm boiler clinker concrete mixture was about 53.3 MPa, which is about 30.7 % higher than the control oil palm shell concrete [4]. The compressive strength of concrete with lightweight coarse aggregate of Dmax =25 mm, SF, and superplasticiser increased by 27%, reaching 31.5 MPa. The maximum compressive strength achieved in this study with expanded clay was achieved by using lightweight coarse aggregate with Dmax =95 mm [5]. In general, the results showed a substantial decrease in strength of 29 % and 43 % for 15RBC and 25RBC, respectively, indicating that the strength loss is proportional to the amount of rubber used [6, 8]. The compressive strength test results obtained on concretes having water-binder ratio 0.35 and 0.25. It can be observed from the results that, as the Meta kaolin and silica fume (MS) dosage increases the later compressive strength also increases. In the case of 0.35 water-binder ratio concretes, at 28 days 10 to 13% strength reduction was observed due to the incorporation of MS. This may be due to the phenomena called dilution effect, a consequence of replacing a part of cement by the same quantity of met kaolin and silica fume as shown in fig.3 [9]. By using expanded aggregate clay

(Leca). It is observed that whenever the aggregate size is changed from 2 to 4 mm to 1 to 2 mm and 0.5 to 1 mm, compressive strength is increased about 20 and 27 %, respectively [10]. As shown in fig. 4. the isolated effect of SF increases the compressive strength, The percentages of gaining strength with respect to the control mix for w/c 0.26, 0.3, 0.34, 0.38 and 0.42 at 5%, 10%, 15%, 20% and 25% SF replacements are 15.8%, 29.1%, 35.5%, 31.5% and 31.25%, respectively [11]. The maximum compressive strength was obtained at 20 ˚C, 10% silica fume admixture and 1% polypropylene fiber [14].

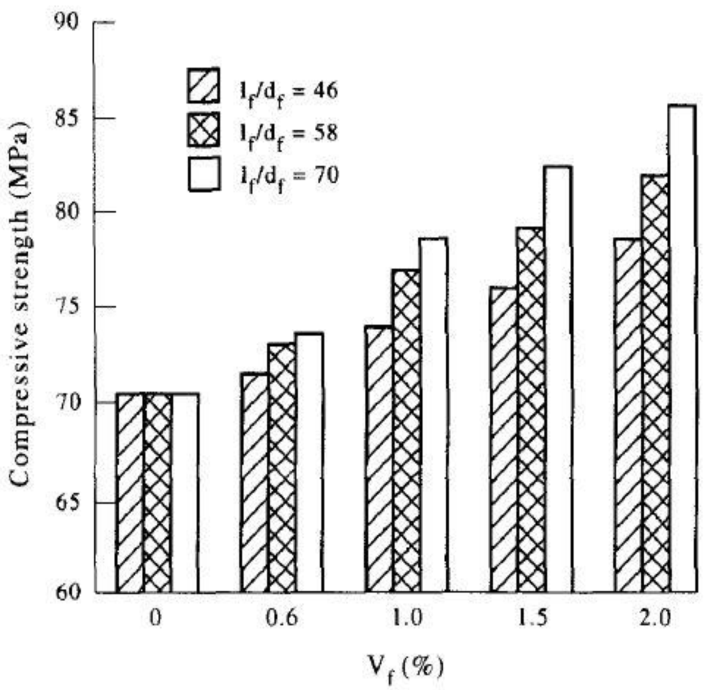


Fig. **1.** Effect of Vf and *1,/d, on* compressive strength [1].

