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Elastic Stress-Strain Behaviour of Concrete with Potential Pineapple Leaf Fibre-Reinforced

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Abstract

In the stress-strain curve, the stress in the linear region of concrete increases when reinforced with fibre reinforcement. This research aims to investigate the potential of natural fibre from pineapple leaves as reinforcement in concrete regarding its elastic modulus. The natural fibre of pineapple leaves has good tensile strength and is not inferior to the artificial fibre commonly used in fibrous concrete. This research used a pineapple leaf fibre (PLF) composition of 0.04%, 0.09% and 0.15% wt of cement with a water-cement ratio of 0.38. The compressive strength applied is only limited to 40% of the design concrete strength to see the stress-strain character in the elastic region of the pineapple leaf fibrous concrete. The research results show that the amount of pineapple fibre 0.15% provides higher strength and 0.04% and 0.09% fibre in line with ACI and Eurocode. During the hardening process, concrete contains pineapple leaf fibre. The stress is higher than normal concrete for 7 days. Normal concrete begins to approach the stress of fibre concrete when it is 28 days old. Pineapple leaf fibre in concrete contributes to strength even when the concrete is at an early age.

1. Introduction

Based on the elastic stress-strain relationship, the modulus of elasticity (MoE) can be determined when the elastic stress of the concrete is up to 40% of the maximum concrete compressive strength [1]. The stress-strain behaviour of concrete is fascinating and important to explore. However, the interesting thing about concrete is that it does not have a definite MoE, depending on various parameters. This has been found from classical research until now, for example, concrete strength, concrete age, density, type of loading, sample shape and characteristics of the concrete forming material, water/cement ratio, maximum size of the aggregate, aggregate type, and fly ash [2]-[10]. Concerning fibrous concrete, the use of artificial or natural fibres as concrete reinforcement can affect the MoE. The elastic MoE value during strain hardening in concrete reinforced with fibre varies greatly; several researchers stated their findings with the statement that each fibre influences the MoE value of concrete [11]-[16]. Using natural fibres as reinforcement has many advantages regarding physical, mechanical, and chemical properties [17], [18]. For example, coconut fibre can bind the concrete matrix, and bridging cracks occur in the concrete [19]. The performance of concrete with coconut fibre can reduce the thickness of concrete for roads by up to 8% but can increase MoE and Compressive strength by up to 31% [20]. This study recommends that fibre from pineapple leaves (PALF) be used as a waste material to replace artificial fibre because PALF is very cheap and abundant to produce. As a natural material, PALF has a high degree of crystallinity and contains a high cellulose content of 70-82%. Apart from that, PALF is very good in terms of tensile strength, namely 400-1600 MPa [21], allowing the easy occurrence of fibrillation in the concrete matrix. Fibrillation occurs at the microstructural level. The fibres that work in the concrete create bonds in the concrete matrix, namely binding between the aggregates in the concrete matrix [22]. After mixing is carried out in the mortar, the fibres in the concrete experience fibrillation, where the fibres seem to split and bind the surrounding material, causing microbonds in the concrete matrix. This bond will reduce fine cracks (micro-cracks) in the concrete matrix [23]. Failure in concrete structures starts from the weakest part, namely fine cracks. At greater loading stages, fine cracks will create larger cracks, ultimately causing the concrete structure to fail (fracture). Fibrillation plays an important role in bonding in the interfacial transition zone (ITZ) area in the concrete matrix, thereby influencing the increase in concrete strength and modulus of elasticity. ITZ can be expressed as a system property depending on the overall concrete composition and fabrication method, including fibres in the concrete mix [24], [25]. The relationship between fibres in concrete and MoE can be explained by modelling [26], that the effectiveness of the ITZ elastic modulus is influenced by the volume of the fibre fraction in concrete, thus affecting the overall strength and MoE of fibrous concrete. PALF transpires fibrillation, where each fibre will be full-out of the bundle, debonding, and fibrillation occur, then dispersion occurs in the matrix, and fibre-matrix adhesion is achieved [27]-[30]. In the concrete matrix, fibres will fibrillate more easily because water and the rough aggregate surface help fibrillation occur. Fibrillation will also occur without fibre full-out; interfacial adhesion to the matrix will occur when breakage occurs only at the fibre ends [31]. Fibrillation affects the crack length, opening, and fracture process zone (FPZ) [32].

