SMARTek
SIPIL ◇ MESIN ◇ARSITEKTUR ◇ELEKTRO

COMPRESSIVE AND TENSILE STRENGTH OF EXPANDED POLYSTYRENE BEADS CONCRETE

Tengku Fitriani L. Subhan *

Abstrak
Penelitian ini betujuan untuk mempelajari property dari beton ringan yang mengandung expanded polystyrene beads, yaitu kuat tekan (compressive strength) dan kuat tarik (tensile strength). Property tersebut kemudian dibandingkan dengan beton normal (beton tanpa expanded polystyrene beads) sebagai campuran pengontrol.
Hasil penelitian ini menunjukkan bahwa jumlah *polystyrene beads* yang dimasukkan sebagai campuran beton mempengaruhi property beton; yaitu dapat menurunkan kuat tekan beton. Tetapi, pada campuran beton dengan 15 % polystyrene beads (Mix II) pada 28 hari kuat tekannya dapat bertahan hingga 86 % dan kuat tariknya 87 % jika dibandingkan dengan beton normal.
Kata kunci: beton, *polystyrene beads*

Abstract
The main purpose of this investigation is to study the properties (compressive and tensile strengths) of lightweight concrete containing expanded polystyrene beads. Its properties are compared those of the normal weight concrete (control mix).
The results showed that the amount of polystyrene beads incorporated in concrete influence the properties of hardened concrete; that is lightweight aggregate could reduce the strength of concrete. However, the compressive strengths of lightweight concrete with 15 % polystyrene beads (Mix II) at 28 days for example, could maintain up to 86 % compared to those of normal weight concrete, while the tensile strength was 87%.
Keywords: *concrete, polystyrene beads*

I. Introduction

1.1. Compressive Strength

Strength of concrete is the most important, although other characteristic may also be critical and cannot be neglected. Strength is an important indicator of quality because strength is directly related to the structure of hardened cement paste.

Even though strength is not a direct measure durability or dimensional stability, it has a strong relationship with the water to cement ratio of the concrete, which in turn influences durability, dimensional stability and other properties of concrete (Shah, S.P. and Ahmad, S.H., 1994).

The strength measured in concrete depends on some factors including the age, degree of hydration, rate of loading, method of testing, specimen geometry, and the properties and proportions of the constituent materials. Mostly, concrete strength improves with the increase of age.

The strength of saturated specimens may have lower strength than dry specimens. Compressive strength measured in impact loading will be higher than that in a normal rate of loading. Cube specimens may result higher strength than cylinder specimens.

The properties of constituent materials that are the quality of aggregate, the quality of cement paste, and the bond between aggregate and cement paste, influence the strength of concrete.

* Staf Pengajar Jurusan Teknik Sipil Fakultas Teknik Universitas Tadulako, Palu

Therefore, concrete using crushed aggregates, which have rough surface, have a better interfacial bond with cement paste than uncrushed. Hence, higher strength concrete can be achieved.

Particularly for lightweight concrete, according to Newman (Clarke, J.L., 1993), the increase of strength not only depending on the type of aggregates used but also depends on cement content. He points out that generally, greater cement contents are required than for normal weight concrete; that is about 10% greater for concrete with strength up to 40 MPa and 20% to 25% for concrete with higher strength.

1.2. Tensile Strength

Tensile strength governs the cracking behavior and affects other properties such as stiffness, damping action, and durability of concrete. It is also important regarding the behavior of concrete under shear loads. Tensile strength is determined by either direct tensile tests or by indirect tensile tests such as flexural or split cylinder tests accordance with national standards.

According to Newman (Newman, J. & Choo, B.S., 2003), moreover, tensile strength is important when cracks in concrete elements are considered. The factors influencing compressive strength also influence tensile strength.

He also points out that there are principal differences between lightweight aggregate concrete and normal weight concrete. They are fracture path (this travel through lightweight aggregate particles), and a significant reduction in tensile strength in drying situation due to grater moisture gradients of lightweight aggregates.

