Open Journal of Civil Engineering, 2018, 8, 205-220
http://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Polymer Modified Concrete of Blended Cement and Natural Latex Copolymer: Static and Dynamic Analysis

Sih Wuri Andayani[1,2], Rochim Suratman[1], Iswandi Imran[3], Mardiyati[1]

[1]Material Engineering, Bandung Institute of Technology, Bandung, Indonesia
[2]Centre for Material and Technical Product, Ministry of Industry, Bandung, Indonesia
[3]Civil Engineering, Bandung Institute of Technology, Bandung, Indonesia
Email: wurisih@yahoo.com

How to cite this paper: Andayani, S.W., Suratman, R., Imran, I. and Mardiyati (2018) Polymer Modified Concrete of Blended Cement and Natural Latex Copolymer: Static and Dynamic Analysis. *Open Journal of Civil Engineering*, **8**, 205-220.
https://doi.org/10.4236/ojce.2018.82016

Received: April 18, 2018
Accepted: June 18, 2018
Published: June 21, 2018

Abstract

This paper deals with the effect of blended cement and natural latex copolymer to static and dynamic properties of polymer modified concrete. The polymer was used copolymer of natural latex methacrylate (KOLAM) and copolymer of natural latex styrene (KOLAS) with composition of 1%, 5%, and 10% w/w of weight of blended cement in concrete mixture. They are tested for compressive strength, flexural strength, splitting tensile strength, and modulus elasticity for static analysis, and impact load and energy dissipation profile for dynamic analysis. The result shows that KOLAM with concentration 1% give better performance in static and dynamic properties. The KOLAM 1% gives improvement in flexural strength, splitting tensile strength and modulus elasticity about 4%, 13% and 3% compared to normal concrete. And for dynamic properties, KOLAM 1% could reduce impact load up to 35% and improve energy dissipation capacity about 45% compared to normal concrete. The concentration of KOLAM higher than 1% resulting negative effect to static and dynamic properties, except modulus of elasticity. For KOLAS, there were no positive trends of static and dynamic properties.

Keywords

Blended Cement, Dynamic Properties, Polymer Modified Concrete, KOLAM, KOLAS, Static Properties

1. Introduction

Concrete had been used in many decades due to its properties and economics. However, it has some limitations such as low failure strain, low flexural and tensile strength, low chemical resistance, and etc. There are many solutions for eliminating its limitation. The most common in construction is using steel reinforcement for improving flexural and tensile strength [1]. Research had been done by using titanium alloy for steel reinforcement system in aiming of earthquake resistant building [2]. The other solution was high performance concrete application [3]. The high performance concrete is produced by low water/cement ratio, adding admixture, additive and etc. So, high performance concrete will need more cement and costly. Also high performance concrete will be brittle, and more susceptible for cracking [4].

The polymer addition into concrete mixture could be used for eliminating concrete limitation. The polymers in concrete have been used in many decades for widen the concrete applications. The polymer in concrete could be functioned as binder either with or without cement in form of polymer modified concrete, polymer concrete or polymer reinforcement concrete, or filler. Polymer as binder would improve the interfacial zone, and polymer as filler would fill the void. So it would result low porosity concrete [5]. The polymers for concrete additives are varied, such as elastomer (natural rubber, synthetic rubber), thermoplastic (PVA, styrene-acrylic, etc.), thermoset (epoxy), bituminous (tar, asphalt) and latex modification [6]. And they have been researched for many concrete applications.

The Natural rubber had been researched for improving the concrete strength [7] and durability in extreme environment [8]. For synthetic rubber, the most used in construction is Styrene Butadiene Rubber. Researches had been done by interacting SBR with silica fume for modifying of interfacial zone [9], its effect in concrete into microstructure and chloride permeability [10] and its effect as admixture in high performance concrete [11]. The other polymer used in construction is epoxy. Research of epoxy had been done for improving concrete durability [12], its effect to microstructure [13] and fire resistant [14].

The polymer addition into concrete mixture could be used for improving the earthquake resistant and damping capacity. The styrene Butadiene Rubber (SBR) had been research for that purpose by evaluating of energy dissipation of concrete [15]. Also, rubber in form of crumb rubber had been research for improving the energy dissipation [16] and static and dynamic properties [17].

Indonesia is second largest producer natural rubber in the world. The rubber is exported as natural rubber, about 80% [18]. In order to get added value of rubber, research have been done of modification of natural rubber (latex form) into copolymer [19]. The modified latex had been research for improving strength and durability of concrete [20], its effect into fire resistant properties [21] and earthquake resistance [22]. The Researches of copolymer of natural latex modified concrete used ordinary Portland cement as binder.