Table 1 presents codes and formulas stated by several studies that proposed calculating the relationship between MoE and concrete compressive strength. MoE for normal concrete below 40 MPa can be calculated using Eq. (1) [33]. When using Eurocode [34], the relationship between MoE and compressive strength is expressed by Eq. (2). Some MoEs are calculated under specific conditions for a particular concrete. For example, for high-strength concrete above 55 MPa, as in this study, calculations should be considered using Eq. (3) [35]. Likewise, Indonesian Standard [36] which is a derivative of ACI [35], considers that the Modulus of Elasticity of concrete takes into account the weight of the unit. MoE can be determined using Eq. (4), where WC is the concrete density between 1500 and 2500 kg/m^3. This is necessary considering that in this study, the weight of concrete reached 2443 kg/m^3.

The use of high-quality concrete, such as Ultra-High-Performance Concrete (UHPC), is a consideration for comparison with this study, which is stated in Eq. (5) [37]. The elastic modulus of concrete using reinforced steel [12] with provisions for the strength of 30 MPa < f_c' < 75 MPa is expressed by Eq. (6). Eq. (7) carried out by Aslani & Samali [14], shows this study determines the MoE by considering the fibre's volume fraction (V_f), which is polypropylene. Meanwhile, MoE with Sisal as fibre-reinforced concrete [15] is expressed by Eq. (8). In another study on concrete using kenaf fibre as reinforcement reinforcement [13]. This investigation calculates changes in stress and strain in concrete using potentiometer pairs around the cylindrical test object. It shows that the strength of the concrete ranges from peak strain with a value of 0.004-0.005, higher than conventional concrete, namely 0.002, but still below the mortar strain value, 0.01. The compressive strength value of kenaf concrete reaches 54.6 MPa with a composition of 1.2% kenaf by volume fraction. So, the MoE calculation is determined by Eq. (9).

Table 1 *Relationship between compressive strength (f_c') and MoE of concrete in previous formulas*

Reference	Equation	
ACI 318-14 [33]	$E_c = 4700\sqrt{f'_c}$	(1)
Eurocode [34]	$E_c = 22(f'_c/10)^{0.3}$	(2)
ACI 363 [35]	$E_c = 3{,}320\left(\sqrt{f'_c}\right) + 6900$	(3)
SK SNI [36]	$E_c = (W_c)^{1.5} \times 0.043\left(\sqrt{f'_c}\right)$	(4)
Alsalman et al. [37]	$E_c = 8{,}010(f_c')^{0.36}$	(5)
Thomas & Ramaswarmy [12]	$E_c = 4{,}200\left(\sqrt{f'_c}\right)$	(6)
Aslani & Samali [14]	$E_{cf} = E_c - 31.177V_f$	(7)
Okeola et al. [15]	$E_c = 47{,}498(f'_c/10)^{0.3} - 31{,}010$	(8)
Elsaid et al. [13]	$E_c = 1{,}100\left(\sqrt{f'_c}\right)$	(9)

Note: *f_c' is compressive strength, E_c is modulus of elasticity (MoE),*
E_{cf} is MoE with polypropylene fibre,
V_f is volume of fraction polypropylene fibre

