Experimental study of accelerating early age concrete strength under elevated temperature, steaming, and chemical admixture addition of normal and high strength concrete

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Abstract. Conventionally, curing is performed by moisturizing concrete periodically when the fresh concrete is still undergoing chemical reaction processes. This study is focused on early age concrete strength treated with special curing of early heating treatment and steaming. The addition of chemical accelerator and normal curing are also examined. Tests were conducted on normal and high strength concrete specimens. Treatments of the test specimens with steaming and early heating were carried out for 3 and 8 hours, respectively, at a temperature of about 70° C. Test results showed that concrete compressive strengths gained in 3-days compared to 28-days under normal curing, chemical accelerator, steam curing, and elevated temperature curing were 39%, 50%, 64% and 59%, respectively. While in 7-days were 66%, 75%, 80% and 83%, respectively. And in 14-days were 87%, 91%, 93% and 93%, respectively. For high-strength concrete, the compressive strengths gained in 3-days were 37%, 62%, 68% and 71%, respectively. The strengths in 7-days were 65%, 77%, 83% and 82%, respectively. And in 14-days were 85%, 89%, 90% and 93%, respectively. Test results indicated that the additions of chemical accelerator, steam and elevated temperature curing in order to obtain the high early age concrete strengths are highly recommended.

1 Introduction

1.1 Background

Concrete is a very popular building material in the construction industry because of its strength to withstand high compressive forces. Concrete is an artificial conglomerate stone made essentially of water, cement, and aggregates. A chemical reaction takes place when the first mixed water and cement establish of paste surrounding all the individual piece of aggregates. This chemical reaction is called hydration when the heat is given off during the

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reaction as the cement hydrates. In order to achieve the designed properties of the mixture, concrete needs a curing to maintain an adequate moisture content during chemical reaction at early ages.

Curing begins immediately after placement and finishing so that the concrete may develop the desired strength and durability. Traditionally, curing is performed by moisturizing concrete periodically to reduce water loss due to evaporation and concrete hydration. This traditional method requires a relatively long maintenance time. However, in construction work, sometimes a concrete that has a high initial strength is needed to accelerate the time consumed during the whole construction. Special treatments of early age concrete to accelerate initial strength using steam curing have been used in several precast concrete industries [1, 2].

This study focused on early age concrete strength treated with special curing of early heating treatment and steaming. The effects of adding chemical accelerator on the compressive strength at an early age are also examined. The traditional curing of normal strength and high strength concrete specimens are also conducted as standard and comparator specimens. Tests were conducted in the Laboratory of Material and Structural, Department of Civil Engineering, Faculty of Engineering, University of Mataram.

1.2 Literature review

The heat of hydration is caused by the temperature raise that occurs when the cement reacts with water, expressed in calories/grams. Silicate and aluminate on the cement react with water into a solid adhesive material and form a hard mass. Hydration of cement is exothermic with an amount of heat released approximately 120 calories/gram. For the usual hot cement type, it varies between 37 calories/gram at 5°C to 80 calories/gram at 40°C. For all types of cement in general about 50% of the total heat is released between 1 and 3 days, about 75% of the heat changes depend on the composition of the cement [3].

Concrete treatment is influenced by the temperature and moisture of the concrete itself. Therefore, concrete treatment not only affects the strength of the concrete but also affects the resistance of the concrete. The use of effective treatment methods depends on the type of material used, the type of construction and expected exposure of the concrete. There are two methods of concrete treatment based on the temperature used, i.e. normal treatment and maintenance at elevated temperature [4].

According to the Indonesian Standard accelerated curing is a treatment with high-pressure steam, evaporation at atmospheric pressure, heating and moisturizing or other acceptable processes. These processes may be undertaken to accelerate concrete strength and reduce maintenance time [5]. The optimum temperature is in the range of 65°C to 80°C. The use of lower temperatures requires a longer maintenance time but provides better strength [6].

Early age of concrete under various curing method and treatment have been done in the laboratory [7, 8]. The investigation included the curing with elevated temperature. The comparison to normal treatment by moisturizing concrete specimens was then evaluated. Test results indicated that concrete compressive strengths of 3, 7, and 14 days were rapidly accelerated under elevated temperature. However, the 28 days concrete compressive strength slightly decreased.

