
THE INFLUENCE OF ADDING SUPERPLASTICIZER WITH TIME INTERVAL AND VARIATION OF WATER REDUCTION ON THE EARLY STRENGTH AND WORKABILITY OF CONCRETE

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ABSTRACT

Acceleration of early strength of concrete can be obtained by reducing water in the concrete mixture followed by addition of superplasticizer. The application of the addition of superplasticiser to water-reduced concrete mixtures requires innovation in providing a time lag to produce good workability. This study analyzes the effect of giving a time delay when adding superplasticizer followed by reducing water with certain variations on the workability and early strength of concrete. The results of this research are very important for the concrete industry with the purpose of shortening the removal time of formwork and optimizing the construction process. Water cement ratio is adjusted by reducing its volume by a fraction of 10% to 30%, superplasticizer 1% to the weight of cement is added in two stages, during the initial mixing and after one or two hours afterwards. 0.3% retarder was added to control homogeneity during mixing. The test results concluded that the reduction of water that provided the highest increase in concrete compressive strength at 4 days was LN25-1 of 21.94 MPa (87% of the design compressive strength) and LN20-2 of 19.12 MPa (76% of the compressive strength plan). The optimal amount of water reduction at the initial age of the concrete is 20 – 25% of the design water weight. Giving a time lag does not reduce the increase in concrete strength due to the addition of superplasticizer. Giving a time lag of 1 hour and 2 hours has been proven to still be able to provide better workability to the concrete mixture through the double dispersion process, thereby giving the concrete mixture extra time to compact and creating a higher compressive strength value for the concrete.

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INTRODUCTION

The Indonesian construction world is advancing in line with its economic development. Concrete construction is the most widely used type of construction in Indonesia so that the *ready mix concrete* industry is increasingly mushrooming. The *ready mix concrete* industry is a service industry in the field of providing ready-mixed fresh concrete that has several advantages, one of which is the quality that is strictly controlled during the manufacturing and delivery process so as to produce concrete with good quality (Salim & Santoso, 2018). Formwork technology and methods in the implementation of high-rise building castings using concrete structures are increasingly sophisticated. *Cycle time* (formwork execution time from the start of schafoding to casting) in formwork installation with the latest methods can be achieved in 4 to 5 days per floor. The speed of formwork installation is not matched by the speed of concrete's ability to withstand workloads at the beginning of the concrete age, so the formwork cannot be dismantled 4 to 5 days after casting. A lot of formwork inventory due to the slow increase in *early strength of concrete* results in cost and time inefficiencies. Innovation is needed to accelerate the *early strength of concrete* and good *workability* in the implementation of casting.

Accelerating the increase in *early strength of concrete* can be done by reducing water in the concrete mixture accompanied by the addition of *superplasticizer to the concrete mixture*. *Superplasticizer* can not only increase the *early strength of concrete mixtures*, this *admixture* is also able to accelerate the hardening of concrete, reduce water usage, and facilitate the processing (*workability*) (Theodorus et al., 2011). Research by Rahman et al. (2017) using Sikament LN *su-perplasticizer* concluded that the highest average concrete *strenght test* results at the age of 3, 7, 14, and 28 days were using a concrete mixture with the addition of 1% *superplasticizer* - 20% water. The concrete mixture has a concrete strength of 40.05 MPa (160% of the planned strength of 25 MPa) at the age of 28 days and 23.52 MPa at the age of 3 days (94% of the planned strength of 25 MPa).

The application of *superplasticizer* addition and water reduction in concrete mixtures to increase *early strength in actual implementation in the field* there are several obstacles and obstacles, especially related to time *constraints* that can affect *workability* and compressive strength values of concrete. The process of procuring ready-mixed concrete in the field often encounters obstacles, including the distance from the batching plant to the project site, unpredictable traffic

conditions, damaged road conditions, and the waiting time required for pouring ready-mixed concrete at the project site. The time lag in the addition of *superplasticizer* to water-reduced concrete variations was further investigated in this study to determine its effect on *workability* and *early strength* improvement of concrete.

Cement Water Factor.