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2. Experimental Program

2.1 Materials

2.1.1 Concrete

The ingredients used to prepare PALF Concrete are regular Portland Cement from locally available brands, natural sand, crushed natural aggregate, and tap water obtained commercially. The maximum diameter of coarse aggregate passes the sieve 38 mm, with a fine modulus of 7.1, and the diameter of the sand passes 9.52 mm with a fine modulus of 2.78. High-strength concrete depends on the concrete-making process and material selection. Fig. 1 shows the sieve analysis results for fine (FA) and coarse (CA) aggregates, displaying the percentage analysis passing it on a logarithmic scale. Both aggregates have met the minimum and maximum limit requirements. Furthermore, from the results of this sieve analysis, the fine modulus of the two aggregates was obtained. Fine aggregate has a rather coarse fine modulus, but the gradation distribution of fine aggregate is sufficient.

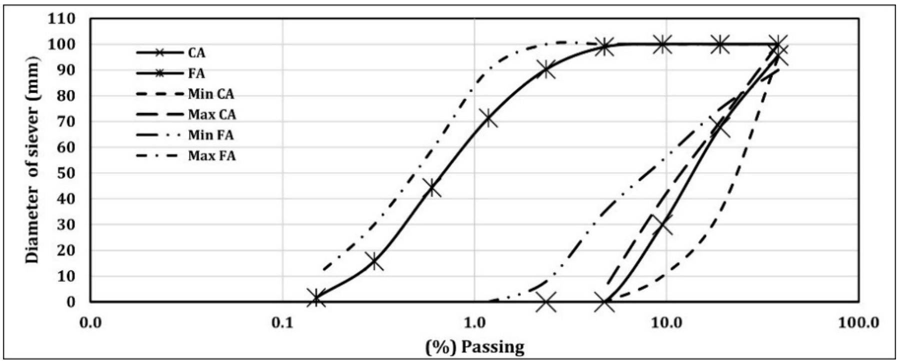


Fig. 1 *Fine and coarse aggregate sieve analysis results*

Raw material tests objects before making concrete and treating them according to the National Indonesian Standard (SNI) and ASTM. The fine modulus of aggregate is executed to obtain the appropriate concrete aggregate gradation analysis. Some tests are implemented for raw material, as in Table 2. It should be emphasised that every aggregate test is important as a control to obtain sufficiently high quality and strength of concrete. Usually, fine aggregate obtained from rivers has a high mud content; this will disrupt the w/c ratio in the concrete mixture and impact the absorption of water by the mud. In addition, the high abrasion value of coarse aggregate will reduce the strength of concrete [38].

Table 2 *The constituent material test object before it was formed into concrete*

Raw material test properties	Fine Aggregate	Coarse Aggregate
Fine Modulus	2.78	7.10
Specific gravity (g/cm^3)	2.57	2.72
Water absorption (%)	1.73	0.75
Moisture content (%)	2.15	0.61
Mud content (%)	3.30	0.77
Bulk Density (g/cm^3)	1.16	1.51
Abrasion (%)	NA	16.46

2.1.2 Pineapple Leave Fibre

Pineapple leaves are abundant in waste agriculture when the farmer finishes harvesting them. The chemical properties of PALF were determined experimentally by [30], [39]. The physical and mechanical properties of PALF based on its density were reviewed and reported by [30], [40]. The separation or retrieval of the pineapple leaf fibres (see Fig. 2) from the leaves (fibre extraction) is done manually [41]. Table 3 shows the properties of PALF, which should be dried, cleaned from the dirt, and chopped to a length of 1.5 cm. The results of experimental measurements recorded that PALF has an average diameter of 12 micrometres, so according to research conducted by [42] and reported by [30], PALF has a tensile strength of 170 MPs, a Modulus of elasticity of 6.26

GPa, an elongation of 0.8-1.6%, and a density of 1.44 gr/cm3. Its physical and mechanical properties are presented in Table 3.