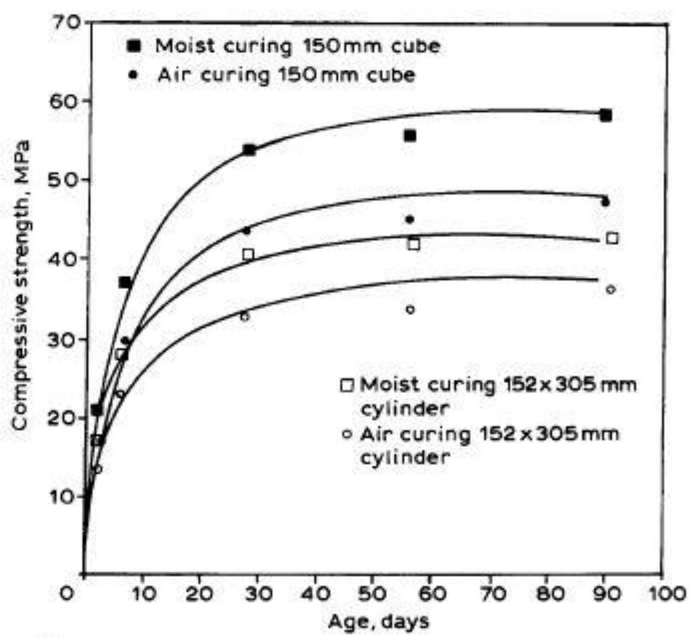
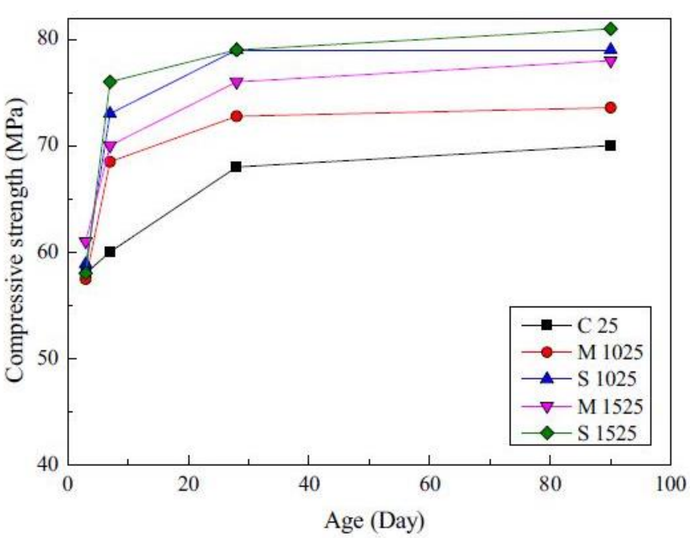


Fig. 2. Effect of moist and air curing on compressive strength [3].



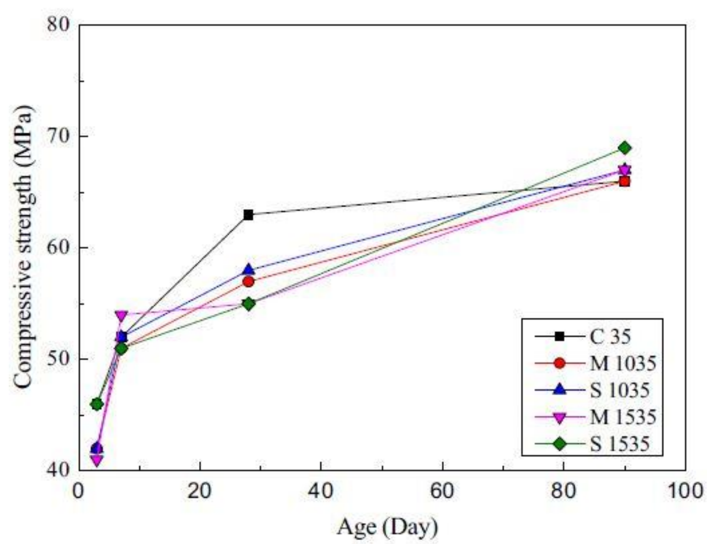


Fig. 3. Effect of MK and SF on compressive strength (w/b= 0.25 and 0.3) [9].