2. Materials used in this investigation are:

2.1 Portland cement

The type of cement used for these studies is general purpose Portland cement (GP)-Blue Circle Southern, complying with the requirement of the Australian Standard specification, AS 3972.

2) Aggregates
   The aggregates used throughout this investigation are:
   a. Coarse aggregates
   b. Fine aggregates
3) Polystyrene beads
   The lightweight aggregate used is expanded polystyrene beads BST premium (supplied by BST Australia) with mean diameter 3 mm. They were coated with non-toxic chemical compounds to achieve bonding to the cement paste and to avoid segregation. The color is reddish brown. The density of these polystyrene beads was 55 kg/m^3.
4) Fly ash
5) Superplasticiser

Superplasticiser used in this study is Rheobuild 2000A as high-range water reducer in order to produce workable high strength concrete.

6) Water.

Table 1. Compositions of control concrete mixture

Materials	Content (kg/m^3)
Cement	448
Fly ash	102
Fine Aggregate	626
Coarse Aggregate	1088
Superplasticiser	9.9
Water	140

Table 2 shows the mix composition of each mixture. The (water + superplasticiser) to (cement + fly ash) ratio of 0.27 in every batch of concrete in this investigation were maintained the same. The amount of fine aggregate, on the other hand, is adjusted depending on the percentages of polystyrene beads used in fine aggregate replacement. There are four mixes of concrete with varying content of polystyrene beads (PB), namely: Mix I

(0% PB) as a mix control, Mix II (15 % PB), Mix III (30 % PB), and Mix IV (45 % PB).

Table 3 shows the concrete materials, which were batched by weight for every mix. The amount of fine aggregate was changed for different mixes according to percentage of polystyrene beads put in the mixes. The higher the amount of polystyrene beads, the lower the amount of sand. Polystyrene aggregate composition is varied among the concrete mixtures to determine the maximum lightweight aggregate needed concrete and to see the effect of polystyrene beads in the high strength concrete. The amount of materials and water needed were calculated before mixing, the moisture content and absorption capacity of aggregate were carried out. Then, a day before mixing concrete, the coarse and fine aggregate were air dried to achieve uniform moisture content.

Table 2. Mix Composition (kg/m^3)

Materials	Mix I	Mix II	Mix III	Mix IV
Cement	448	457	465	464
Fly Ash	102	104	106	106
Water	140	143	145	145
Superplasticiser	9.9	10.1	10.3	10.3
Fine Aggregate	626	541	453	356
Coarse Aggregate	1088	1112	1128	1128
Polystyrene Beads	0	208	3.92	6.03
W+S/C+F	0.27	0.27	0.27	0.27
A/C+F	3.12	2.95	2.77	2.70

Table 3. Batch weight of materials (kg) for each mix

Materials	Mix I (0% PB)	Mix II (15% PB)	Mix III (30% PB)	Mix IV (45% PB)
Coarse Aggregate	37.4	37.4	37.4	37.4
Fine Aggregate	21.5	18.2	15	11.8
Polystyrene Beads	0	0.07	0.13	0.2
Cement	15.4	15.4	15.4	15.4
Fly ash	3.5	3.5	3.5	3.5
Superplasticiser	0.34	0.34	0.34	0.34
Water	4.8	4.8	4.8	4.8

However, before pouring concrete mixture it is essential to do moisture content tests for the coarse and fine aggregates in order to adjust water content. The moisture content of coarse sand just before pouring concrete for example was 9 %, which is high water absorption, so the amount of water for mixture should be reduced. For fine sand, on the contrary, it was very dry with the moisture content was much lower, that was 0.05 %. Therefore specific amount of water should be added.

For Mix II, III, and IV, the polystyrene beads were spreaded evenly before the coarse aggregate was added. After mixing of concrete, the temperature of mixture was measured. The fresh concrete properties (wet density slump) were immediately tested accordance with AS 1012 (1970). The concrete temperature was found to 18 ^{o}C.