There is a new trend of Indonesian cement industry, by reducing the production of ordinary Portland cement and more production volume in blended cement production, as a commitment to Kyoto protocol for CO_2 reducing. So, this research was developed by replacing the Ordinary Portland cement into blended cement in producing polymer modified concrete. The blended cement was composing of min 65% clinker and max 35% supplementary cementitious materials such as fly ash, *trass*/natural pozzolan, and lime. The supplementary cementitious materials have been used for improving concrete durability by forming additional CSH [23] and producing sustainable concrete. The use of supplementary cementitious materials could reduce the CO_2 emission and to be environmental friendly in cement production [24].

Besides using blended cement, this research was dealing with modified natural latex as concrete additives. The polymers are copolymer of natural latex methacrylate (KOLAM) and copolymer of natural latex styrene (KOLAS). The polymer modified concrete of blended cement and copolymer of natural latex were evaluated for static and dynamic analysis. The static properties are compressive strength, flexural strength, splitting tensile strength and modulus of elasticity. The static properties were evaluates as a base of concrete strength evaluation. Based on the static properties, research was developed into dynamic evaluation. The dynamic evaluation was done based on impact load and energy dissipation profiles. The dynamic evaluation will be used as a preliminary research for concrete with impacting resistant (good damping capacity) and earthquake resistant application. So, by polymer addition will widen concrete application.

The involved blended cement and copolymer of natural latex could be used as an alternative for improving concrete performance in more sustainable. Due to blended cement more sustainable than ordinary Portland cement and copolymer of natural latex is renewable material. Thus, the research could be used as a reference in green construction for designing of impact and earthquake resistant building.

2. Experiment

2.1. Materials

The materials used in this research were Indonesian local resources. They were chosen based on the previous research and survey result.

2.1.1. Aggregates

The aggregates prior to use were prepared and characterized based on relevant Indonesian National Standard (SNI) and ASTM. The fine aggregate was *Pasir Galunggung* and coarse aggregate was *Maloko* crushed stone. The fine and coarse aggregates were washed to reduce the clay lump and organic content. Clamp lump and organic content should be reduced until maximum value 5%. They should be minimized cause of retarding cement setting process. For fine aggregate, continued by drying process in room temperature to get saturated surface dry (SSD) condition. The SSD condition could eliminate the error from water content correction due to aggregate moisture. So, there will be no water correction and composition of concrete mixture will equal. They were characterized based on ASTM C 33 requirement as per Table 1 [25].

2.1.2. Cement

As well as aggregates, cement was characterized using Indonesian National Standard SNI 0302-2014: *Semen Portland Pozola*n (Portland Pozolan cement) [26]. The quality of cement was shown in Table 2. The Portland Pozolan cement is blended cement, with supplementary cementitious material (SCM) combination between natural pozolan (*trass*) and fly ash, and lime as filler material.

2.1.3. Polymers

The research used copolymer of natural latex methacrylate (KOLAM) and copolymer of natural latex styrene (KOLAS) as concrete additives. They were research product of National Nuclear Energy Agency of Indonesia (BATAN) and have been commercialized by PT. Rel Ion Indonesia. The polymers were characterized based on ASTM [27]. The quality of polymers described in Table 3. Based on Table 3, density and viscosity of KOLAM were slightly higher than KOLAS. These properties could affect the polymer performance in concrete. So, it was predicted that KOLAM would give better performance than KOLAS. The KOLAM modified concrete would give better performance than KOLAS modified concrete.

2.2. Samples Preparation

Concrete samples were prepared and mixed based on ASTM C39/C 39 M [28],

Table 1. Fine Aggregate and Coarse Aggregate Properties.

Parameters	Fine Aggregate	Coarse Aggregate	Requirement of ASTM C 33
Sieve analysis (fine modulus)	2.657	7.391	Fine: 2.3 – 3.1
Bulk Density			
• Compacted (kg/L)	1.546	1.280	
• Loose (kg/L)	1.656	1.420	
• Void (%)	31.78	43.82	
Density and water absorption			
• Oven dry (kg/L)	2.43	2.53	
• SSD (kg/L)	2.54	2.58	
• Density (kg/L)	2.71	2.67	
• Water absorption on SSD (%)	4.24	2.13	
Material finer than 75 μm	0.62	0.26	Fine: max 5% Coarse: max 1%
Abrasion and impact by Los Angeles Machine	-	23.86	Coarse: max 50%
Lightweight particles in aggregates	0.34	0.34	Fine/Coarse: Max 0.50%
Clay lump and friable particles in aggregates	0.25	1.27	Fine: max 3% Coarse: max 2%
	7.37	NA	Fine: max 10%

Table 2. Cement properties.