Highlights the ability of PALF, when being reinforced in a polymer composite, to have a fairly high stiffness when it is loaded, especially when the size is short; this is related to ductility [31]. With a short size, PALF is easier to spread evenly in a mixture of fresh concrete in a random direction, consequently becoming reinforcement for all directions in the concrete matrix. The laboratory analysis results underline that PALF can absorb water, so more water must be added when mixing concrete so as not to interfere with the ratio of w/c.

Table 3 *Physical and mechanical properties of PALF [30]*

Fibre's diameter (μmeter)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation (%)	Density (gr/cm^3)
5.0–30.0	170	6.26	0.8 – 1.6	1.44
30–60	413	6.5	1.6	-
50–91	210–695	15–53	-	-
105–300	293.08	18.934	1.41	-

Fig. 2 *Raw pineapple leaf fibre (PALF) before being cut to size as reinforcement*

2.2 Mix Design and Sample Preparation

The design compressive strength for plain concrete (PC) and PALF concrete (PFC) is 49 MPa. The material composition in this test has a cement, sand, and coarse aggregate ratio of 1, 1.34, and 2.74, respectively. The design compressive strength plan for PC and PFC is 49 MPa; all provided in this test have composition ratios of cement, sand, and coarse aggregate are 1, 1.34, and 2.74, respectively. The water-cement ratio is 0.37, but the water content in PFC must be increased because PALF absorbs up to 5.6% water by weight. PALF is added to the mixture variants of 0.04%, 0.09%, and 0.15% of the cement weight with codes PFC1, PFC2, and PFC3, respectively. All mixtures are added with a superplasticizer of 0.09% by weight of cement for similar mix consistency and to help flow the concrete mixture in the mould.

Cement, sand, and gravel are mixed in a mixer to get an even mixture. Next, add water slowly until it runs out. The mixture was rotated on a PC for 5 minutes to obtain a homogeneous mixture. Meanwhile, for PFC, PALF is poured into the mix after the concrete mixture is homogeneous. PALF is added to the mortar admixture gradually so that the PALF can be mixed evenly and does not clump in the admixture. Fresh concrete with PALF is rotated for two minutes to achieve a homogeneous mixture and produce good PFC. Nevertheless, in reality, add two minutes to get a better mixture. This mixing part is very important because, at this stage, PALF often clots in the mixture or bleeding occurs. For this reason, the mixing time can be increased to achieve homogeneous results and PFC has good workability.

Table 4 *Mix design PC and PALF concrete*

No	Sample Code	PALF (% wt of binder)	Ratio of w/c	Water Addition (% wt of PALF)	Ratio of			Sp (% wt of binder)	Slump (mm)
					Cement	Fine Aggregate	Coarse Aggregate		
1	PC	-	0.37	-	1	1.24	2.76	0.09	30
2	PFC1	0.04	0.37	5.6	1	1.24	2.76	0.09	30
3	PFC2	0.09	0.37	5.6	1	1.24	2.76	0.09	35
4	PFC3	0.15	0.37	5.6	1	1.24	2.76	0.09	35

Slump tests were carried out on PC and PFC with varying values. Observations of slump values for all samples are presented in Table 4. These results note that the difference in slump test values between PC and PFC is caused by differences in the presence of water in the two mixtures. Increasing the amount of PALF in the mix increases the slump value, but the slump of PCF is not much different from that of PC. PALF has the property of absorbing and storing water and releasing it when there is pressure. Thus, during the mixing process, PALF releases additional water in addition to the w/c ratio.

2.3 Sample Preparation

The prepared admixtures are poured into a cylindrical mould with a 150 mm diameter and a height of 300 mm. In this investigation, 12 PFC variations were made each for 7, 14, and 28 curing days (see Fig. 3(a)). The Specimens demould after 24 hours and cured in tanks at room temperature 23±2° C. All specimens use a bond cap with a thickness of 0.5 mm using sulphur material [43]. The deviation of the cylindrical concrete specimen surface from perpendicular to the specimen axis is less than 5° (1 mm from 100 mm).