3. Compressive Strength

All compressive strength tests in this study were performed by using Avery universal testing machine with loading rate 20±2 MPa per minute according to AS 1012.9-1999. The test specimens were 3 cubes of 100x100x100 mm for each age, tested at 3, 7, 28, and 56 days at the room temperature of 20^{o} C and 65 % RH. After removal from the curing environment, the surplus water on all cubes was wiped out as soon as possible and dimensions and weight were determined.

3.1 Compressive strength development with age

Compressive strength development results are summarized in both Table 4 and Figure 3, while relative compressive strength development with age is shown in Table 5 and Figure 4. It is shown that the compressive strength of all concrete mixtures increased with the increase of age.

It is clear from the Table 4 that the larger the amount of polystyrene beads in concrete, the lesser the compressive strength. As expected, the normal weight concrete has the largest compressive strength for all days compared to lightweight concrete. At 28 days, it was found that compressive strength of Mix II, Mix III, and Mix IV compared to control concrete were 86%, 65%, and 59%, respectively.

Figure 1. Compressive strength test

Figure 2. Splitting of specimen under tension

In Mix I, at 3 days the compressive strength was 53 MPa, then at 28 days it increased considerably to 80 MPa. During the next 28 days the strength was increased to 81 MPa. In Mix II and Mix III on the other hand, the compressive strength increased from 28 days to 56 days about 6 MPa and 5 MPa, respectively.

The compressive strength of control concrete increased from 53 MPa at 3 days to 80 MPa at 28 days (increased of 51%). However, with 15% of fine aggregate replaced by polystyrene beads, the 28-day strength of Mix II was increased by 60.5% from its 3-day strength (69 MPa). When the amount of lightweight aggregate increased up to 30% to replace the fine aggregate (Mix III); the increase of compressive strength at 28 days is 40.5%.

Table 4. Compressive strength development with age

Mixtures	Compressive strength (Mpa)			
	3 days	7 days	28 days	56 days
Mix I	53	67	80	81
Mix II	43	51	69	75
Mix III	37	47	52	57
Mix IV	28	33	39	42

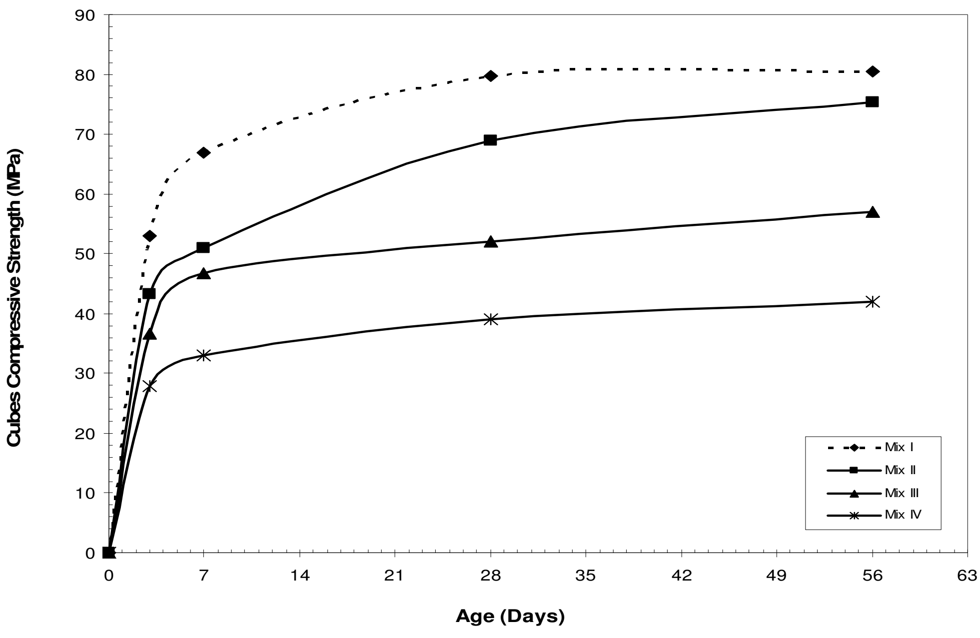

Figure 3. Compressive strength development with age

Table 5. Relative compressive strength development with age

Mixtures	Relative compressive strength development with age			
	3 days	7 days	28 days	56 days
Mix I	1.00	1.26	1.51	1.53
Mix II	1.00	1.19	1.60	1.74
Mix III	1.00	1.27	1.40	1.54
Mix IV	1.00	1.18	1.40	1.50