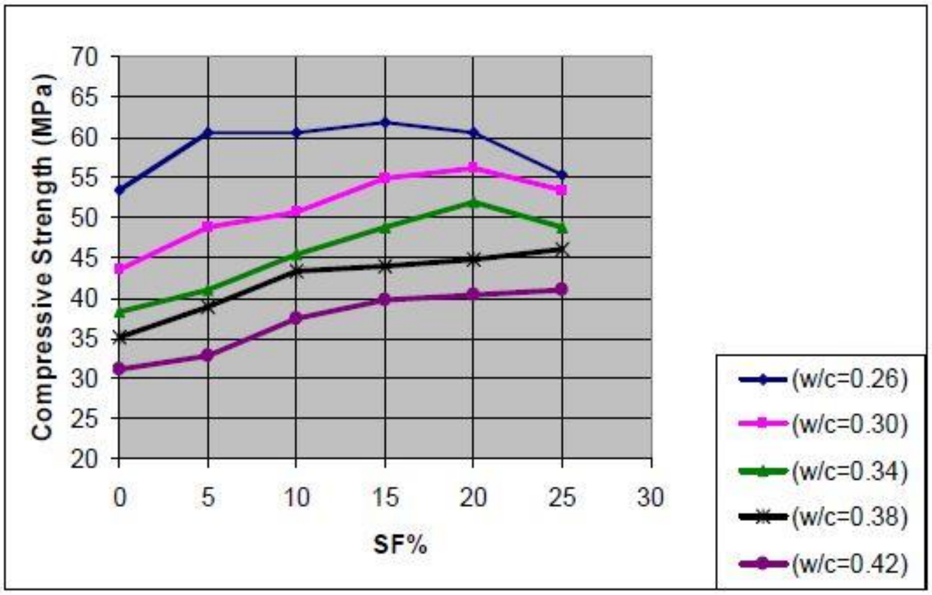


Fig. 4 Relationship between 28 day compressive strength and percentage replacement of silica fume [11].

4.2 Modulus of Elasticity:

The addition of steel fiber to high-strength, lightweight concrete, and the modulus of elasticity of concrete gradually increased with increasing steel fiber volume fraction as shown in fig. 5 [1, 2]. It was reported that the modulus of elasticity for structural lightweight concrete is 17-28 GPa while it is 20-40 GPa for normal weight concrete .The modulus of elasticity of the oil Palm Shell concrete (OPSC) and Oil Palm Boiler Clinker Concrete (OPBCC) mixes were 7.9 and 15.7, respectively. The OPS concrete was considered as a concrete with low elastic modulus, while the replacement of OPS by 50% OPBC aggregates significantly increased the modulus of elasticity by about 50% [4]. The modulus of elasticity is increased by increased the compressive strength as in the fig. 6 [5]. The reduction in the static modulus of elasticity is caused by adding rubber to the concrete mixture resulting in a reduction from 53.6 GPa in the case of Zero Rubberized concrete (ZRBC) to 38.2 GPa and 36.6 GPa in the cases of 15% Rubberized concrete replacement (15RBC) and 25% Rubberized concrete replacement (25RBC) respectively [6].The variation in the static elastic modulus of RBC with respect to the control mixture is due to the reduction in the compressive strength of the RBC specimens [8].

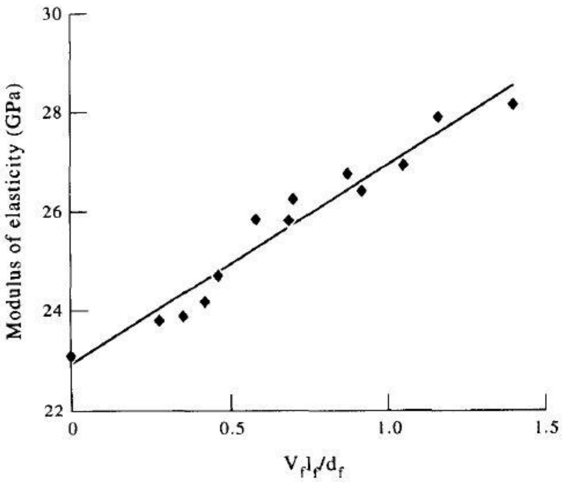


Fig. 5. Effect V l/d on modulus of elasticity [1].