The ground granulated blast-furnace slag has been used at the precast concrete factory for the purpose of durability improvement on the resistance of concrete product [9]. Ground granulated blast furnace slag is used under the maximum curing temperature of 70ºC and deforming from 2.5 hours. The results indicated that high fluidity concrete has the capability to save labor in placement work and improve the working environment as well as improve concrete durability. Under 3 hours steams curing at 60ºC, the compressive strengths of concrete compare to 28 days compressive strength were 44% and 71% for the ages of 15 hours and 7 days, respectively.

A relationship between initial strength at early age of concrete calculated by Maturity Method and Arrhernius Law was evaluated using experiment investigation. The experiment use cube specimens of size Ø50x100 with various water-cement ratios of 30%, 40%, 50% and exposed under curing temperatures variations of 10°C, 20°C, 30°C. The accuracy of the prediction was different in each condition such as cement type, water-cement ratio, steam curing temperature, and material age [10]. By promoting cement hydration, raising steam curing temperature to 70°C could significantly increase initial compressive strength as well as the permeability of concrete specimens. However, it has several negative effects on the durability caused by surface resistivity and capillary absorption [11].

2 Materials and experimental procedure

2.1 Materials

Based on the examinations of fine and coarse aggregates, mixed design of the concrete specimens can be composed according to the Indonesian Standard [5]. Viscocrete 311N has been used as a superplasticizer to produce high-strength concrete. In order to accelerate the early strength of specimens, SikaCim Accelerator is also added as a chemical addition. Portland cement type I has been used for all specimens. The mix proportion of 1 m3 concrete mixture can be seen in **Table 1** as follow:

Table 1. Mix Proportion of 1 m3 Concrete

Specimens	f'c (MPa)	w/c	Water	Cement	Fine Aggregate	Coarse Aggregate	Accelerator	Superplasticizer
			(kg)					
NN	30	0.45	225.00	500	565.46	906.54	-	-
NA			185.63	500	565.46	906.54	79.20	-
HN	50	0.30	225.00	750	551.46	761.54	-	2.48
HA			185.63	750	551.46	761.54	79.20	2.48

Where: NN = Normal-strength concrete
NA = Normal-strength concrete with accelerator
HN = High-strength concrete
HA = High-strength concrete with accelerator

2.2 Test specimens

In this study, a 15 × 15 × 15 cm cube of both normal and high strength concrete specimens was prepared for compressive strength testing at ages 3, 7, 14 and 28 days, respectively. Specimens curing were performed under three conditions: normal curing, steam curing and elevated temperature curing. Specimens with an addition of chemical accelerator under normal curing also conducted for evaluation and comparison to the concrete compressive strength acceleration at early age. The numbers of test specimens are presented in **Table 2**. Its can be seen in the table that the total numbers of the test were 96 specimens.

Table 2. Test Specimens

Concrete Strength	Curing	Number of Specimens under Compressive Test				Total
		3 Days	7 Days	14 Days	28 Days	
Normal Strength	Normal curing	3	3	3	3	12
	Steam curing	3	3	3	3	12
	Elevated temperature	3	3	3	3	12
	Accelerator	3	3	3	3	12
High Strength	Normal curing	3	3	3	3	12
	Steam curing	3	3	3	3	12
	Elevated temperature	3	3	3	3	12
	Accelerator	3	3	3	3	12
Total Number of Specimens						96

2.3 Instrumentation and test procedure

2.3.1 Steam curing

According to the Indonesian Standard [5], early age accelerated strength of concrete is a treatment with high-pressure steam, evaporation at atmospheric pressure, heating and moisturizing or other acceptable processes. Steam curing will increase the compressive strength of early age concrete and reduce maintenance time. Steam treatment can prevent rapid and irregular hydration processes with high temperatures, so concrete compressive strength can be quickly achieved and concrete pores can be avoided.

Treatment with steam curing has been carried out in this investigation by inserting the specimens into a steam room. Shown in **Fig. 1**, the tool used in this research is a steamer tool made from two pieces of a steamer connected together. Water was boiled in the first steamer and the steam heat was then distributed to the stowing specimens in the second steamer using heat resistant pipe. The time-temperature relationship of the steamer is given in **Fig. 2** in which the following can be explained.

After ± 2 hours of steaming, the steam room temperature begins to gradually raised. Further ± 30 minutes the steam room reaches a temperature of 70°C. Keep the steam room at this temperature for 3 hours before turning off the heater. Then the temperature begins to decrease and reaches the room temperature of 30°C within 30 minutes. After 1 hour of cooling, remove the specimens from the steam room, store it in a save place and then it is ready to be tested in due course.