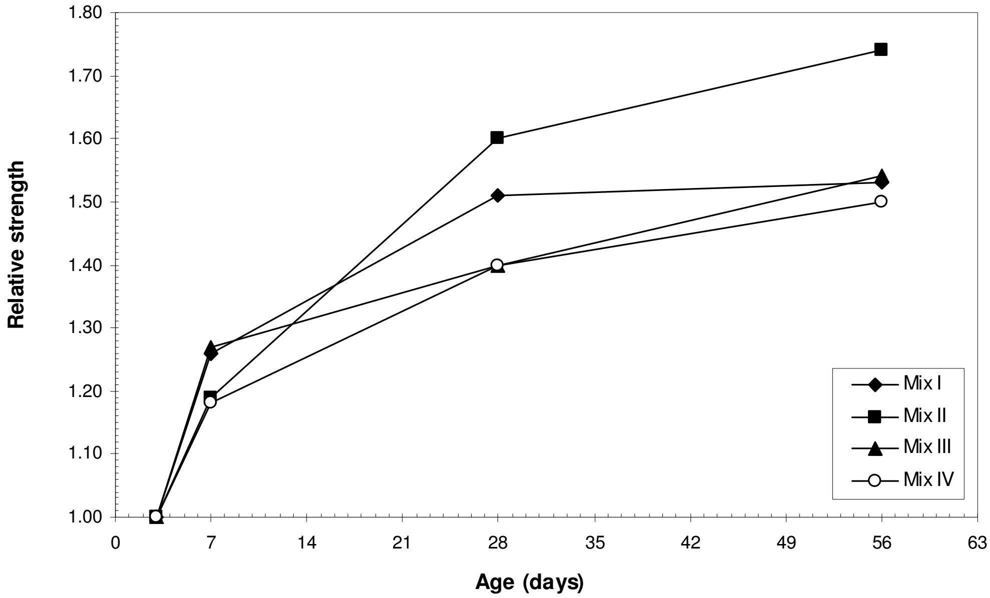

Figure 4. Relative compressive strength development with respect to 3-day strength

Table 6. Relative compressive strength of polystyrene aggregate concrete

Mixtures	Relative strength			
	3 days	7 days	28 days	56 days
Mix I	1.00	1.00	1.00	1.00
Mix II	0.81	0.76	0.86	0.93
Mix III	0.70	0.70	0.65	0.71
Mix IV	0.53	0.49	0.49	0.52