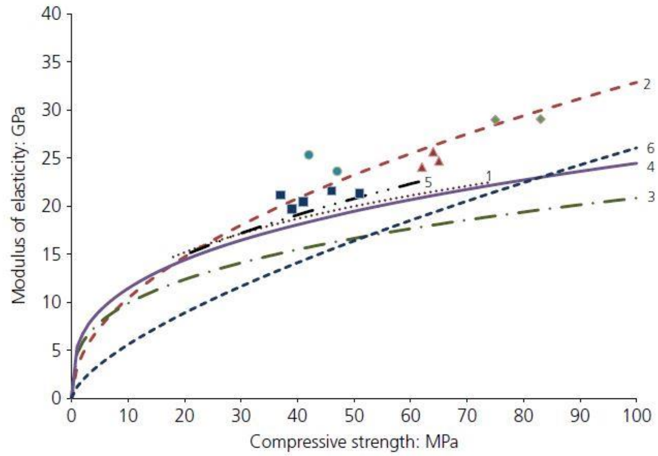


Fig. 6. Modulus elasticity curves [5].

4.3 Flexural Strength:

When the fiber volume fraction increased from 0 to 2%, flexural strength increased from 6.2 to 11.8 MPa. The rate of increase of flexural strength is 9.6 to 90%, depending on the fiber volume fraction and aspect ratio [1].The effect of polypropylene fibers on the modulus of rupture is less marked, on the average an increase of about 13% was measured [2]. Various sizes and shapes of flexural specimens were tested under air and moist curing conditions. The results for flexural strengths is presented in Tables 2, it can be seen that flexural strength is more sensitive to drying conditions than compressive strength at all ages. At 90 days the strengths under air curing were less that those under moist curing by about 18% for compressive strength, regardless of the shape of the specimen, and 39% for flexural strength [3].the flexural strength of OPBCC mix is also higher than OPS control mixture. In order, the OPBCC mix showed the flexural strengths of about 8% higher than the control OPS concrete [4]. The average flexural tensile strength is clear that the negative influence of rubber on strength of concrete includes the flexural tensile strength with a similar reduction pattern of the compressive strength. As can be observed, the flexural strength declines by 16% and 21% for 15RBC and 25RBC respectively [6]. The use of limestone in lightweight concretes results in the flexural strength increase up to 40 %, without

a noticeable increase in the specific gravity [10]. Fig. 8 shows the variation of flexural strength with the SF replacement percentages at different w/c ratios. There is an obvious gain in flexural strength due to SF replacement. This strength increase is better compared with the compressive and tensile strengths for lightweight high strength concrete, the results show that the optimum SF replacement percentage for obtaining maximum 28 day flexural strength of lightweight high strength concrete is depending on the w/c ratio [11].

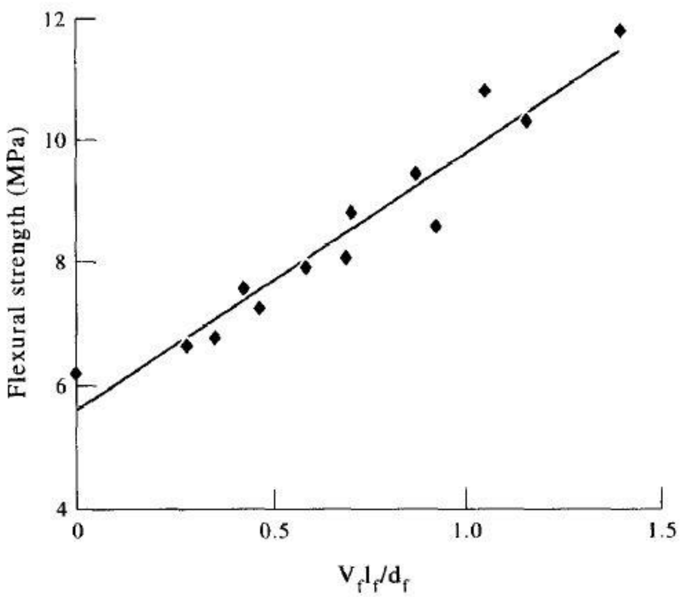


Fig. 7. Effect of V l/d on flexural strength [1].

