

The study of the reasons for increased cost of concrete containing special pozzolanic cement and presenting strategy for production of low cost pozzolanic concrete (case study of Roudbar dam of Lorestan)

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Abstract: Nowadays, concrete is one of the mostly used construction material. Due to various benefits including lower price compared to other cements, special Pozzolanic cement is a desired option for producing low cost concrete. This study deals with this question that concerning the relative low price of special Pozzolanic cement, is the concrete containing Pozzolanic cement cheaper than ordinary concrete? Based on evaluations, the comparison of the cost price of concrete mixing scenarios in three strength classes of c20, c25 and c30 shows that the cost of concrete containing Pozzolanic cement becomes higher than ordinary concrete due to lower 28-day compressive strength of standard Pozzolanic cement that leads to increased cement content in similar mixing scenario and higher Blaine that leads to increased additive materials in similar scenario for supplying uniform slump. It means that despite the low cost of raw materials, the cost price of final product has increased. Since the trend of Pozzolanic cement strength doesn't stop after 28 days, this study tried to optimize and reduce the cement content and dose of additive materials by changing the determination age of compressive strength of mixing scenarios of concrete containing Pozzolanic cement and constructing mixing scenario based on determination of strength in 42, 56 and 90-day ages to make the use of concrete containing Pozzolanic cement economically justified by reducing its cost price. The results of this study indicates that 45 days is appropriate age for determination of compressive strength of C20, 56 days for c25 and 90 days for C30 concrete containing Pozzolanic cement and in higher ages, concrete containing Pozzolanic cement becomes cheaper than ordinary concrete. Thus, changing the determination age of compressive strength of Pozzolanic concrete makes its use more justifiable.

Key words: Price of Pozzolanic concrete; compressive strength; Pozzolanic cement; Roudbar dam of Lorestan

1. Introduction

Pozzolan is a silicon or Alumina-Silica material that has no or a bit cement value in itself; however, it chemically reacts with calcium hydroxide obtained from Portland cement dehydration and creates compositions with cement specification (Kasmatka and Panares, 2003). Pozzolan mixed cement has many advantages including lower energy consumption, environment protection (production of one ton cement is along with production of one ton of CO₂), reduced cement price, increased strength, increased elasticity module, increased impenetrability, resistance against chemical attack due to lower water, increased durability against melting and freezing cycles, increased concrete durability against Sulfate and choler attack and decreased destructive expansions due to Alkali-silica reaction of reactive aggregate with cement alkali (sodium oxide and potassium oxide) (Ramezanyanpour et al., 2003). Pozzolanic cement leads to delay in concrete hardening time so it is used mostly in dams with the aim of controlling the thermal tracks. It worth noting that the effect of this concrete is reduced to some extent, through some

additives such as lubricants, it is possible to prevent its efficiency reduction (Tadyn, 2003).

In Roudbar dam project, Pozzolanic cement has been used for implementation of concrete working concerning the results of early studies on loan resources of concrete aggregate and proving of aggregates' reactivity. Comparing the compressive strength and Blaine of Pozzolanic cement and its cost price with type 2 cement, the present study showed that despite lower price of special Pozzolanic cement compared to normal cement, in case the criterion is determination of compressive strength of concrete in age 28-day and construction of the concrete mixing scenario based on this, the cost price of concrete containing this kind of cement is higher than ordinary concrete, thus, it is required to consider some solutions to compensate this deficiency.

Since the growth of Pozzolanic concrete strength after 28 days is considerable, in this study, the strength increased from 18 to 90 days and for construction of new samples, the mentioned increase was reduced in each 42, 56 and 90 days of early special strength and the concrete mixing scenario was prepared based on lower special strength according to standard. In this method, the designed concrete reaches the assumed special strength of the scenario in 28 days and reaches the main special

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strength in days 42, 56 or 90 days. Thus leads to decreased cement content and additive dose in mixing scenario of Pozzolanic concrete and its relatively lower cost compared to ordinary concrete.

Since the main reasons for increased price of Pozzolanic cement are lower compressive strength in age 28-day and higher special level compared to cement type 2, first these two have been compared.