The water cement factor (FAS) is the ratio of the weight of water to the weight of cement in the concrete mix. The lower the FAS in concrete, the higher the quality of the concrete. The function of water in concrete mixtures is twofold, first as an activating agent for the hydration process of cement and second to increase the fluidity of the mixture by reducing the shear between particles. Excessive water will be in the form of free water, and cause voids in the concrete after evaporation. In these voids cement crystals in the form of ettringite will form freely. These crystals are flat and long, increasing the likelihood of micro-cracking in the concrete.

Excessive water also forms a thin membrane around the aggregate, thus weakening the interface between the mortar and the aggregate. Too little water will cause difficulty in the mixing process, and result in inhomogeneous fresh concrete. Difficulties also occur when pouring the mortar in the formwork, especially when there are thin structural components or tight reinforcement. There is thus a critical turning point between the benefits of water reduction, and the negative effect on density.

The use of *vibrators* can increase density, but the critical point of water reduction will still occur. It is necessary to add *admixtures* so that the concrete mix can still work properly even though the FAS is very low.

Superplasticizer.

The use of *superplasticizer* or *high range water reducer* (hrwr) serves to eliminate vibrations between particles, and change the charge of repulsion between particle surfaces so that optimal *slump* values can be obtained in fresh (*workable*) concrete with low FAS, so that good concrete casting performance can still be produced (Benaicha, Hafidi Alaoui, Jalbaud, & Burtschell, 2019; Pujianto, 2011). By adding this material to concrete, it is possible to reduce the amount of mixing water by a sufficiently high amount so that the expected strength of the resulting concrete is high, but the *workability of the* concrete is also higher (Li, Yu, & Brouwers, 2017; Qian et al., 2018). The use of *superplasticizer* must comply with ASTM-C 494-81 type F standard.

Superplasticizer dosage can be used at 0.20% - 1.8% of the total weight of cementitious materials depending on the requirements on workability and strength. The dosage can also be combined with water reduction of 3% to more than 20% to obtain higher compressive strength in concrete. The *superplasticizer*

mixing process requires stirring for 3 to 5 minutes before pouring into the formwork mold.

Superplasticizer molecules in the form of negatively charged salts surround cement grains containing positive ions through an electrostatic process that makes cement grains repel each other and cement dispersion occurs (Coppola, Lorenzi, Kara, & Garlati, 2017). The result of this cement dispersion can reduce the water trapped in the collection of cement particles thereby improving the *flowability of the concrete mix*. Zhang & Kong, (2015) conducted research on the relationship of *superplasticizer* disperse ability to the heat generated by cement hydration. The molecular structure of *superplasticizers* affects the behavior of cement-based materials, a review of this influence can be found in the work of Sha (Sha, Wang, Shi, & Xiao, 2020).

Comparison of Concrete Compressive Strength with Flexural Strength of Concrete for Formwork Demolition.

The parameter for whether or not to dismantle or remove the formwork is the compressive strength of the concrete. Ginting, (2019) conducted research on the comparison of concrete compressive strength with the flexural strength of concrete beams at various ages to ensure that the compressive strength of the beam cylinder can be used as a basis for dismantling the formwork. Researchers compared the percentage of sample compressive strength and flexural strength of concrete beams with the plan compressive strength and theoretical flexural strength. The samples used in addition to cylinders are also concrete beams measuring 14 x 20 x 120 cm. Tests of the compressive strength of cylinders and flexural strength of reinforced concrete beams were carried out at the ages of 3, 7, 14, 21, and 28 days. In the study, it was found that the compressive strength of the cylinder at the age of 3 days was 31.9% of the planned compressive strength and the bending strength of the beam was 64.9% of the theoretical bending strength. At the age of 7 days, the concrete strength was 71.4% of the planned compressive strength and the flexural strength was 86.8% of the theoretical flexural strength. While at the age of 14 days the concrete strength is 84.9% of the plan compressive strength and the flexural strength of the concrete beam is 87.7% of the theoretical compressive strength. The compressive strength of concrete cylinders at the age of 3 days is still too small (31.9%) and the flexural strength at the same age variation is also still 64.9%. So that usually the dismantling of formwork is carried out at the age of 7-14 when the compressive strength of the concrete cylinder and the flexural strength of the concrete beam are above 70%.