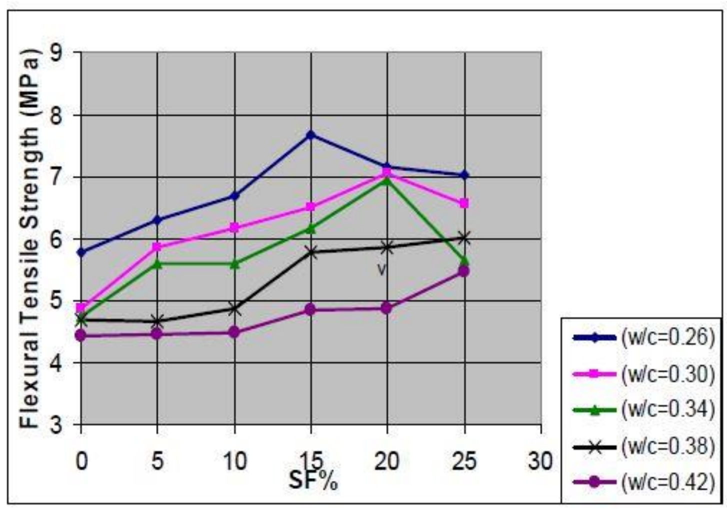
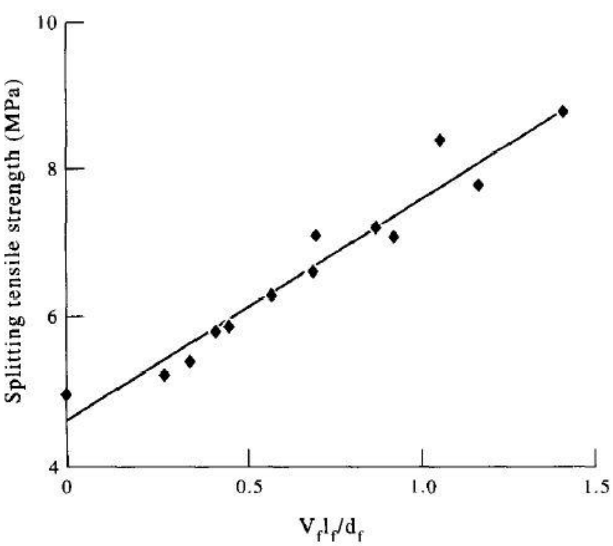


Fig. 8. 28 day flexure strength and % replacement of SF [11]

4.4 Splitting Tensile Strength:

When the fiber volume fraction increased from 0% to 2%, the splitting tensile strength increased from 4.95 to 8.8 MPa. The rate of increase of splitting tensile strength is 9-78%, depending on the various fiber volume fraction and aspect ratios as shown in fig. 9 [1].The indirect tensile strength has increased by the inclusion