Parameters	Value	Requirement of SNI 0302:2014
Chemical Properties		
Insoluble residue	13.11 ± 0.06	NA
Silicone dioxide, SiO_2	23.84 ± 0.21	NA
Ferric oxide, Fe_2O_3	3.24 ± 0.09	NA
Aluminum oxide, Al_2O_3	8.08 ± 0.25	NA
Calcium Oxide, CaO	57.52 ± 0.16	NA
Magnesium oxide, MgO	0.82 ± 0.05	Max 6.0
Sulfur oxide, SO_3	1.63 ± 0.07	Max 4.0
Loss of ignition	4.52 ± 0.05	Max 5.0
Alkalinity as Na_2O	0.50 ± 0.04	NA
Free lime	0.94 ± 0.09	NA
Physical Properties		
Fineness, by Blaine Apparatus, m^2/kg	317	Min 280
Setting time, Vicat test		
- Initial. minute	191	Min 45
- Final, minute	270	Max 240
Autoclave expansion		
- Shrinkage, %	NA	Max 0.8
- Expansion, %	0.12	Max 0.2
Compressive strength		
- 3 days, kg/m^2	184	Min 130
- 7 days, kg/m^2	234	Min 200
- 28 days, kg/m^2	317	Min 280
Air content of mortar, % (v/v)	5.9	Max 12
Density, g/ml	2.94	NA

Table 3. Polymer characterization.

Parameter	KOLAS	KOLAM	Testing Method
Total alkalinity calculated as Ammonia as % latex	0.20	0.14	ASTM D 1076-10
Dry rubber content, %	NA*	NA*	
Total solid content, %	39.14	40.57	
Coagulum content, %	0.003	0.030	
Sludge content, %	0.07	0.07	
pH	10.35	9.95	
Density, g/mL	0.98628	1.00704	
Viscosity, cP	6	8.9	Internal method

and their compositions were calculated using ACI 211.1-91 (reapproved 2002) [29]. The samples were cured in saturated lime solution for 28 days [30]. The compositions of concrete samples were shown in Table 4.

3. Discussion

The polymer modified concretes of blended cement and copolymer natural latex were analyzed for static and dynamic properties, including interaction between blended cement and copolymer of natural latex in concrete to get better performance. The static properties were analyzed to get information about strength of concrete. And the dynamic properties were analyzed to get information about energy dissipation capacity.

3.1. Static Analysis

In this research, the static analysis was dealing with mechanical properties of concrete. They are compressive strength, flexural strength, splitting tensile strength and modulus of elasticity. The testing methods of static analysis refer to ASTM.

3.1.1. Compressive Strength

The compressive strength is a method for justifying the strength of concrete. It was determined using ASTM C 39/C 39 M Standard test method for compressive strength of cylindrical concrete specimen [28]. The test was done with load rate 0.25 N/mm^2. The data of compressive strength summarized in Table 5.

Based on Table 5, polymer addition into concrete mixture did not give positive effect to concrete strength, except KOLAM 1%. As higher concentration of polymer in concrete mixture, the strength will be more decrease.

It was evaluated from the crack pattern of samples. The crack pattern was affected by loading profile, compactness of concrete specimens and distribution between aggregates and cement paste. Based on Indonesian National Standard SNI 1974:2011 [31], the crack pattern corresponded to Figure 1 point 1, 2, and 3. They represent loading position during the test are well distributed on sample surface.

Table 4. Concrete mix design.

Material	Composition (kg/m^3)						
	Normal	KOLAM 1%	KOLAM 5%	KOLAM 10%	KOLAS 1%	KOLAS 5%	KOLAS 10%
Water	216	216	216	216	216	216	216
Cement	569.92	569.92	569.92	569.92	569.92	569.92	569.92
Coarse aggregate	809.4	809.4	809.4	809.4	809.4	809.4	809.4
Fine aggregates	657.86	657.86	657.86	657.86	657.86	657.86	657.86
KOLAM	0	2.16	10.8	21.6	0	0	0
KOLAS	0	0	0	0	2.16	10.8	21.6

Remarks: Normal is blended cement concrete (as reference). KOLAM/KOLAS is type of polymer. 1%, 5%, 10% is polymer composition in concrete (w/w of cement).

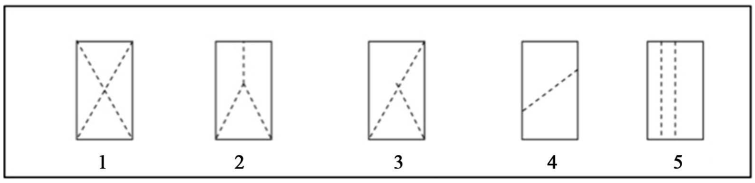

Figure 1. The crack pattern of compressive strength testing based on SNI 1974: 2011.