2. Compressive strength of concrete containing Pozzolanic cement

Certainly, when Pozzolan is replaced for cement, calcium hydroxide production should be expected. Thus, the initial and final hardening of Pozzolanic cement becomes a bit longer and the early strength decreases in lower ages; however, some factories use more active Pozzolan and aggregate Pozzolanic cements to remove this deficiency (Ramezanyanpour et al., 2003).

Compressive strength of concrete is the main criterion for concrete acceptance in short time and the type of consumed cement has great effect on it. The use of Pozzolanic cement usually has strength of less than 28 days or equal strength to ordinary Portland cement (Tadyn, 2003). In most cements containing Pozzolan, the strength growth beyond other cements begin from age of 28 days onward. The most growth trend of strength increase happens in ages 1 to 7 days and then the growth trend decreases gradually; however, in Pozzolanic cement, the ascending trend is still seen (Kader et al., 2003).

For comparison, the trend of compressive strength in the case study, the compressive strength of standard grout of special Pozzolanic cement and cement type 2 of Doroud Company have been tested on 30 samples of the cements entered to the company (Fig. 1).

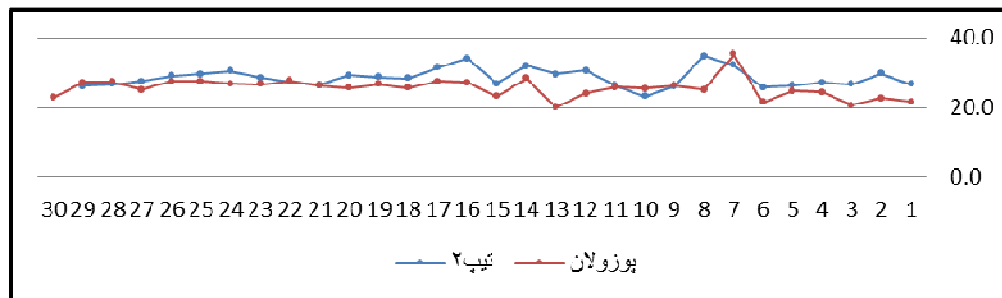


Fig. 1: The comparison of compressive strength of Pozzolan and type 2 cement grout

As seen in the Fig. , the compressive strength of the grout made of cement type 2 in age of 28 days has been more than Pozzolanic cement that might lead to increased Pozzolanic cement content in mixing scenarios for compensation of this weakness and obtaining required compressive strength in age of 28 in similar concretes. One of the probable reasons for increased cost of concrete containing Pozzolanic cement is increased cement content compared to the concrete made of cement type 2. In mixing scenario, three concrete classes of 25, 20 and 30 MPa have been evaluated.

3. The comparison of specific area (Blaine) of Pozzolan and type 2 cement

The softness of cement is expressed based on specific area that is the mass unit area in terms of cm^2/g and m^2/kg . It is obvious that the higher is the specific area of cement, it is softer. The most common method for measuring of specific area of cement is the use of air penetrability or Blaine method. In this method, air is passed through cement such that the duration of air passing from the cement is proportionate to the size of cement aggregate. It means that the softer is the cement (more aggregated and fine), due to lower porosity of cement mass, the air passing lasts longer; thus, proportionate to increased time, the softness of cement increases.

The comparison of the Blaine results of cement type 2 and special Pozzolanic cement shows that the mean Blaine of Pozzolanic cement is $4670 \text{ cm}^2/\text{g}$ and the mean Blaine of cement type 2 is $3070 \text{ cm}^2/\text{g}$ (Fig. 2) and that the mean Blain of Pozzolanic cement is 1.53 times more than Blaine of cement type 2, that is a big number and certainly leads to increased water consumption for plasticity or constant fluidity compared to cement type 2, or increased dose of additives in water to cement ratio similar to cement type 2. It means that in a constant water to cement ratio, certainly Pozzolanic cement needs a higher percent of additives to achieve a certain slump, which leads to increased cost price of concrete containing Pozzolanic cement.