of either polypropylene or steel fibers on the average by about 50% [2]. Results for the splitting tensile strength of moist cured specimens are given in Table 2. From the data obtained, and using linear regression analysis [3]. As can be seen in Table 2, both mixes showed significantly higher splitting tensile strength (39% for OPSC and 44% for OPBCC) than the minimum requirement of ASTM-C330 (2005). Generally, the splitting tensile strength of the concretes is proportional to its compressive strength, the higher the compressive strength higher will be the splitting tensile strength [4]. As can be seen in Table 2, both mixes showed significantly higher splitting tensile strength (39% for OPSC and 44% for OPBCC) than the minimum requirement of ASTM-C330 (2005). Generally, the splitting tensile strength of the concretes is proportional to its compressive strength, the higher the compressive strength higher will be the splitting tensile strength [5]. Similar to compressive strength the 28 days splitting tensile strength of concrete, Table 4, was affected by the rubber replacement, in which the observed reduction were 4% and 17% for 15RBC and 25RBC respectively [8]. Fig. 10 shows the variation of split tensile strength with the SF replacement percentages at different w/c ratios. The trend in the strength gain is almost similar to that in compressive strength. The percentages of gaining strength with respect to the control mix for w/c 0.26, 0.3, 0.34, 0.38 and 0.42 at 5%, 10%, 15%, 20% and 25% SF replacements are 26.9%, 22.29%, 28.43%, 27.7% and 39.07%, respectively [11].



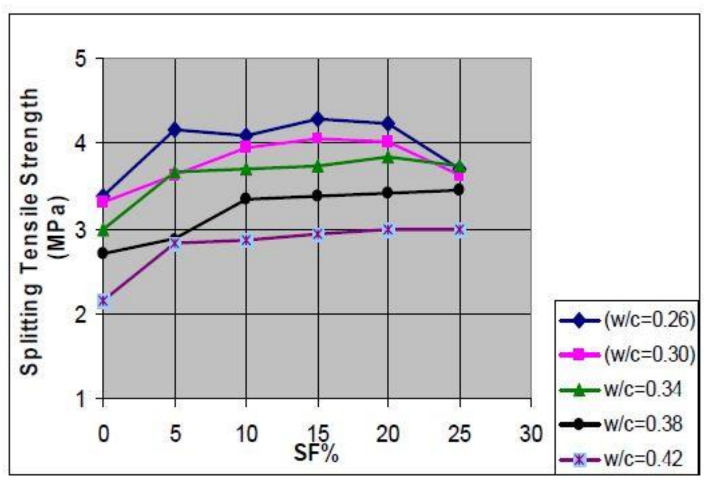


Fig. 9.Effect of V l/d on splitting tensile strength [1]. Fig.10. 28 day split tensile strength and % replacement of S.F [11].

4.5 Density:

It can be seen from Fig. 11 that the density was not affected by the aspect ratio of steel fiber. The fresh concrete density was mainly affected by fiber volume fraction, Increasing the aspect ratio of steel fiber would create mixing problems and may result in concrete of a lower density for the same fiber volume fraction. [1].Reduction of weight of concrete for structural use is the primary advantage of lightweight concrete. The value of the unit weight of high strength tuff lightweight aggregate concrete used in this study was found to be less than that of normal density concrete, and amounted to 1880 kg/m^3 [3]. Table 2 shows that concrete containing OPBC aggregate is heavier than OPS concrete. This is due to the density of OPBC is more than OPS. However, it should be noted that, although the incorporation of OPBC in OPS concrete increased the density, however, the density of OPBC concrete is still in the acceptable range for the structural lightweight concrete [4]. Analyses of LWAC mixtures with superplasticiser and SF showed that C4 (50% mortar) had the lowest density and lower compressive strength at 28 d. It can thus be concluded that density, absorption and voids content are inversely proportional to the concrete strength [5]. The density of the concrete decreased in proportion to the increase in rubber content. This change is due to the significant difference between the specific gravity of rubber and natural stone particles [6]. The dry density of HSLWAC at 28d is shown in Fig. 12. It is noted that HSLWAC prepared by the vibration mixing process possesses a greater dry density than that of the non-vibration mixing process at the same mixing proportion. Therefore, the vibration mixing process can be applied to consolidate HSLWAC and decrease the large air voids and micro-pore sizes, which lead to the optimized mechanical performance of HSLWAC [7]. It has been found that as the quantity of rubber in concrete increases, the density of the concrete decreases. This change is due to the large variation in specific gravity between rubber and natural stone particles [8]. There are differences between limestone and Leca contents. It is seen that dry density has been increased from 1,727 to 1,810 kg/m3. Overall, the density is increased by about 0.5 % using 10 % of limestone in each mix. Increasing the Leca content from 30 to 40 % resulted in a 12 % reduction in the specific gravity. In all the mixtures, it was observed that the increase in density caused increase in compressive strength [10].