RESEARCH METHOD

The method used in this research is laboratory experimentation, namely by using data obtained through direct experiments to correlate the various *variables* investigated (Gammarya, 2012). This study analyzes and compares the *slump* value and compressive strength of normal concrete minus the cement water ratio

and added *retarder* and *superplasticizer* with a time lag. The compressive test will be conducted when the concrete is 3; 4; 5; 6 and 28 days old.

The object of this research is a concrete cylinder measuring Ø15 cm with a height of 30 cm. The concrete quality used was $f'c = 25$ MPa. The dose of *retarder* used was 0.3% by weight of cement, while the dose of *superplasticizer* was 0.5% of the amount of cement at the initial time of making the concrete mixture which is hereinafter referred to as the first stage and 0.5% in the second stage after being given a time lag variation. The research stages were carried out in accordance with the *flowchart* presented in Figure 4.

A total of 165 cylindrical samples measuring Ø15 cm x 30 cm were prepared through the distribution as shown in Table 1. Cylinder BC 0 is a normal control concrete without water reduction and *superplasticizer* addition, while BC 20 is a control concrete without *superplasticizer* addition that is reduced by 20% of the normal amount of water. Test specimen code LN10-1 shows a concrete sample with a variation in the time lag of *superplasticizer* addition of 1 hour with 10% water reduction. The variation of *superplasticizer* addition time lag for 2 hours is given to samples LN 10-2, LN 20-2, LN 30-2 with water reduction of 10%, 20%, 30% of the normal amount of water respectively.

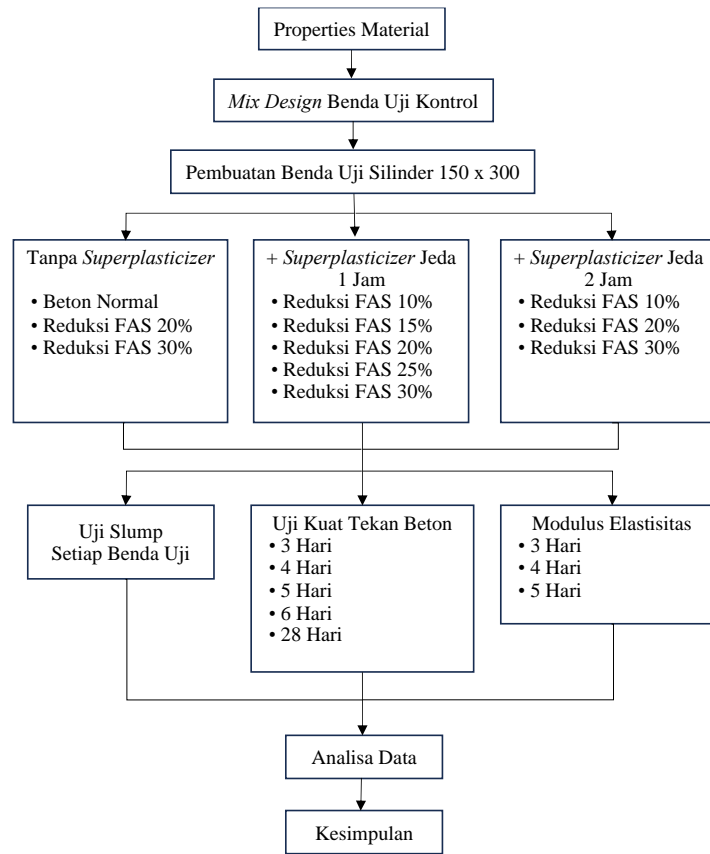


Figure 1. Research *Flowchart*

Table. 1. Material requirements per test piece at various variations.

Variasi	Benda Uji (buah)	Vol. Benda Uji (m ³)	Semen (Kg)	Pasir (Kg)	Split ½ (Kg)	Air (Kg)	Super plasticizer (Liter)	Retarder (Liter)
BC 0	15	0,113	48,09	73,479	124,865	21,012	0	0,144
BC 20	15	0,113	48,09	73,479	124,865	16,809	0	0,144
BC 30	15	0,113	48,09	73,479	124,865	14,708	0	0,144
LN 10-1	15	0,113	48,09	73,479	124,865	18,911	0,48	0,144
LN 15-1	15	0,113	48,09	73,479	124,865	17,860	0,48	0,144
LN 20-1	15	0,113	48,09	73,479	124,865	16,810	0,48	0,144
LN 25-1	15	0,113	48,09	73,479	124,865	15,759	0,48	0,144
LN 30-1	15	0,113	48,09	73,479	124,865	14,708	0,48	0,144
LN 10-2	15	0,113	48,09	73,479	124,865	18,911	0,48	0,144
LN 20-2	15	0,113	48,09	73,479	124,865	16,810	0,48	0,144
LN 30-2	15	0,113	48,09	73,479	124,865	14,708	0,48	0,144