Table 5. Concrete Compressive strength.

No.	Concrete	Concrete Density (kg/m^3)	Difference from reference (%)	Compressive strength (MPa)	Difference from reference (%)
1	Normal	2302.43	0.00	63.64	0.00
2	KOLAM 1%	2264.69	−(1.64)	63.58	−(0.09)
3	KOLAM 5%	2094.83	−(9.02)	40.87	−(35.78)
4	KOLAM 10%	1711.72	−(25.66)	12.55	−(80.28)
5	KOLAS 1%	2259.02	−(1.89)	47.56	−(25.27)
6	KOLAS 5%	2000.47	−(13.11)	29.35	−(53.88)
7	KOLAS 10%	1741.92	−(24.34)	11.39	−(82.10)

For normal concrete, the crack pattern was following pattern no. 1 that shown by Figure 2. There was difference with crack pattern of polymer modified concrete that shown by Figure 3. Based on the crack pattern of polymer modified concrete, there was additional bonding among aggregates and cement paste by polymer film. When the concrete loaded during test, the polymer could propagates the load and prevent any failure. Thus, based on crack pattern, the research was followed by dynamic analysis. The dynamic analysis was approached from load and energy dissipation profile.

Beside the crack pattern analysis, the decreasing of compressive strength was evaluated from density of concrete. Increasing of polymer in concrete mixture, the density will be more decrease. This research used blended cement with composition of clinker about 80%, combination of natural pozolan (*trass*) and fly ash about 12% - 14% and lime about 6%. When they are mixed with polymer, there was bubbling (shown by Figure 4), and resulting void during setting and hardening process (shown by Figure 5). The bubbling was a negative result between supplementary cementitious material (SCM) and polymer. Lotenbach [23] stated that kinetic and thermodynamic of reaction of supplementary cementitious material (SCM) will be different, depends on chemical composition, fineness and reactivity (based on amorphous phase). The filler material of cement will affect the cement hydration. It will increase pH and temperature, and also accelerate cement hydration. The blended cement contains lime as filler. In this case, lime will increase the pH and temperature and might interacted with polymer resulting bubbling.

This phenomenon will be useful for lightweight or pervious concrete research

Figure 2. The crack pattern of normal concrete.

Figure 3. The crack pattern of polymer modified concrete.

Figure 4. Bubbling as result of cement and polymer mixture.

by engineering the void structure to get high strength concrete.

3.1.2. Flexural Strength

The flexural strength or modulus rupture was determined using ASTM C 78/C 78 M standard test method for flexural strength of concrete (using simple beam

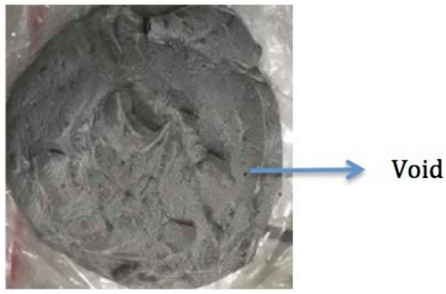

Figure 5. Void in concrete.

with third point loading) [32]. The flexural strength affected by polymer in concrete. The polymer addition into concrete mixture did not give positive effect, except KOLAM 1%. There was about 4% increasing of flexural strength by adding KOLAM 1%. The higher concentration of polymer, the flexural strength will be more decreasing either KOLAM or KOLAS addition. The data was summarized in **Table 6**.

3.1.3. Splitting Tensile Strength

The splitting tensile strength was determined using ASTM C 496/C 496 M Standard test method for splitting tensile of cylindrical concrete specimen [33]. The polymer addition into concrete mixture, either KOLAM or KOLAS, will increase the tensile strength with concentration of 1%. Increasing concentration of polymer, splitting tensile strength will be more decrease. The data was summarized in **Table 7**. The data in **Table 7** showed that KOLAM and KOLAS in 1% would reduce brittleness of concrete. There were about 13% and 8% increasing of tensile strength after KOLAM and KOLAS addition 1%.

3.1.4. Modulus of Elasticity

The modulus of elasticity was determined using ASTM C 469/C 469 M Standard test method for static modulus of elasticity and poison's ratio of concrete compression [34]. The polymer addition into concrete mixture will reduce the stiffness of concrete. Based on test result, polymer addition will affect the stiffness of concrete. The higher concentration polymer, the elasticity of concrete will be improved. The modulus of elasticity of concrete was summarized in **Table 8**.

3.2. Dynamic Analysis

The dynamic evaluation was approached by load and energy dissipation profile of concrete [35]. The load and energy dissipation were evaluated from impact test. The impact test was done using equipment that reverse engineered from Dynatup Instron 8250. The samples impacted from 50 cm height with impacting head 18.4 kg as shown by **Figure 6**. The load data was captured by Lab view that supported with some acquisition data system as shown by **Figure 7**. The energy dissipation was calculated from load data, with some assumption that impacting head following free fall rule and impact speed was constant about 3.13 m/s.