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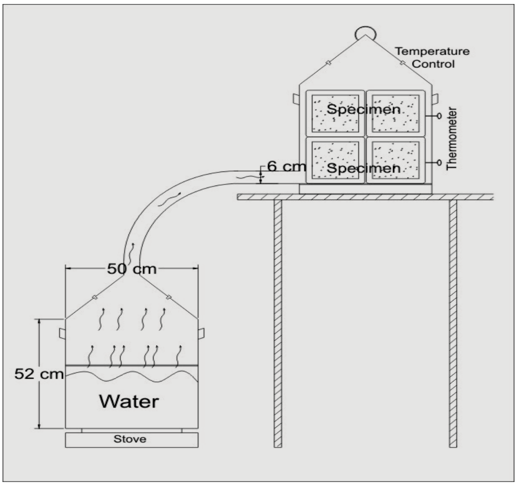

Fig. 1. Steamer tool

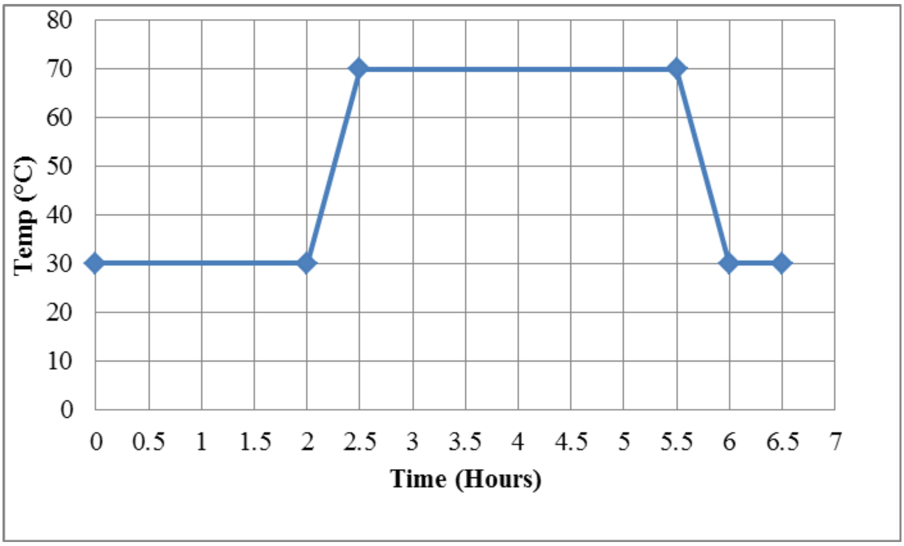

Fig. 2. Time - temperature of steamer

2.3.2 Elevated temperature curing

The hardened concrete specimens after final setting were removed from the casting and placed into a heating furnace. The heating furnace instrument (oven) can be seen in **Fig. 3**. While **Fig. 4** gives the curve of time versus temperature setting. The figure shows that the temperature has been held at 70°C under duration of 8 hours. After cooling, the specimens were removed from the furnace and kept in a save place before their compressive strength was tested in intended time.

Fig. 3. Heating furnace instrument (oven)

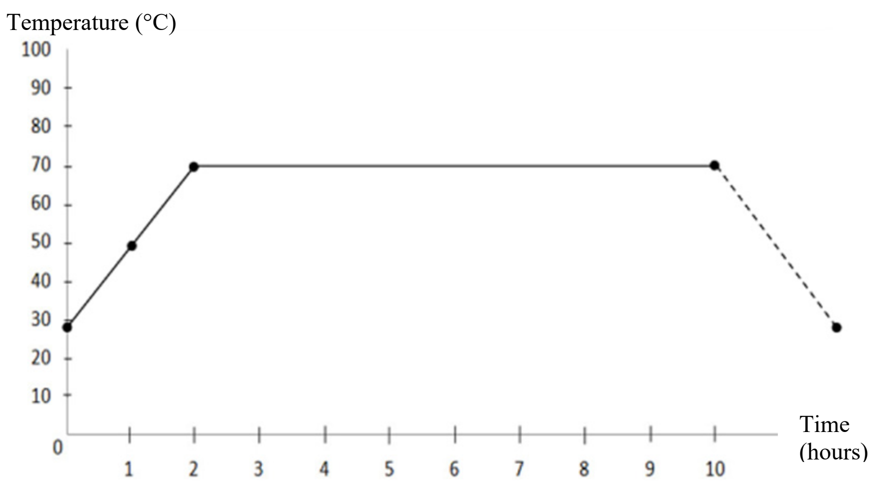

Fig. 4. Time - temperature of oven

2.3.3 Normal curing

Normal curing begins immediately after the concrete has hardened at the final setting which is generally at about 12-24 hours. Curing in concrete at early age has the purpose of ensuring the cement hydration process to proceed completely by maintaining an adequate moisture content and temperature conditions. This treatment will avoid shrinkage cracks on the surface and the desired quality of the concrete can be achieved.