RESULT AND DISCUSSION

Effect of *Superplasticizer* Addition with Time Delay on *Workability* of Concrete Mix.

Mehta and Monteiro (2014) conducted research related to *slump* and hydration of Portland cement paste. *Slump* loss is the loss of consistency in *fresh concrete* over time due to gradual hardening and hydration of Portland cement paste. The process occurs when water hydrates and absorbs moisture on its surface resulting in evaporation. In normal concrete, *slump loss* generally occurs after the first 30 minutes to 60 minutes so that it is possible to affect mixing, bonding, placing, compaction, and finishing will be difficult.

In concrete samples BC 0, BC 20, BC 30, *slump testing* was carried out every 30 minutes from minute 0 until the *slump loss test* sample no longer occurred when the Abrahms cone was withdrawn. *Slump* testing on concrete samples LN 10-1, LN 15-1, LN 20-1, LN 25-1, LN 30-1 (variation of water reduction with a 1-hour pause in the addition of *superplasticizer*) was carried out at the time:

1. In the first minute after the aggregate, cement, water that has been reduced according to the percentage reduction, *retarder*, and 50% *superplasticizer* are mixed and stirred in the *concrete mixer* machine.
2. 30 minutes after mixing.

3. at 60 minutes before mixing 50% of the second *superplasticizer*
4. After mixing the second 50% *superplasticizer* at a time lag of 1 hour.
5. Every 30 minutes after mixing the second 50% *superplasticizer* until the *slump* test sample did not drop anymore when the Abrahams cone was withdrawn.

The results of the *slump* test on control concrete specimens, water reduction variation specimens with the addition of *superplasticizer* pause 1 hour, and water reduction variation specimens with the addition of *superplasticizer* pause 2 hours are presented in Table 2.

Table 2. *Slump test* results on several variations of specimens.

Variasi Sample	0	30	60 Menit		90	120 Menit		150	180
	Menit	Menit	Awal	Akhir	Menit	Awal	Akhir	Menit	Menit
BC 0	9,0	8,5	8,0	8,0	7,0	5,0	5,0	-	-
BC 10	9,0	7,0	5,0	5,0	2,0	-	-	-	-
BC 20	8,0	6,0	3,0	3,0	-	-	-	-	-
BC 30	5,0	2,0	-	-	-	-	-	-	-
LN 10-1	18,0	17,0	8,0	14,0	11,0	8,0	8,0	5,0	2,0
LN 15-1	16,0	13,0	7,0	14,0	10,0	7,5	7,5	5,0	2,0
LN 20-1	14,5	11,0	6,0	13,0	9,0	7,0	7,0	5,0	-
LN 25-1	11,0	7,0	4,0	11,0	6,0	4,0	-	-	-
LN 30-1	9,0	5,0	2,0	10,0	6,0	2,0	-	-	-
LN 10-2	17,0	13,0		7,5	4,0	1,0	8,0	4,0	1,0
LN 20-2	14,5	10,0		6,0	2,5	0,5	7,5	3,5	0,5
LN 30-2	9,0	4,5		1,5	0,0	0,0	2,0	-	-