4. Consumed materials

The consumed materials for construction of mixing scenarios of concrete cement type 2 of Doroud and Pozzolanic cement include 70% cement of type 2 (Doroud) and 30% Pozzolan of Dodahak that are grained in the factory with Clinker and sent to workshop. The consumed sand and gravel are river materials and circular that are supplied from river aggregate resources. The coarse aggregate materials have no problems and were placed in the requested grading according to Standard ASTM C33; however, natural sand materials have inherent lack and deficiency in mine and due to lower sources of

filler or aggregate, its softness module is usually in range of 3.5 and this leads to increased sand in the concrete mixing scenarios.

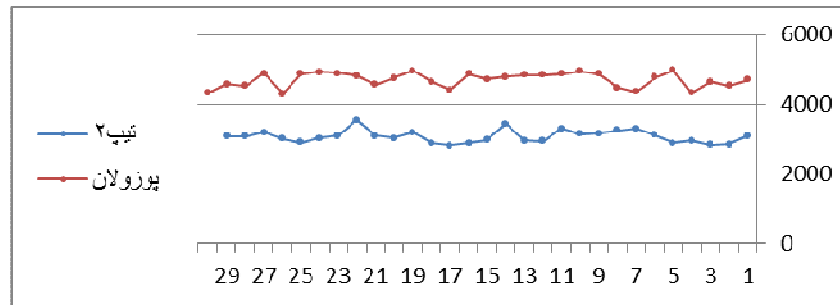


Fig. 2: The comparison of special level of type 2 cement and special Pozzolan

5. The comparison of the numbers related to mixing scenario of Pozzolan and type 2

Concerning the results of compressive strength of cement grout and special level (Brain) of cement and the study of concrete mixing scenarios in other similar projects and the scenarios in Roudbar dam of Lorestan, it is predicted that the cost of preparation and implementation of mixing scenario of concrete and special Pozzolan cement is higher than mixing scenario of concrete and cement type 2.

Thus, mixing scenarios of concrete with similar specification in three levels of 20, 25 and 30 MPA were prepared with both kinds of cement and their cost price were studied. In all these mixing scenarios,

the efficiency and required slump of concrete have been similar to prevent any difference in the materials in mixing scenarios and to make correct comparison.

Table1 presents the numbers related to mixing scenarios of Pozzolan concrete and table 2 presents the values related to mixing scenario of concrete containing cement type 2. All these concrete mixtures were first designed through ACI 211 and then optimized through national scenario of Iran concrete mixture to acquire required efficiency and pumping. The grading of concrete mixtures has been corrected based on Iran National Standard grading push.

Table 1: Mixing scenarios of Pozzolan concrete

Concrete class	Water	Cement	W/C	Natural sand	Gravel 5-9.5	Gravel 9.5-19	Additives (%)	Additives (gr)	Initial slump
C30	160	400	0.4	1100	410	330	1	4000	21
C25	163	370	0.44	1080	430	350	0.83	3071	20
C20	160	325	0.49	888	387	663	0.42	1369	15

Table 2: Mixing scenarios of concrete and cement type 2

Concrete class	Cement content	Water	W/C	0-5	5-9.5	9.5-19	Additives (%)	Additives (gr)	Slump
30	350	140	0.4	1000	550	410	0.66	2300	21
25	320	140.8	0.44	925	460	600	0.58	1850	20
20	280	137.2	0.49	900	450	640	0.39	1100	15

6. Price comparison of mixing scenarios of concrete containing Pozzolan cement and type 2

After construction of these scenarios, their cost prices were compared and studied to specify the result of early question of the research and above explanations. Since the aggregate materials in both mixing scenarios remain constant and the cost price depends on the change of cement and additives' type and value, just the cement and additives' prices in mixing scenarios have been considered that are presented in Table 3.

As the calculations of the above table show, the price difference of concrete mixing scenarios in three classes is clear; however, its trend is logical. In concrete class of 20 MPA that doesn't require efficiency and consumption of many materials, the

price difference has been negligible. The increase of special strength of concrete and the necessity for reduction of water to cement ratio naturally lead to increased consumption of lubricant additives in mixing scenarios that is more in Pozzolan cements. As the table indicates, price difference of two studied scenarios has increased in 25 MPA class and the price of Pozzolan in this scenario becomes 1.2 times more than concrete containing cement type 2. Furthermore, in concrete mixing scenario of 30 MPA, the above trend is repeated and increased price of Pozzolan concrete compared to concrete containing cement type 2 becomes 1.24 that indicates higher price difference in higher classes (Fig. 3).