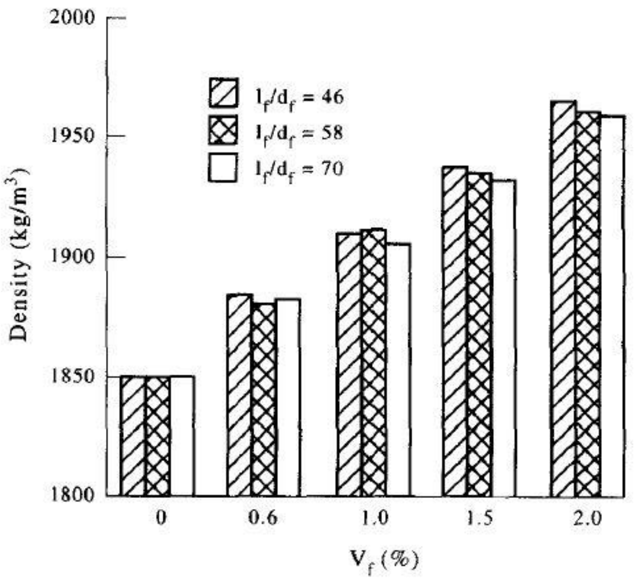


Fig. 11**.** Effect of fiber volume fraction on density [1].

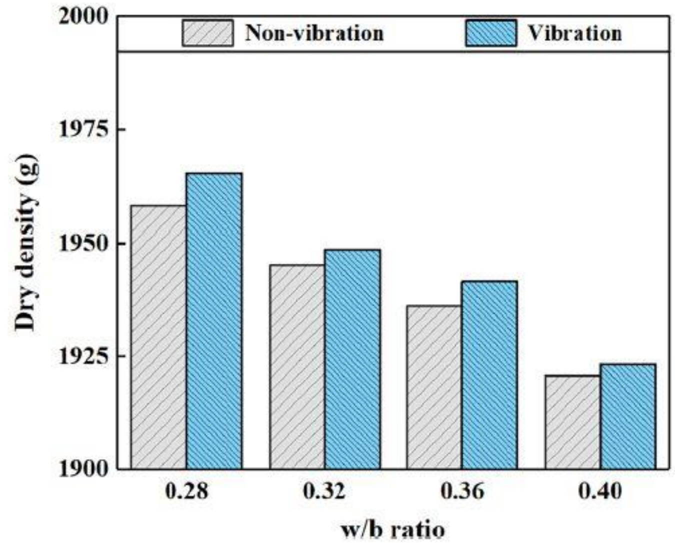


Fig. 12. The dry density under two mixing processes at 7, 28d [7].

Table 2. Mechanical properties of HSLWC from experiments

References	f'_c	E_c	f_r	f_{ct}	γ
	(Mpa)	(Gpa)	(Mpa)	(Mpa)	(KN/m3)
[1]	70.2	23	6.2	4.95	18.5
	70.2	23	6.2	4.95	18.5
	70.2	23	6.2	4.95	18.5
	71	23.9	6.6	5.1	18.8
	72.5	23.9	6.65	5.25	18.6
	74	24.15	7	5.9	18.7
	74.5	24.8	7.5	5.95	19.1
	77	25.9	7.9	6.3	19.15
	78	26	8	6.8	19
	76	26.2	8.8	7	19.35
	79	26.3	8.7	7	19.3
	83	26.45	9.5	6.9	19.25
	78	26.5	10.3	7.8	19.65
	82	27.9	11	8.3	19.6
	85.4	28.15	11.8	8.8	19.55