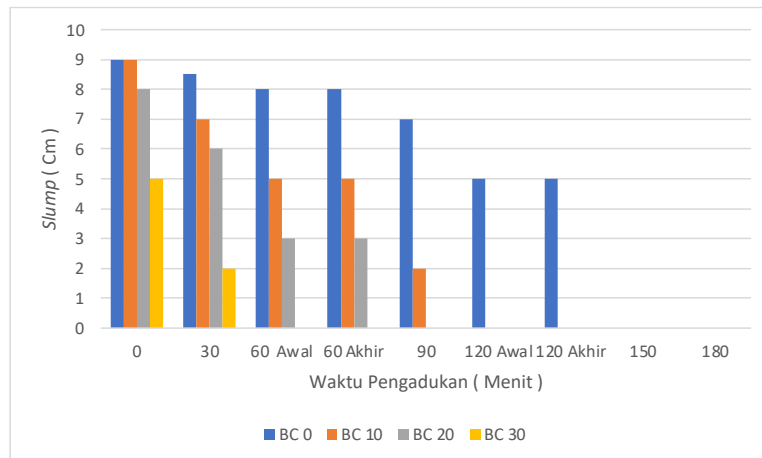


Figure 2. Slump test results without the addition of *superplasticizer*.

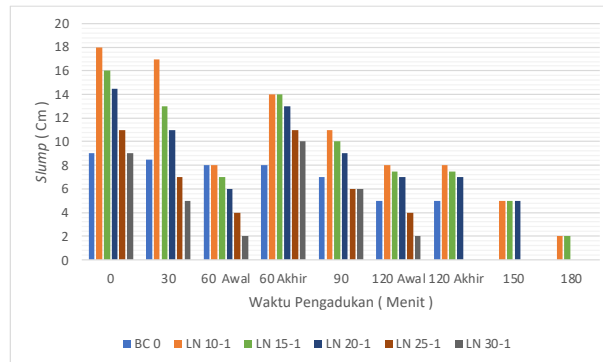


Figure 3. Results of Slump Testing with the Addition of *Superplasticizer* 1 Hour Pause.

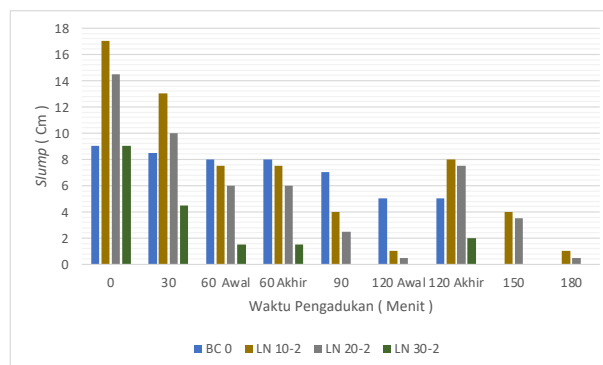


Figure 4. Results of Slump Testing with the Addition of *Superplasticizer* 2 Hour Pause.

Based on the slump test results shown in Table 2 and Figure 5, in BC0 concrete, the *slump value* is used as a control that shows the *slump* value of normal concrete. The amount of *slump* in normal concrete $f'c = 25$ MPa was 9 cm at the initial mixing and decreased further until it was only 5 cm at 120 minutes. Reducing water by 10% did not really affect the *slump* value at the beginning of mixing BC 10, but the *slump loss* was faster than normal concrete so that the *slump* value fell at 90 minutes to only 2 cm. The *slump* value of BC 30 can only be observed up to the 30th minute because after that the test cone does not fall anymore so the *slump* value can no longer be measured. The smaller the FAS the faster the *slump* value of the concrete will be reduced as in BC 10, BC 20 and BC 30, so that the concrete mixture has poorer *workability* or the level of concrete *work in the field* is more difficult. In concrete mixtures with too small FAS in the absence of *admixtures*, the hydration process runs very fast due to the limited water that becomes the hydration activating material so that the cement is not hydrated completely and the concrete hardens quickly.

Figure 6 shows that the addition of *superplasticizer* to LN20-1 resulted in a *slump* value of 14.5 cm at the beginning of the mixture, a *slump* value of 6 cm before the second mixing, and became 13 cm after the second *superplasticizer mixture*. The LN20-2 variation in Figure 7 *slump* value at the beginning of the 2nd *superplasticizer* mixing was 0.5 cm and increased to 7.5 cm after the second mixing. The use of *superplasticizer* and *retarder* can maintain the *slump* up to 180 minutes.