It means that despite the emphasis of all resources on relative low price of Pozzolan cement and its lower price in the factory compared to cement type 2, due to the mentioned reasons, the

Pozzolan concrete has higher price than ordinary concrete as indicated in Fig. 3. This is an issue that has not been yet considered and a strategy should be

proposed for tackling this problem and its economic justification to reduce direct cost of project.

Table 3: The price comparison of Pozzolan concrete and concrete containing cement type 2

Scenario	Additives (kg)	Unit price (IRR)	Additive cost	Cement value (kg)	Unit price (IRR)	Cement price	Total cost (IRR)
Pozzolan c20	1.369	78500	107466.5	325	820	266500	373966.5
Type 2 C20	1.1	78500	86350	280	980	274400	360750
Pozzolan c25	3.071	78500	241073.5	370	820	303400	544473.5
type 2 C25	1.85	78500	145225	320	980	313600	458825
Pozzolan c30	4	78500	314000	400	820	328000	642000
type 2 C30	2.3	78500	180550	350	980	343000	523550

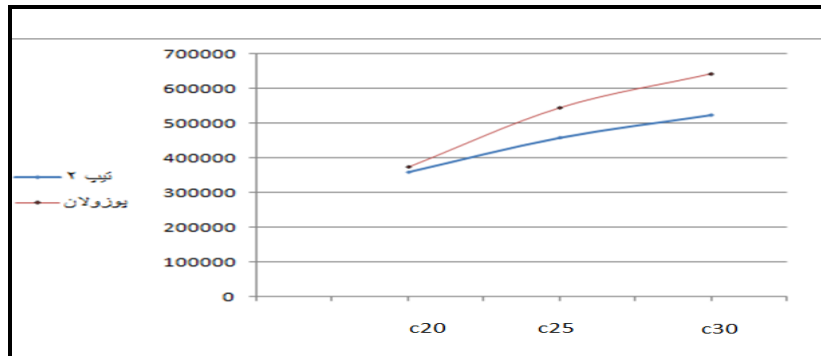


Fig. 3: The price comparison of Pozzolan and ordinary concrete in case of strength determination in 28 days

Since it was specified that the cost price of concrete containing Pozzolan cement is higher than concrete containing cement type 2, a strategy should be proposed to remove this issue and make the consumption of Pozzolan cement more economic compared to cement type 2 and make its use justifiable.

7. The study of increasing trend of compressive strength in concrete containing Pozzolan

One of the special benefits of Pozzolan cement is significant increase of compressive strength in age range of more than 28 days up to 90 days that doesn't happen in other types of cements and is special to Pozzolan cement. To investigate this issue and determine the increasing trend of strength in ages above 28 days, the compressive strength determination tests of concrete containing

Pozzolan cement in ages 42, 56 and 90 days were performed. For this purpose, in addition to the samples taken for determination of strength in low ages, some samples with higher ages were also considered and their strength was determined in due time. The study of this process was done for three classes of concrete 20, 25 and 30 MPA with strength determination of 30 concrete samples to be able to determine the growth of compressive strength of the samples related to each class of concrete and to remove the problem based on this. To determine the sample strength in each age, 2 cylindrical samples of 30*15 were prepared and their strength was determined through ASTM C39. The mean strength of the concrete samples in various ages has been presented in Table 4.

Table 4: The mean compressive strength of concrete samples in various ages

Concrete class	Compressive strength of Pozzolan concrete (MPA)				
	Age	28 days	42 days	56 days	90 days
C20	Mean compressive strength	23.6	24.9	26.75	27.9
	Growth rate of strength after age of 28 days		1.3	3.15	4.3
C25	Mean compressive strength	23.9	24.9	26.75	27.9
	Growth rate of strength after age of 28 days		1	2.85	4
C 25	Mean compressive strength	24.2	24.9	26.75	27.9
	Growth rate of strength after age of 28 days		0.7	2.55	3.7

In Table4, the strength growth rate after 28 days for each concrete class and in each special age has been determined.