(a) (b) (c)

Fig. 3 (a) *Cylindrical specimens maintenance; (b) Capping; and (c) The cylindrical concrete sample with an extensometer*

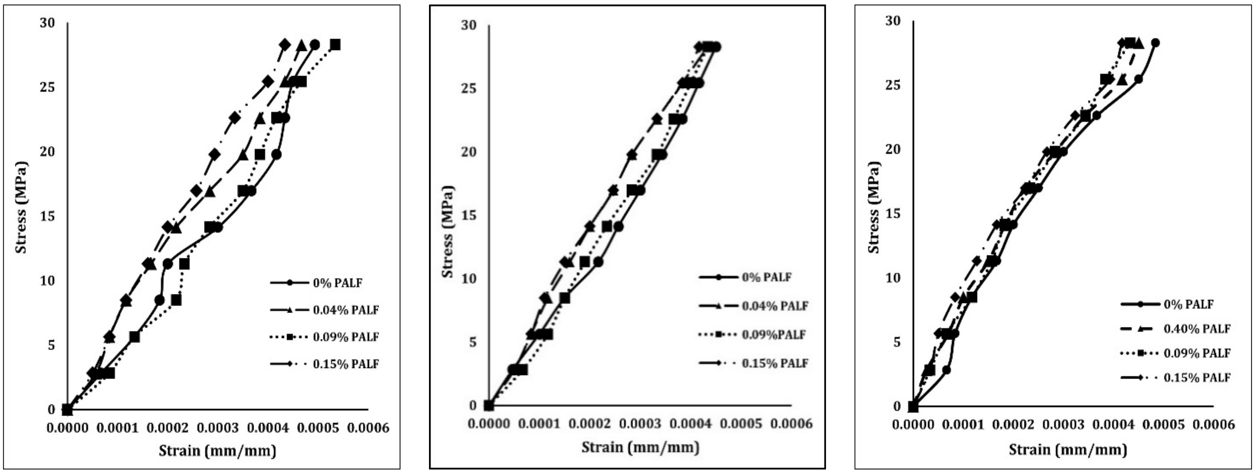
The behaviour of the elastic modulus of cylindrical specimens was tested using a compression testing machine and a dial strain gauge or extensometer (see Fig. 3(b)). The recorded concrete cylinder strain due to load is 40% of the planned concrete compressive strength [1], [44], and this condition is still in the elastic regime of concrete. Tests are carried out on all specimens at a constant speed equivalent to 0.29 MPa/s. The load increases continuously every 50 kN/min or can be read from the compressometer and extensometer.

Changes in the shape of concrete in units of length due to pressure are used according to the provisions in SNI 03-4169-1996 and ASTM C-469. Changes in shape that are read by the compressometer are taken as 50% and then analyzed for the modulus of elasticity. Concrete is a non-homogeneous material, so the MoE designation will repeat changes with increasing compressive strength. However, concrete will experience constant deformation even with small loads. Apart from the MoE of concrete, it is influenced by its material constituents, including the age of the concrete and the loading speed.