In concrete with the addition of *superplasticizer* at the beginning of mixing, there is an increase in *slump* value up to 15 cm, this is due to the increase in fluidity due to the addition of *superplasticizer* which causes cement particles surrounded by SO₃⁻ so that there is a separation of cement charge and repulsion with the same charge. After stirring for 30 minutes to 60 minutes, the *slump* of the concrete slumped in accordance with the *slump* of the control concrete of approximately 4.5 cm, this is in accordance with the conclusion presented by Neville and Brooks, (2010) that the *workability* of concrete with the addition of *superplasticizer* will return to normal at minute 30 to minute 90.

Effect of water reduction on concrete compressive strength.

The results of the compressive strength of concrete in the variation of normal concrete mixes and concrete with water reduction can be seen in Table 3 below.

Table. 3. Compressive Strength Table of Concrete Variations.

Sample	Kuat Tekan Beton (MPa)				
	3 Hari	4 Hari	5 Hari	6 Hari	28 Hari
BC 0	12,9	17,6	20,0	21,5	31,5
BC 20	13,9	18,1	21,7	23,2	32,1
BC 30	16,6	18,7	22,9	25,8	47,4
LN 10-1	15,4	17,5	21,1	25,4	40,7
LN 15-1	17,6	19,3	23,5	24,7	41,0
LN 20-1	14,9	18,7	22,5	22,4	33,4
LN 25-1	18,3	21,9	25,6	26,8	45,1
LN 30-1	15,2	20,4	23,7	25,0	53,7
LN 10-2	16,5	18,8	20,9	22,8	56,5
LN 20-2	15,9	19,1	23,3	25,9	30,4
LN 30-2	16,0	18,2	22,3	24,7	55,8

In Figure 8, it can be seen that the reduction of water in concrete can increase the compressive strength of concrete. The compressive strength of BC0 concrete at the age of 3 days = 12.93 MPa or 51.72% of the planned compressive strength of 25 MPa. The compressive strength of BC20 concrete at the age of 3 days = 13.94 MPa or 55.75%, while the compressive strength of BC30 concrete at the

same age = 16.6 MPa or 66.4% of the plan compressive strength. At the age of 4 days BC30 was 106.37% stronger than BC0, and it increased as the concrete aged. The higher the water reduction, the lower the FAS and the higher the concrete quality seen in the results above. Less amount of excess free water from the residual cement hydration process, after evaporation, leaves less voids so that the mixture is denser and increases the compressive strength of concrete faster.

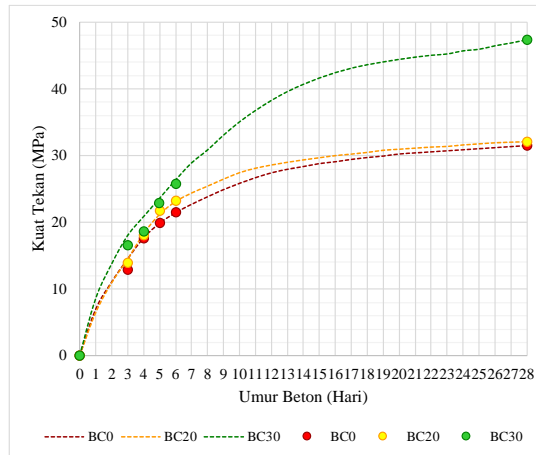


Figure 5. Relationship between FAS, age of concrete, and compressive strength of concrete in water-reduced mixtures

Effect of Time Delay Variation of Superplasticizer Application on Concrete Compressive Strength.

Comparison of compressive strength results of control concrete, water-reduced concrete, and *superplasticizer* addition with time lag can be seen in Fig. 9 and Fig. 10.

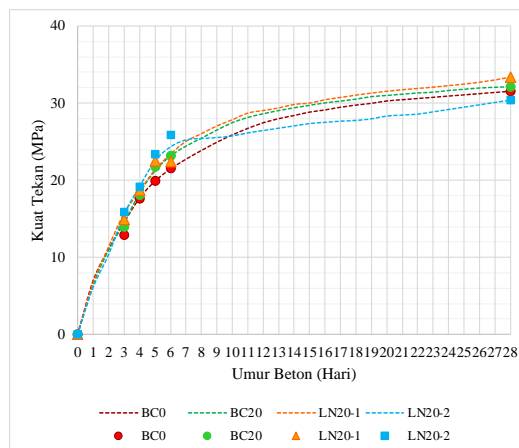


Figure 6. Relationship between concrete compressive strength and concrete age for the concrete variation with 20% water reduction.