Table 6. The flexural strength of concrete.

No.	Concrete	Flexural Strength (MPa)	Difference from reference (%)
1	Normal	4.2852	0.00
2	KOLAM 1%	4.4544	3.95
3	KOLAM 5%	3.3331	−(22.22)
4	KOLAM 10 %	2.0232	−(52.79)
5	KOLAS 1%	3.4561	−(−19.35)
6	KOLAS 5%	2.1940	−(48.80)
7	KOLAS 10%	1.1086	−(74.13)

Table 7. The splitting tensile strength of concrete.

No.	Concrete	Splitting tensile Strength (MPa)	Difference from reference (%)
1	Normal	12.95	0.00
2	KOLAM 1%	14.63	12.97
3	KOLAM 5%	12.03	−(7.10)
4	KOLAM 10 %	6.77	−(47.72)
5	KOLAS 1%	14.02	8.26
6	KOLAS 5%	10.95	−(15.44)
7	KOLAS 10%	4.92	−(62.01)

Table 8. The modulus elasticity of concrete.

No.	Concrete	Modulus of Elasticity (MPa)	Difference from reference (%)
1	Normal	25725.48	0.00
2	KOLAM 1%	26338.57	2.38
3	KOLAM 5%	17834.75	−(30.67)
4	KOLAM 10 %	10199.58	−(47.72)
5	KOLAS 1%	23524.62	−(8.26)
6	KOLAS 5%	15157.70	−(15.44)
7	KOLAS 10%	8334.15	−(62.01)

The load data were resulted by load cell. Figure 8 showed the load profile of concrete. Based on Figure 8, KOLAM will improve concrete performance. The KOLAM addition into concrete mixture will lower impact load. It was about 35% maximum decreasing of impact load of KOLAM 1%. The increase of KOLAM concentration, the decreasing of impact load was not significant. They were about 4% and 3% decreasing for KOLAM 5% and KOLAM 10%. For KOLAS addition, there were no positive trends in impact load decreasing.

The energy dissipation was calculated from load data. Figure 9 showed energy dissipation profile of concrete. Based on Figure 9, KOLAM will improve energy

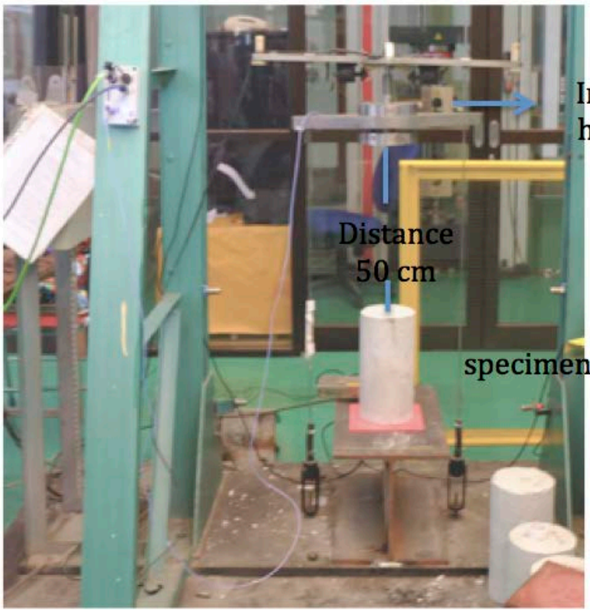

Figure 6. Impact test equipment.

Figure 7. Setting of acquisition data system.

dissipation. It could increase about 45% of KOLAM 1%. The higher concentration of KOLAM, the increasing of energy dissipation were not significant. They were about 7% and 5% for KOLAM 5% and KOLAM 10%. There was not positive trend while using KOLAS as concrete additive. Detail data of impact load and energy dissipation were summarized in Table 9.

Due to KOLAS did not give positive effect in concrete, research should be developed for KOLAS. Development could be done by improving KOLAS physical