3. Results and Discussion

3.1 Stress-Strain Behaviour in The Concrete Hardening Process

Fig. 4 presents the stress-strain curve behaviour during the hardening process in concrete containing PALF variations. It was obtained by considering the stress conditions occurring in the elastic region. When the concrete is seven days old, the character of the stress-strain curve in the concrete is shown. Currently, the strains that occur are quite large (see Fig. 4(a)) compared to the ages of 14 and 28 days (see Fig. 4(b) and Fig. 4(c)) because the stability of the hydrate phase has not been achieved perfectly. The concrete is not yet completely hardened [45]-[47]. At 14 and 28 days, the stress strength was higher in concrete with the PALF variation, and at these ages, the strain tendency was almost the same. In plain concrete (PALF 0%), the strain increases by 28 days compared to 14 days. At seven days old, PALF 0.15% had a smaller strain than other PALF compositions. This is related to water absorption by the fibre because PALF's character as a hydrophilic fibre absorbs water significantly. Devi et al. [48] mixed PALF with Polyester as a composite, which could absorb 123% water, but Polyester could only absorb 2% water. Large concentrations of PALF composition might cause significant moisture loss during concrete moulding, which can impede the hydration process. Therefore, this study added extra water as much as the PALF absorption rate into the concrete mixture [49]. However, PALF helps increase the parameter of interface fractional bond strength in the concrete matrix and will involve the stress-strain behaviour of the concrete as a whole. Adding fibre to concrete increases its strain and plasticity during the hardening process. Concrete with PALF is stiffer than plain concrete (PALF 0%). Concrete's 0.15% PALF composition accelerates strain hardening but reduces compressive strength at 28 days (see Fig. 4(c)). This is not much different from concrete, with a PALF variation of 0.04%. Meanwhile, the PALF composition of 0.09% in concrete, aged 28 days experienced a decrease in strain compared to those 7 days old. Overall, the characteristics of the stress-strain curve values for all concrete appear to be close to each other at the age of 28 days.



(a) (b) (c)

Fig. 4 *Stress-strain curve with the variation of PALF at (a) 7 days; (b) 14 days; and (c) 28 days ages*

3.2 The Effect of Fibrillation on Compressive Strength

In this study, compressive strength is the crushing strength of concrete when it passes through the elasticity regime and reaches its ultimate strength. The relationship between the compressive strength of concrete in the compression test and the difference in the amount of PALF content in the concrete is presented in Fig. 5. It can be seen that concrete with PALF has higher strength than concrete without PALF. The increase in concrete strength at a PALF amount of 0.09% reached 8.5% of plain concrete and decreased when more PALF was added to the concrete mixture. In general, the strength of concrete has increased due to the success of the fibres in carrying out their duties by fibrillation in the mortar. Fibrillation plays a more important role in fibrous concrete, which is related to mortar bonding and increasing concrete strength [22], [50], [51]. Microcracks in the concrete matrix are created and generated into macrocracks when the elastic isotropic concrete material begins to experience damage [52]. Regardless of the fibre ductility calculation used in this study, fibre reduces the cracking load in the concrete matrix compared to plain concrete [53]. This can be understood when PALF in hybrid form in concrete mortar spreads throughout the concrete well, effectively reducing drying shrinkage strains [54], [55]. Drying shrinkage can occur due to several factors, such as the amount and properties of hardened cement paste, aggregate type, curing treatment, and concrete testing methods [56].

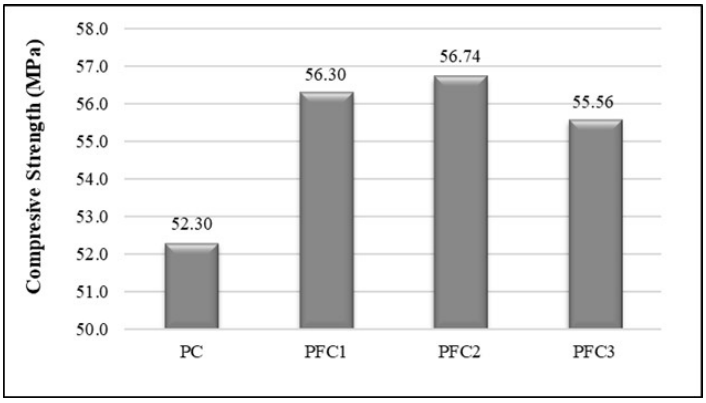


Fig. 5 *Compressive strength of PFC*

3.3 Relationship Between Modulus of Elasticity and Compressive Strength in Current Study

A simple regression analysis was performed to obtain the MoE calculation of compressive strength from experimental results, and a comparison of several codes and previous research results was made, as shown in Fig. 6. PFC1 and PFC2 slope together with Thomas & Ramaswary and Aslani, Alsalam, which tends with ACI363-10, Eurocode, SNI2847-13, and ACI318. While PFC3 tends to increase MoE as compressive strength increases, this tends to have similarities with Okeola and Elsaid, which use natural fibres (sisal and kenaf, respectively). The high fibre content in PFC3 compared to PFC1 and PFC2 provides a higher MoE effect and quite low strain values. So, in this case, the behaviour of PFC3 is equivalent to normal concrete containing natural fibres as a result of research by Elsaid et al. [13] and Okeola et al. [15].