In Fig. 9 it can be seen that the addition of *superplasticizer* with a time lag can increase the compressive strength of concrete especially at the age of 3 days, 4 days and 5 days. In concrete mixtures that reduced water by 20%, the compressive strength of LN20-2 concrete at the age of 3 days was 22.73% stronger than BC0. At the age of 4 days LN20-2 has reached 76.48% of the planned compressive strength of 25 MPa. Giving a time lag for *superplasticizer application* does not reduce the increase in concrete compressive strength due to *superplasticizer* application. Water reduction by 20% and assisted dispersion of cement granules by *superplasticizer* makes the compressive strength of concrete increase dramatically at the beginning of the concrete age.

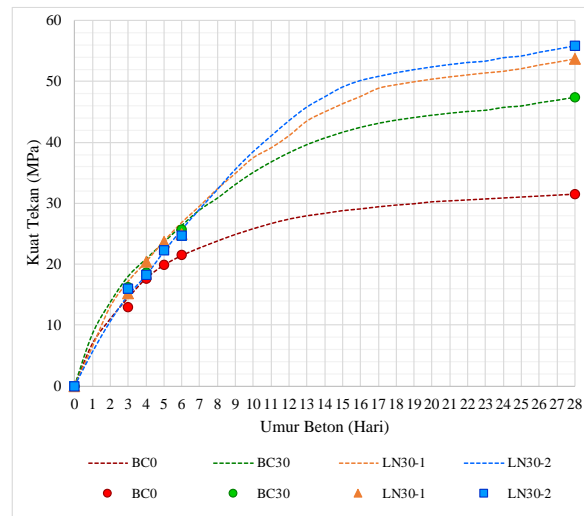


Figure 7. Relationship between compressive strength of concrete and age of concrete in the variation of concrete with 30% water reduction.

The 30% water reduction variation as shown in Fig.10 shows that the addition of *superplasticizer* with a time lag can also increase the compressive strength of concrete. At the age of 4 days, the compressive strength of LN30-1 concrete is 16% stronger than BC0. Giving a time lag also still does not affect the increase in concrete strength due to the addition of *superplasticizer*. Giving a time lag of 1 hour and 2 hours proved to still be able to provide better *workability* to the concrete mixture through a double dispersion process due to *superplasticizer* molecules in the form of negatively charged salts surrounding cement grains containing positive ions through an electrostatic process so as to make the cement grains repel each other. The double dispersion process that occurs at the beginning of *superplasticizer* mixing and the second *superplasticizer* mixing provides extra time for the concrete mixture to solidify so that it has a higher concrete compressive strength value.

Effect of Water Reduction and Addition of Superplasticizer with Time Delay on the Compressive Strength of Concrete.

The effect of variations in water reduction as well as the application of *superplasticizer* with a time lag of 1 hour can be seen in Fig. 11. 25% water reduction has the most impact on increasing the compressive strength of concrete especially at the age of 3, 4, 5, 6 days. At the age of 4 days, the compressive strength of LN25-1 concrete has reached 21.94 MPa, which is 24% higher than BC0 and 87% higher than the planned compressive strength of 25 MPa.

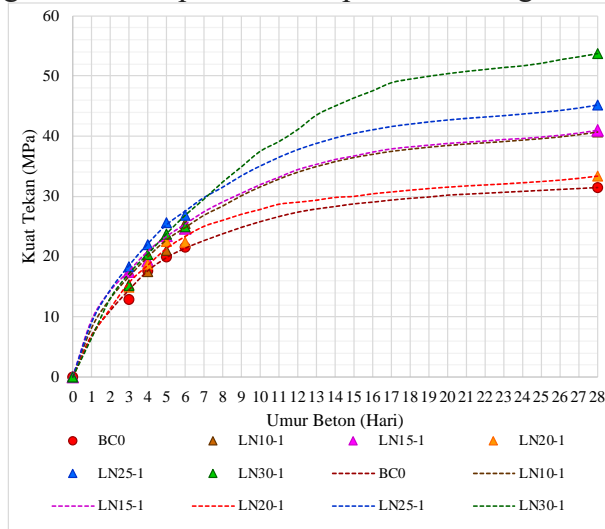


Figure 8. Relationship between concrete compressive strength, concrete age and cement water reduction when *superplasticizer* is applied at 1 hour intervals.