In this study, 48 specimens have been treated under normal curing including 24 specimens with chemical accelerator addition for early strength of normal and high strength concrete. Immediately after they were removed from the mould, the specimens are stored and submerged in a water tank. When the considered time arrived, the specimens are taken out of the water tanks, capped with very high strength sulphur compound and tested for the compressive strength investigation.

3 Test results and discussions

3.1 Normal strength concrete

Results of the compressive test presented in **Table 3** for normal strength concrete and the normalized percentage of compressive strength to 28 days is given in **Table 4**. Furthermore, the percentage of high-strength concrete compressive test to 28 days is performed in **Fig. 5**.

Table 3. Compressive strength (MPa)

Specimens	Ages of specimens			
	3 Days	7 Days	14 Days	28 Days
NN	12.12	20.51	27.03	31.07
NA	16.67	25.01	30.34	33.34
NS	18.94	23.68	27.53	29.60
NT	17.78	25.01	28.02	30.13

Where: NN = Normal strength concrete under normal curing
NA = Normal strength concrete with accelerator
NS = Normal strength concrete under steam curing
NT = Normal strength concrete under elevated temperature curing.

Table 4. Normalized percentage of normal concrete compressive test to 28 days

Specimens	Ages of specimens			
	3 Days	7 Days	14 Days	28 Days
NN	39 %	66 %	87 %	100 %
NA	50 %	75 %	91 %	100 %
NS	64 %	80 %	93 %	100 %
NT	59 %	83 %	93 %	100 %

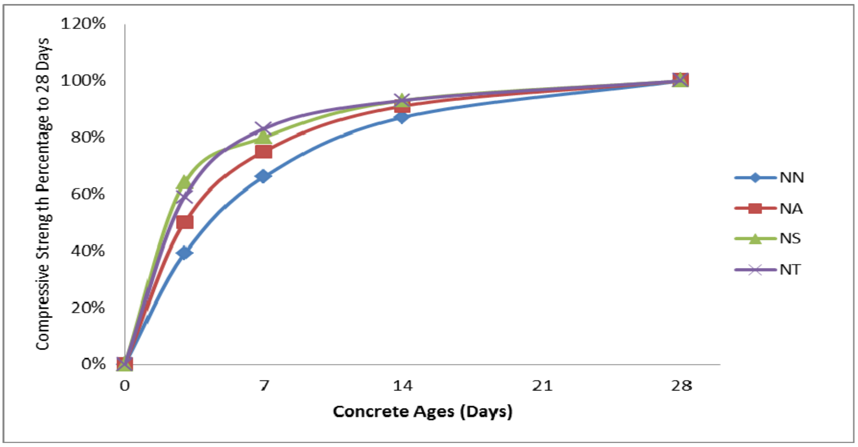

Fig. 5. Percentage of normal strength concrete compressive test to 28 days

Under normal curing, the value of concrete strength in 3, 7 and 14 days compared to 28 days were 39%, 66%, and 87%, respectively. The results show that the experimental results agree with the typical conventional normal strength concrete. In the age of 3 days, the specimen under steam curing has the highest accelerated concrete strength of 64%. This indicates that the early concrete strength is accelerated by 165% compare to normal curing.

Concrete compressive strengths gained in 3-days compared to 28-days under normal curing, chemical accelerator addition, steam curing, and elevated temperature curing were 39%, 50%, 64% and 59%, respectively. The concrete strengths in 7-days were 66%, 75%, 80% and 83%, respectively. While in 14-days were 87%, 91%, 93% and 93%, respectively. Based on the results, the special curing of steam and elevated temperature have a significant effect to accelerate the early age concrete strengths as well as using chemical accelerator.

3.2 High strength concrete

The compressive strength of 3, 7, 14, and 28 days is shown in **Table 5**. The normalized percentage compressive strength to 28 days is given in **Table 6** and illustrated in **Fig. 6.**

Table 5. Compressive strength (MPa)

Specimens	Ages of specimens			
	3 Days	7 Days	14 Days	28 Days
HN	19.09	33.54	43.86	51.60
HA	30.09	37.37	43.19	48.53
HS	31.92	38.96	42.25	46.94
HT	32.28	37.29	42.29	45.47

Where: HN = High strength concrete under normal curing
HA = High strength concrete with accelerator
HS = High strength concrete under steam curing
HT = High strength concrete under elevated temperature curing.