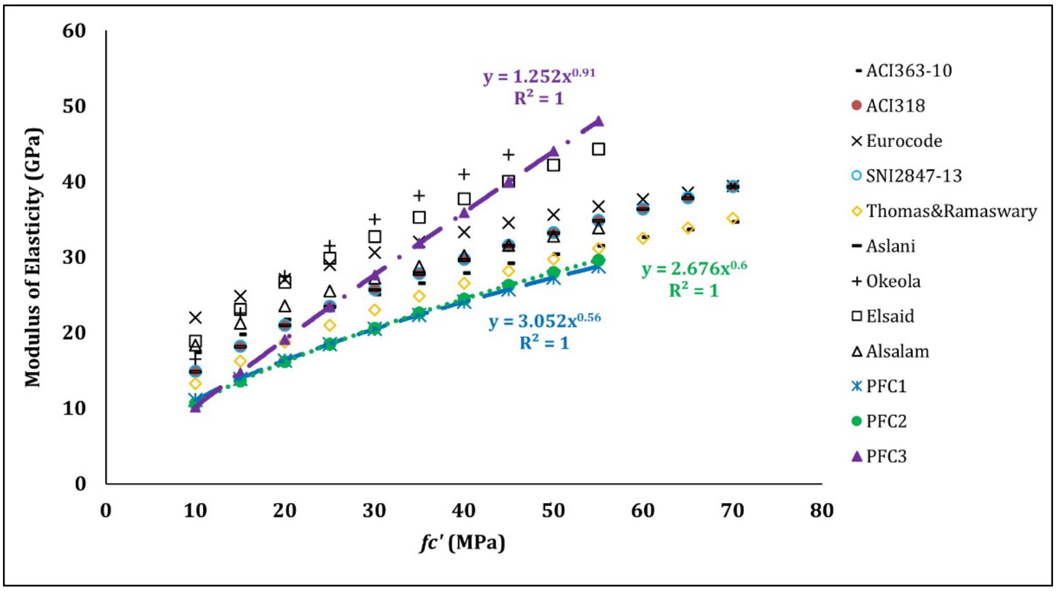


Fig. 6 *Relationship MoE with Compressive strength current studies and several codes*

4. Conclusions

In the initial hardening process, concrete with pineapple leaf fibre has a higher stress than normal concrete. Pineapple leaf fibres are drowned in the concrete matrix to form a bond when the concrete is still undergoing initial cement hydration. This process is still accompanied by increased strain value in the concrete due to the concrete not yet hardening. At 14 and 28 days, the concrete hardens and reduces the strain value, but fibrous concrete has a greater value than normal concrete. This means that the binding of pineapple leaf fibres to the concrete matrix becomes stronger. As with high-strength concrete, this research sample has concrete characteristics like those made by Elsaid et al. [13] and Okeola et al. [15]; however, pineapple leaf fibrous concrete has the characteristics of a drastic increase.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Josef Hadipramana and Fetra Venny Riza;* ***data collection:*** *Josef Hadipramana, Fetra Venny Riza, and Zukifli Siregar;* ***analysis and interpretation of results:*** *Josef Hadipramana, Fetra Venny Riza, and Zulkifli Siregar;* ***draft manuscript preparation:*** *Josef Hadipramana and Sharul Niza Mochatar. All authors reviewed the results and approved the final version of the manuscript.*

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