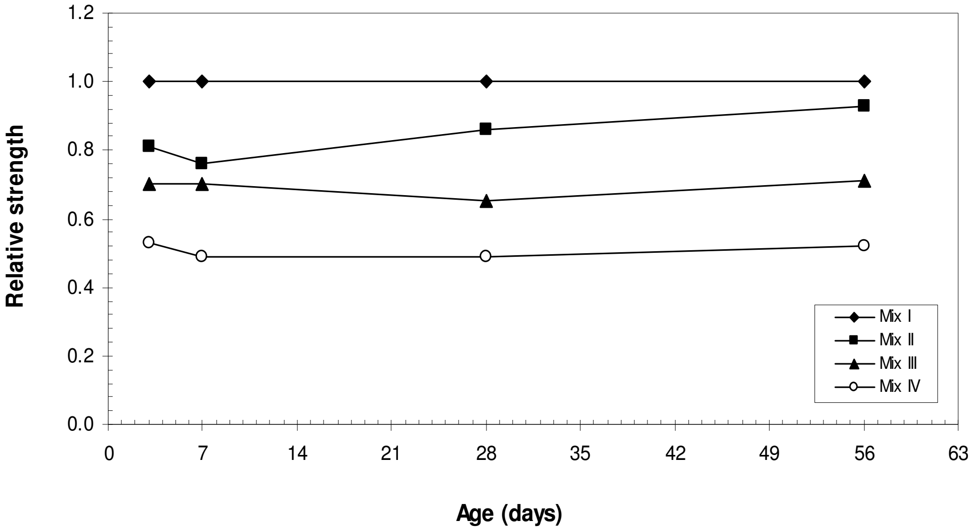

Figure 5. Relative compressive strength of polystyrene aggregate concrete

3.2 Relative compressive strength of polystyrene aggregate concrete

The relative compressive strength of polystyrene aggregate concrete is shown in Table 6 and Figure 5. As represent in Table 6, Mix I has a role as control mixture. For Mix II, the relative development of compressive strength varied between 76% and 93%, while Mix III has lower variation of strength development; from 65% to 71%. In Mix IV, the development of strength even lower, varied among 50%.

4. Tensile Strength of concrete at 28 days

In this investigation, tensile strength test was done with 3 cylinders of 100x200 mm for each mix at the age of 28 days after cured in 20 °C water, using indirect tensile test, accordance with AS 1012.10-2000. Tested were done in room temperature of 20 °C and 65% RH. Figure 2 shows one of the tensile strength tests of concrete.

After taken out from the water curing and the surplus water was wiped out, the mean diameter and lengths of specimens were measured. The hardboard bearing strips were placed between the platen of the machine and specimen to avoid local crushing. The load is at the rate of 1.5±0.15 MPa per min.

Table 7 and Figure 6 show the results of tensile strength of concrete at 28 days. It is clear from the bar chart that the higher the amount of polystyrene beads in concrete mixture, the lower the tensile strength. Relative tensile strength of lightweight concrete compared to normal weight concrete are shown in Table 8, while Table 9 represents the comparison between tensile strength and 28 days compressive strength of all concrete mixtures as well as the ratio between them.

As can be seen in Table 7 and Figure 6, the control concrete (Mix I) has the highest tensile strength, stands at 5.53 MPa. Mix II however, has lower tensile strength (4.8 MPa), whereas Mix III has tensile strength only 0.1 MPa lower. As expected, Mix IV has the lowest tensile strength as much as 3.4 MPa due to the large amount of polystyrene beads.

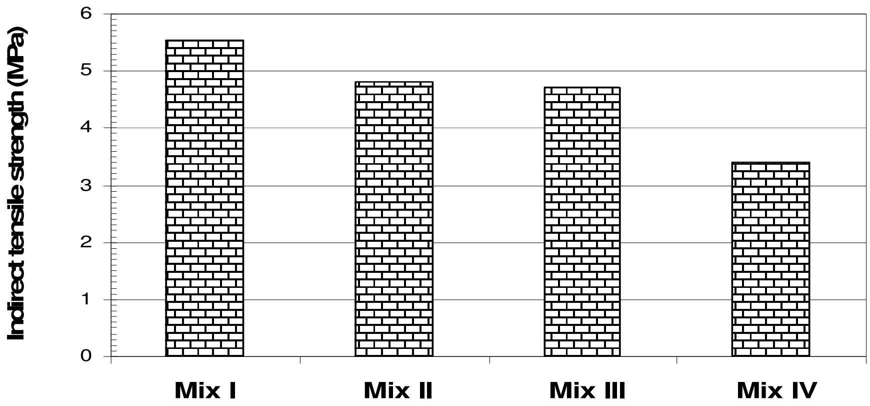

Figure 6. Tensile Strength at 28 days

Table 7. Tensile strength of concrete mixes at 28 days

Mixtures	Tensile strength (MPa)
Mix I	5.53
Mix II	4.80
Mix III	4.72
Mix IV	3.40

Table 8. Relative tensile strength of lightweight concrete to normal weight concrete at 28 days

Mixtures	Mix I	Mix II	Mix III	Mix IV
Tensile Strength (MPa)	5.53	4.80	4.72	3.40
Relative strength	1.00	0.87	0.85	0.62

4.1 Relative tensile strength

It is clear from Table 8 that tensile strength development up to 28 days of concrete with the lowest polystyrene beads content (Mix II) was the highest among lightweight concrete as much as 87%. Subsequently, the higher the lightweight aggregate in concrete, the lower the relative strength.