The effect of *superplasticizer* application with a time lag of 2 hours along with variations in water reduction on the compressive strength of concrete can be seen in Fig. 15. 20% water reduction gives the highest increase in concrete strength at the age of 3, 4, 5, 6 days. At the age of 4 days, LN20-2 concrete has reached 19.12 MPa or 76% of the planned compressive strength of 25 MPa.

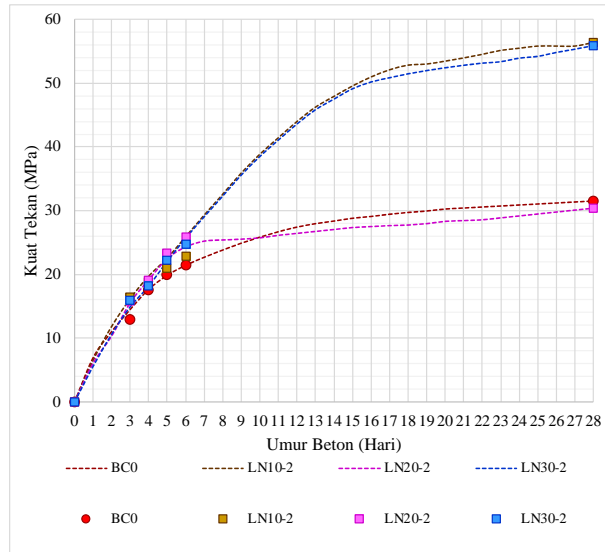


Figure 9. The relationship between concrete compressive strength, concrete age and cement water reduction when applying *superplasticizer* at 2-hour intervals.

From Fig. 11 and Fig. 12 it can be seen that the greatest water reduction increase in compressive strength of concrete at the beginning of concrete age is 20-25% of the plan water cement ratio. The increase occurred drastically at the age of 3 to 5 days but not at the age of 28 days. At the age of 28 days the compressive strength of water-reduced concrete and *superplasticizer* with a time lag remained above the plan compressive strength of 25 MPa.

Based on the graph of the relationship between the compressive strength of concrete and the age of concrete, there is an increase in the compressive strength of concrete as the age of concrete increases. This occurs due to the development of cement bonds in the concrete constituent materials. The increasing age of concrete, the bond between the constituents of concrete is getting stronger, causing the compressive strength of concrete to increase. Concrete with water reduction and accompanied by the addition of *superplasticizer* with a time lag will produce relatively higher compressive strength values compared to concrete mixtures that are only reduced in water without the addition of *superplasticizer* with a time lag. The higher compressive strength value is because the concrete added with *superplasticizer* with a time lag has a better *workability* value so that the concrete compaction process can be carried out more optimally.

CONCLUSION

From the results and discussion above, it can be concluded that: 1. The addition of *superplasticizer* will increase the *workability* of concrete both in the 1st and 2nd mixing. *Workability* will be normal after stirring runs at 30 to 60

minutes after mixing. LN20-1 concrete had a *slump of* 6 cm at 60 minutes and increased to 13 cm after the addition of the 2nd *superplasticizer* so it remained in use in the field until 150 - 180 minutes. 2. Water reduction in concrete can increase the compressive strength of concrete. The *workability of* BC20 concrete is much reduced and it can only be used up to 60 minutes. 3. Giving a time lag does not reduce the increase in concrete strength due to the addition of *superplasticizer*. Giving a time lag of 1 hour and 2 hours proved to still be able to provide better *workability* to the concrete mixture through the double dispersion process so as to give *extra* time to the concrete mixture to be compacted and make higher concrete compressive strength values. 4. Water-reduced concrete with time-lagged *superplasticizer* addition will produce higher compressive strength values. The water reduction that gives the highest increase in compressive strength of concrete at the age of 4 days is LN25-1 at 21.94 MPa (87% of the planned compressive strength) and LN20-2 at 19.12 MPa (76% of the planned compressive strength). The optimal amount of water reduction in the early age of concrete is 20-25% of the plan water weight.

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