[2]	72.5	35	6.9	5.1	23.7
	65	24	4.4	3.4	18.9
	65	22	5.2	5.4	18.7
	68	25	5.3	6.6	19
	58	21	4.6	5.8	18.6
	61	21	5.2	4.1	18.9
	62	21	6.1	6.1	19
	61	21	7.9	7.4	19.4
[3]	55.1		4.26		
	45.2		2.3		
	53.5				
	43.8				
	51.5				
	41.2				
	45.5			3.11	
	37.2				
	43.1			3.02	
	35.1				
	40.8			2.94	
	33.5				
[4]	37	7.9	5.38	3.29	17.9
	53.3	15.7	7	3.58	19.4
[5]	43.3	20.8		3.75	17.1
	46.9	21.4		4.38	17.7
	64.3	25		5.55	19.2
[6]	96.77	53.6	6.77		23.12
	68.5	38.2	5.68		21.91
	55.07	36.6	4.88		21.39
[7]	65				19.63
	62.5				19.5
	57.5				19.35
	53				19.2
[8]	96.77	53.06		5.32	23.12
	68.5	38.2		5.1	21.91
	55.07	36.6		4.39	21.39
[10]	32.9		4.44	3.42	16.1
	41.4		5.28	3.24	16.1
	43.7		4.36	2.86	16.5
	44.9		5.43	4.5	16.75
	47.7		7.17	4.68	17
	47.6		6.76	4.27	17.4
	67		9.71	5.59	17.5
	48.2		6.89	4.21	17.8
	38.1		5.63	4.02	18.4
	43.6		4.64	3.92	19

	54.9		8.68	4.97	20
[11]	55		7	3.7	18.52
	54		6.6	3.7	17.75
	48		6	3.6	17.14
	46		5.5	3.5	16.98
	42		5.4	3	17.03
[12]	43.09	14.1			17.87
	49.45	16.4			18.33
	51.47	20.9			18.79
	56.82	27.6			19.25
	63.2	34.8			19.71
[13]	33.88		1.65		
	26.16		1.5		
	26.96		1.39		
	13.6		1.18		
	24.61		1.75		
	23.11		1.52		
	27.42		1.4		
	15.47		1.26		
	37.69		1.43		
	34		1.33		
	27.38		1.09		
	16.2		0.8		
	26.52		1.31		
	24.66		1.19		
	17.75		0.95		
	10.88		0.39		

Where :

f'c = Compressive strength of concrete

Ec = Modulus elasticity of concrete

fr = Modulus of rupture

fct = Splitting tensile strength

γ = density of concrete

5. Conclusion:

I). The high-strength lightweight concrete with the inclusion of steel fiber, the compressive strength was just slightly improved. Splitting tensile strength and flexural strength, on the other hand, were increased significantly, the use of steel fibers improved the ductility of lightweight aggregate concrete significantly.

II). It was possible to produce high strength concrete with a cube compressive strength of 55-60 MPa at 90 days and a unit weight of 1880 kg/m 3 using lightweight tuff aggregates.

III). Flexural strength of high strength lightweight aggregate concrete is more affected by drying than its compressive strength. At 90 days, air curing reduced both strengths by 39% and 18% respectively.

IV). Because of the round shape of oil palm Boiler Clinker (OPBC) aggregates, using them in Oil Palm Shell (OPS) concrete increases the concrete's workability. The addition of OPBC to OPS concrete increased the density of the concrete by 42 % and an OPBC grain is 42 % heavier than an OPS grain. The compressive, splitting, tensile, and flexural strengths of OPS concrete were greatly increased when 50% OPS was replaced with OPBC.

V). When 25% of the natural aggregates are replaced with coarse and fine rubber aggregates, high-strength rubberized concrete with significantly improved vibration behavior can be produced. Replacing 25% of the natural aggregates by well graded fine and coarse rubber particles reduced its compressive strength by almost 40%.

VI). Silica fume's main purpose in the production of high-strength lightweight concrete is to fill voids and improve compressive strength. The density and compressive strength of lightweight concretes was influenced by the particle size analysis of Leca and its contents.

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