4.2 Tensile strength to compressive strength ratio

As shown in Table 9 and Figure 7, the higher the compressive strength, the higher the tensile strength. The relationship between tensile strength and compressive strength is non-linear (f_t = A $(f_c)^{0.3}$. The ratio between tensile strength and compressive strength does not exhibit similar pattern.

Table 9. Tensile strength to compressive strength ratio

Mixtures	At 28 days		
	f_t (Mpa)	f_c (Mpa)	f_t/f_c
Mix I	5.53	80	7%
Mix II	4.80	69	7%
Mix III	4.72	52	9%
Mix IV	3.40	47	7%

Note: f_t = tensile strength f_c = compressive strength

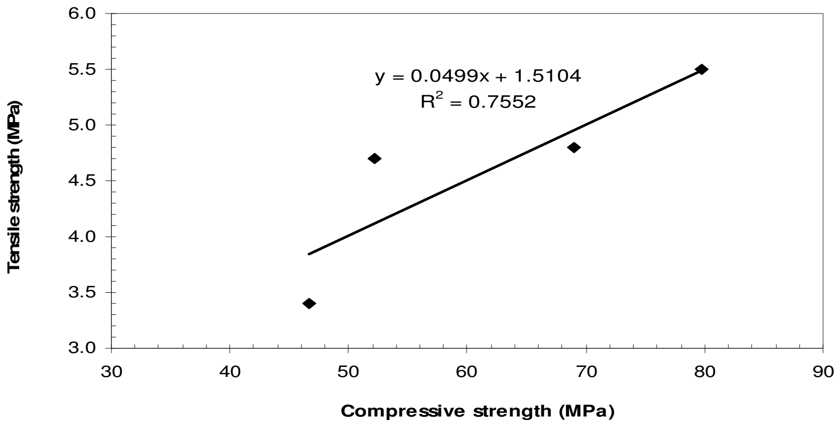

Figure 7. Correlation between compressive and tensile strength

For Mix I, Mix II and Mix IV, the tensile strengths are similar, stand at 7% of its compressive strengths. Surprisingly however, for Mix III, its tensile strength is 9% of its compressive strength.

5. Conclusion and Recommendation for future woks

Increase in the polystyrene beads content in high-strength concrete will reduce the compressive and tensile strength of concrete

It is possible to incorporate polystyrene aggregate in concrete mixture to produce lightweight high strength concrete with fine aggregate replacement up to 30%. However, the use of polystyrene beads as much as 45 % in fine aggregate replacement will not produce satisfy high strength concrete, as the compressive strength is below the lowest limit of high strength concrete (41 MPa).

In this investigation, the water to cement ratio for each mix was remain the same. It is recommended for varying the ratio of water to cement in order to know its effect to the concrete properties with 15 %, 30 %, and 45 % polystyrene beads replaces fine aggregates.

6. References

Clarke, J.L. (1993), *Structural lightweight aggregate concrete*, published by: Blackie Academic & Professional, an imprint of Chapman & Hall, Glasgow, first edition, pp. 1-41.

Newman, J. & Choo, B.S. (2003), *Advanced Concrete Technology, Constituent Materials*.

Shah, S.P. and Ahmad, S.H. (1994), *High Performance Concrete: Properties and Applications*, published by: McGraw-Hill, Inc. Great Britain.

Standards Association of Australia (1970), AS 1012 – *Methods of Testing Concrete*.