In this study, for optimum use of increased strength of Pozzolanic cement and compensation of increased price using this advantage, new special strength has been defined in age of 28 by reduction of increased strength in each age from the early special strength.

Table 5: New special strength of various concrete classes

Concrete class	Early and new special strength of Pozzolanic concrete (MPA)			
	New special strength			
C20	New special strength	19	17.15	15.95
C25	New special strength	23.25	20.3	18.95
C30	New special strength	28.1	25.4	23.75

In Table5, the special strengths of 20, 25 and 30 MPA have been transformed to lower numbers using

the growth rate of concrete samples' strength in various ages. It is expected that this leads to decreased cement and lubricant values and at the end, decreased cost price of Pozzolan concrete and economic justification for its use and determination of the optimum age of preparation concrete mixture and determination of compressive strength of concrete samples. In table 6, the existing special strengths of table 5 that were respectively due to increased strength in ages 42, 56 and 90 days have been considered as the basis and new mixing scenarios have been prepared based on achieving special strength of scenario in above three ages.

In table 5, new special strengths have been defined for 28-day samples by reducing the increased compressive strength in various ages from initial special strength.

In this way, by increased strength of Pozzolan concrete in ages higher than 28 days, the early special strength will also be obtained.

Table 6: The new mixing scenarios data based on achieving special strength in three ages

Concrete class	Water	Pozzolanic cement	W/C	Natural sand	Gravel 5-9.5	Gravel 9.5-19	Additives (%)	Additives (gr)	Initial slump
42 days (C20)	163	320	0.509	893	392	663	0.41	1300	15
56 days (C20)	170	300	0.567	900	397	673	0.43	1280	15
90days (C20)	173	295	0.586	905	397	673	0.43	1265	15
42days (C25)	165	350	0.471	1080	440	673	0.81	2850	19
56 days (C25)	170	325	0.523	1085	450	678	0.77	2500	20
90days (C25)	175	320	0.547	1085	455	678	0.73	2340	20
42days (C30)	167	385	0.434	1100	420	335	0.97	3750	21
56 days (C30)	170	355	0.479	1110	430	345	0.99	3500	20
90days (C30)	175	345	0.507	1110	4440	350	0.93	3200	20

Concerning the relative decrease of cement content and dosage of additives in new mixing scenarios based on strength determination of mixing scenario in ages above 28 days, the cost price of concrete in various ages has decreased that is compared with similar mixing scenario constructed with cement type 2 to determine the optimum age at which Pozzolan concrete is cheaper than concrete containing cement type 2.

Concerning the price comparison presented in Table7, the increased age of compressive strength determination and acquiring the required special strength leads to reduction of price cost of Pozzolan concrete compared to ordinary concrete. In the following figure, the optimum age of compressive

strength determination of concrete mixing scenarios for concrete of class C20 has been determined.

As seen in Fig. 4, (horizontal graph is the age of strength determination- vertical graph is the price ratio of Pozzolan concrete to type 2), assuming that the increased compressive strength is linear in age of 45 days, the cost price of Pozzolan concrete becomes equal to concrete containing cement type 2 with the criterion of strength determination of 28 days.

This means that in concrete of class 20 MPA, if the age of 45 days is considered as the criterion for preparation of mixing scenario and determination of compressive strength of samples, its price will be equal to concrete containing cement type 2. Furthermore, these processes have been performed for concrete of classes 25 and 30 MPA.

For determination of optimum age of concrete 25 MPA, the comparison of cost price of Pozzolan

concrete in various ages with concrete type 2 has been presented.