Table 6. Normalized percentage of high strength concrete compressive test to 28 days

Specimens	Ages of specimens			
	3 Days	7 Days	14 Days	28 Days
HN	37 %	65 %	85 %	100 %
HA	62 %	77 %	89 %	100 %
HS	68 %	83 %	90 %	100 %
HT	71 %	82 %	93 %	100 %

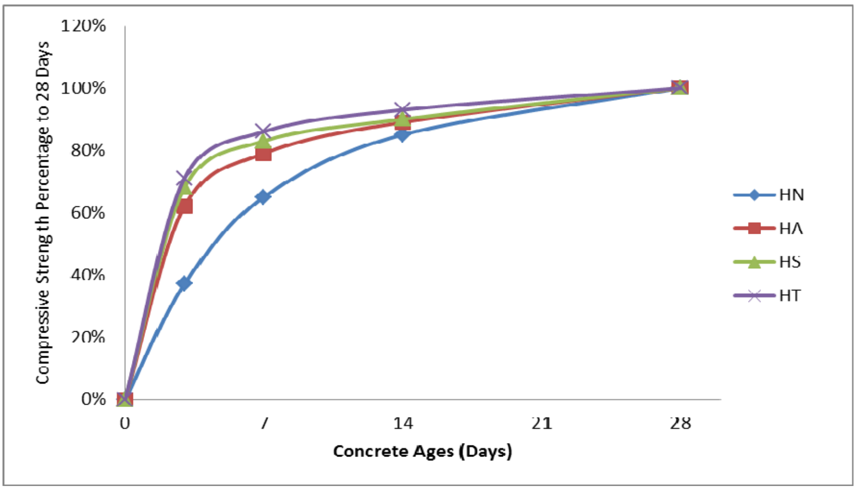

Fig. 6. Percentage of high strength concrete compressive test to 28 days

There are slightly different materials properties of high strength concrete compare to the normal strength concrete. In the age of 3 days, the highest accelerated concrete strength was the specimen under elevated temperature with the value of 71%, almost twice compare to normal curing of 37%. Concrete compressive strengths gained in 3-days were 37%, 62%, 68% and 71%, respectively. The concrete strengths in 7-days were 65%, 77%, 83% and 82%, respectively. And in 14-days were 85%, 89%, 90% and 93%, respectively.

In general, the special curing of steam and elevated temperature have significant effect to accelerate the early age concrete strengths as well as using chemical addition accelerator. Therefore, in order to obtain the high early compressive strength of concrete, the special curing of steam and elevated temperature as well as using chemical addition accelerator are highly recommended.

4 Conclusions

The early compressive strengths gained under normal curing, chemical accelerator addition, steam curing, and elevated temperature curing can be concluded in the following.

- For normal strength concrete:
  - 3-days were 12.12 MPa, 16.67 MPa, 18.94 MPa, and 17.78 MPa, respectively.
  - 7-days were 20.51 MPa, 25.01 MPa, 23.68 MPa, and 25.01 MPa, respectively.
  - 14-days were 27.03 MPa, 30.34 MPa, 27.53 MPa, and 28.02 MPa, respectively.

- 28-days were 31.07 MPa, 33.34 MPa, 29.60 MPa and 30.13 MPa, respectively
Representing normalized percentage result of early age concrete strength to 28 days:
- 3-days were 39%, 50%, 64% and 59%, respectively.
- 7-days were 66%, 75%, 80% and 83%, respectively.
- 14-days were 87%, 91%, 93% and 93%, respectively.

- For high-strength concrete:
  - 3-days were 19.09 MPa, 30.09 MPa, 31.92 MPa, and 32.28 MPa, respectively.
  - 7-days were 33.54 MPa, 37.37 MPa, 38.96 MPa, and 37.29 MPa, respectively.
  - 14-days were 43.86 MPa, 43.19 MPa, 42.25 MPa, and 42.29 MPa, respectively.
  - 28-days were 51.60 MPa, 48.53 MPa, 46.94 MPa, and 45.47 MPa, respectively.

  Normalized percentage result of early age concrete compressive strength to 28 days:
  - 3-days were 37%, 62%, 68% and 71%, respectively.
  - 7-days were 65%, 77%, 83% and 82%, respectively.
  - 14-days were 85%, 89%, 90% and 93%, respectively.

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