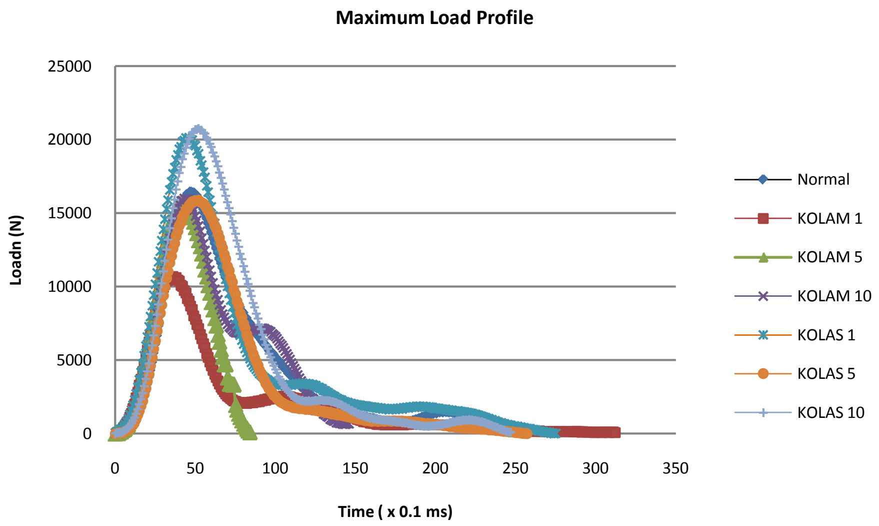

Figure 8. Load profile of concrete.

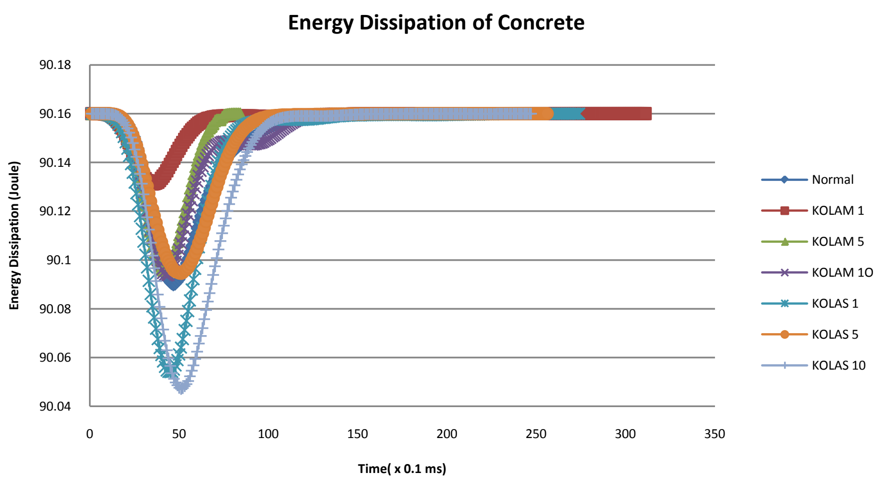

Figure 9. Energy dissipation of concrete.

properties, involving additional materials or introduction additional process in order to get better performance of KOLAS modified concrete. So, KOLAS could be used as polymer for concrete in any concentration.

From Table 9, KOLAM could improve concrete application. The KOLAM modified concrete could be used in designing of concrete with earthquake resistant, impact resistant or damping properties, and other application in certain concentration. In this result, KOLAM gave positive result in 1% concentration. Research could be developed so that it could be used in higher than 1%.

4. Conclusion and Recomendation

1) KOLAM in concrete will reduce brittleness and stiffness of concrete in certain concentration. The positive effect among static properties of KOLAM addition into concrete mixture was limited to 1% w/w of cement.

Table 9. Load and energy dissipation of concrete.

Concrete	Load (N)	Difference (%)	Energy Dissipation (J)	Difference (%)
Normal	16455.18	0.00	90.0898	0.00
KOLAM 1%	10701.9	−(34.96)	90.1312	46.06
KOLAM 5%	15754.21	−(4.26)	90.0959	6.85
KOLAM 10%	16009.65	−(2.71)	90.0936	4.27
KOLAS 1%	20159.03	22.51	90.0541	−(39.81)
KOLAS 5%	15881.93	−(3.48)	90.0946	5.35
KOLAS 10%	20776.83	26.26	90.0471	−(47.53)

2) The higher concentration of KOLAM in concrete will decrease the static performance of concrete, except modulus of elasticity. Increasing KOLAM concentration in concrete mixture will result negative effect. The interaction between blended cement and KOLAM higher than 1% will get negative result due to foaming formation in fresh concrete and resulting void while setting and hardening process (in curing process). This phenomenon will lead to decreasing of concrete strength.

3) KOLAS in concrete did not give positive trend for static properties, except for modulus of elasticity. There were not positive result in concrete strength and brittleness of KOLAS modified concrete. The higher KOLAS concentration cause decreasing of concrete performance. There was negative interaction between blended cement and KOLAS. This phenomenon was about similar with KOLAM addition into concrete mixture. The KOLAS addition will reduce concrete stiffness that showed by modulus of elasticity profile, with decreasing about 62% (maximum).

4) KOLAM will give better improvement in dynamic properties. The effective concentration of KOLAM is 1% that could reduce impact load about 35% and increase energy dissipation about 45%. Increasing KOLAM concentration did not give significant effect of dynamic properties.

5) KOLAS did not give positive trend either impact load or energy dissipation.

6) KOLAM could be used as polymer for modifying blended cement concrete. It could give better performance in static and dynamic properties of concrete. So, there will be positive result when blended cement and KOLAM use together in certain ratio for designing impact and earthquake resistant construction with suitable strength and brittleness of concrete.

7) The research needs further investigation for using antifoaming agent to prevent any bubbling while blended cement interacted with copolymer of natural latex methacrylate and styrene in order to get high strength concrete with better performance of dynamic properties. So, polymer would be used in higher than 1%.

8) The research needs development for dealing with KOLAS as polymer for concrete additives to get better performance of KOLAS modified concrete.

9) Energy dissipation profile is an approach for determining of earthquake resistant. It should be developed and continuing research using full scale seismic testing. Also, for impact resistant properties, it should be developed by suitable testing method.

Acknowledgements

Thanks to Centre for Material and Technical Product Ministry of Industry Indonesia for research grant, PT. Semen Indonesia (Gresik Plant) for cement supply, PT. Holcim Indonesia for coarse aggregate supply, PT. Cisangkan for fine aggregate, PT. Fosroc Indonesia for concrete additive supply and PT. Mobar Sarana Energi for designing and manufacturing of impact testing equipment.

References

[1] Li, Z.J. (2011) Advance Concrete Technology. 2nd Edition, John Willey & Sons Inc., New Jersey. https://doi.org/10.1002/9780470950067

[2] Abdul Hamid, N. (2017) Correlation Between Engineering Stress-Strain and True Stress-Strain Curve for NITI Shape Memory Alloy for Structural Reinforcement Rebar. *Proceeding of* 3*rd International Conference on the Science and Engineering of Materials*, Kualalumpur, 24-25 October 2017.

[3] Patel, V. and Shah, N. (2003) A Survey of High Performance Concrete Developments in Civil Engineering Field. *Open Journal of Civil Engineering*, **3**, 69-79. https://doi.org/10.4236/ojce.2013.32007

[4] Rana, N., Tiwari, A. and Srivastava, A.K. (2016) High Performance Concrete and Its Application in the Field of Civil Engineering Construction. *International Journal of Current Engineering and Technology*, **6**, 982-985. http://inpressco.com/category/IJCET

[5] Wahby, W.S. (2003) Fifty Years History of Polymers in Concrete in Review, Polymer in Concrete: The First Thirty Years. Edited by Kaeding, O.A. and Prusinki, C.R., SP.214-2. American Concrete Institute, Detroit Michigan.

[6] ACI 548.3R-03 (2003) Polymer Modified. Reported by ACI Committee 548, American Concrete Institute, Detroit.

[7] Muhammad, B., Ismail, M., Bhutta, M.A.R. and Abdul-Majid, Z. (2012) Influence of Non-Hydrocarbon Subtances on the Compressive Strength of Natural Rubber Latex-Modified Concrete. *Construction and Building Materials*, **27**, 241-246. https://doi.org/10.1016/j.conbuildmat.2011.07.054

[8] Muhammad, B. and Ismail, M. (2012) Performance of Natural Rubber Latex Modified Concrete in Acidic and Sulfated Environments. *Construction and Building Materials*, **31**, 129-134. https://doi.org/10.1016/j.conbuildmat.2011.12.099

[9] Rosignolo, J.A. (2009) Interfacial Interactions in Concrete with Silica Fume and SBR Latex. *Construction and Building Materials*, **23**, 817-821. https://doi.org/10.1016/j.conbuildmat.2008.03.005

[10] Yang, Z.X., Shi, X.M., Creighton, A.T. and Peterson, M.M. (2009) Effect of Styrene-Butadiene Rubber Latex on the Chloride Permeability and Microstructure of Portland Cement Mortar. *Construction and Building Materials*, **23**, 2283-2290. https://doi.org/10.1016/j.conbuildmat.2008.11.011

[11] Doğan, M. and Bideci, A. (2016) Effect of Styrene Butadiene Copolymer (SBR) Ad-

mixture on High Strength Concrete. *Construction and Building Materials*, **112**, 378-385. https://doi.org/10.1016/j.conbuildmat.2016.02.204

[12] El-Hawary, M.M. and Abdul-Jaleel, A. (2010) Durability Assessment of Epoxy Modified Concrete. *Construction and Building Materials,* **24**, 1523-1528. https://doi.org/10.1016/j.conbuildmat.2010.02.004

[13] Ousama, E., Elhem, G., Valérie, M. and Mongi, O.B. (2012) Mechanical and Physical Properties of Epoxy Polymer Concrete after Exposure to Temperatures up to 250˚C. *Construction and Building Materials,* **27**, 415-424. https://doi.org/10.1016/j.conbuildmat.2011.07.027

[14] Haidar, M., Ghorbel, E. and Toutanji, H. (2011) Optimization of the Formulation of Micro-Polymer Concretes. *Construction and Building Materials*, **25**, 1632-1644. https://doi.org/10.1016/j.conbuildmat.2010.10.010

[15] Goyal, A. and Agarwal, P. (2017) Use of Co-polymer Styrene Butadiene Rubber—A Seismically Innovative Approach toward Energy Dissipation. *Procedia Engineering*, **173**, 1800-1807. https://doi.org/10.1016/j.proeng.2016.12.222

[16] Xue, J. and Shinozuka, M. (2013) Rubberized Concrete: A Green Stuctural Material with Enhanced Energy-Dissipation Capability. *Construction and Building Materials*, **42**, 196-204. https://doi.org/10.1016/j.conbuildmat.2013.01.005

[17] Atahan, A.O. and Yücel, A.Ö. (2012) Crumb Rubber in Concrete: Static and Dynamic Evaluation. *Construction and Building Materials*, **36**, 617-622. https://doi.org/10.1016/j.conbuildmat.2012.04.068

[18] Konsumsi Karet Alam Indonesia. http://indonesia-investment.com

[19] Utama, M. (2007) Teknologi Lateks Alam Iradiasi: Solusi Problema Produksi Barang Karet. Pusat Pengembangan Informatika Nuklir-BATAN, Jakarta.

[20] Andayani, S.W. (2007) Studi Pemanfaatan Kopolimer Lateks Alam Styrena Dalam Pembuatan Polymer Modified Concrete. Magister Thesis, Bandung Institute of Technology, Bandung.

[21] Andayani, S.W. (2008) Ketahanan Bakar Polymer Modified Concrete Berbasis Lateks Alam. Research Report, Centre for Material and Technical Product Ministry of Industry, Bandung.

[22] Basuki, A. and Andayani, S.W. (2014) Ketahanan Gempa Polymer Modified Concrete Dengan Menggunakan Kopolimer Lateks Alam Styrena Sebagai Aditif Beton. *Proceeding of Seminar Nasional Teknologi Industri Hijau* 1, Semarang-Indonesia, 21 May 2014.

[23] Lothenbach, B., Scrivener, K. and Hooton, R.D. (2011) Supplementary Cementitious Materials. *Cement and Concrete Research*, **41**, 1244-1256. https://doi.org/10.1016/j.cemconres.2010.12.001

[24] Schneider, M., Romer, M., Tschudin, M. and Bolio, H. (2011) Sustainable Cement Production—Present and Future. *Cement and Concrete Research*, **41**, 642-650. https://doi.org/10.1016/j.cemconres.2011.03.019

[25] ASTM C 33/C 33M Standard Specification for Concrete Aggregates

[26] Semen Portland Pozolan. SNI 0302-2014.

[27] ASTM D 1076 Standard Specification for Rubber-Concentrated, Ammonia Preserved, Creamed, and Centrifuged Natural Latex.

[28] ASTM C 39/C 39M Standard Test Method for Compressive Strength Cylindrical Concrete Specimen.

[29] ACI 211.1-91 (Reapproved 2002) Standard Practice for Selecting Proportion Nor-

mal, Heavyweight and Mass Concrete.

[30] Andayani, S.W., Suratman, R., Imrana, I., Mardiyatia, Y. and Ariyadi, B. (2016) Preliminary Research on Strength of Polymer Modified Concrete with Copolymer Natural Rubber as Concrete Additives. *Journal of Chemical Engineering and Material Science*, **7**, 18-27.https://doi.org/10.5897/JCEMS2016.0252

[31] Cara Uji Kuat Tekan Beton Dengan Benda Uji Silinder. SNI 1974:2011

[32] ASTM C 78/C 78M Standard Test Method for Flexural Strength of Concrete (Using Simple Beam of Third Point Loading).

[33] ASTM C 496/C 496M Standard Test Method for Splitting Tensile Strength Cylindrical Concrete Specimen.

[34] ASTM C 469/C 469M Standard Test Method for Static Modulus of Elasticity and Poison's Ratio of Concrete in Compression.

[35] Andayani, S.W., Suratman, R., Imrana, I., Mardiyatia, Y. and Ariyadi, B. (2017) Copolymer Natural Latex in Concrete: Dynamic Evaluation through Energy Dissipation of Polymer Modified Concrete. *AIP Conference Proceedings*, **1958**, 020012. https://doi.org/10.1063/1.5034543