Table 7: The price comparison of Pozzolan concrete c20 in various ages with cement type 2

Scenario	Additives (kg)	Unit price (IRR)	Additive cost	Cement value (kg)	Unit price (IRR)	Cement price	Total cost (IRR)	Cost compared to first row
C20 type 2- 28 days	1.1	78500	86350	280	980	274400	360750	1
Pozzolan C20- 28 days	1.369	78500	107466.5	325	820	266500	373966.5	1.037
Pozzolan C20- 42 days	1.3	78500	102050	320	820	262400	364450	1.010
Pozzolan C20- 56 days	1.28	78500	100480	300	820	246000	346480	0.960
Pozzolan C20- 90 days	1.265	78500	99302.5	295	820	241900	341202.5	0.946

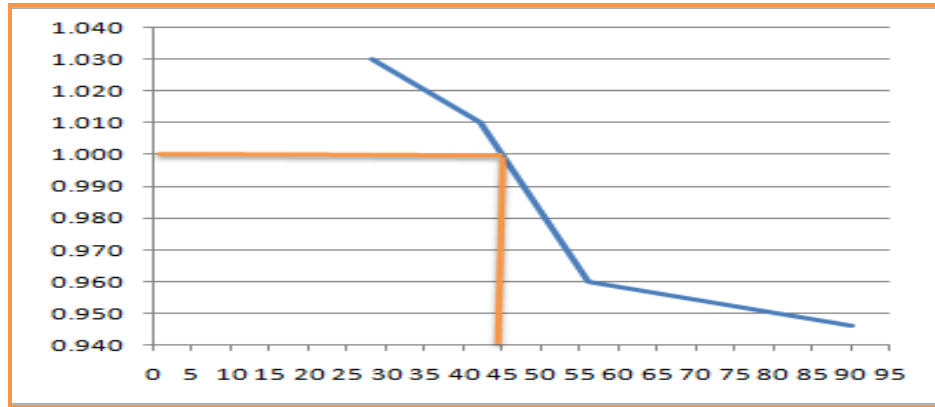


Fig. 4: Age-cost percentage figure of concrete c20

Table 8: The price comparison of Pozzolan concrete c25 in various ages with cement type 2

Scenario	Additives (kg)	Unit price (IRR)	Additive cost	Cement value (kg)	Unit price (IRR)	Cement price	Total cost (IRR)	Cost compared to first row
C25 type 2- 28 days	1.85	78500	145225	320	980	313600	458825	1
Pozzolan C25- 28 days	3.07	78500	240995	370	820	303400	544395	1.186
Pozzolan C25- 42 days	2.85	78500	223725	350	820	287000	510725	1.113
Pozzolan C25- 56 days	2.48	78500	194680	325	820	266500	461180	1.005
Pozzolan C25- 90 days	2.34	78500	183690	320	820	262400	446090	0.972

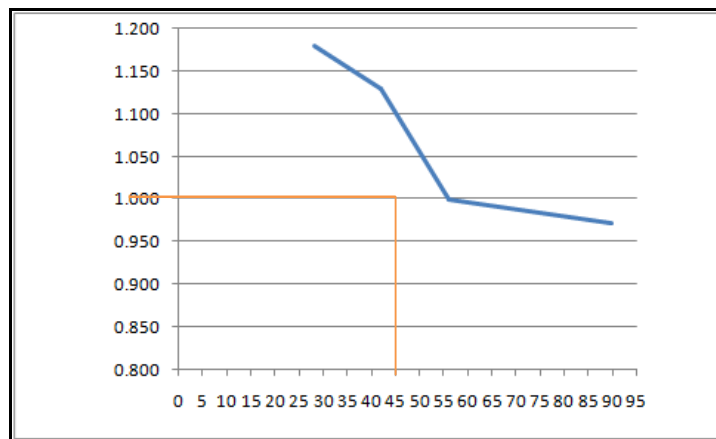


Fig. 5: Age-cost percent of concrete c25

As seen in Fig. 5 (horizontal graph is the strength determination age, vertical graph is the price ratio of Pozzolan to type 2 concrete), increased age of

compressive strength determination of Pozzolan concrete leads to reduction of its cost price compared to concrete containing cement type 2.

In concrete of class 25 MPA, if the age of 56 days becomes the criterion for determination of mixing scenario and determination of compressive strength

of samples, its price will be equal to concrete containing cement type 2.

Moreover, for Pozzolan concrete of class 30 MPA:

Table 9: The price comparison of Pozzolan concrete C30 in various ages with cement type 2

Scenario	Additives (kg)	Unit price (IRR)	Additive cost	Cement value (kg)	Unit price (IRR)	Cement price	Total cost (IRR)	Cost compared to first row
C30 type 2- 28 days	2.3	78500	180550	350	980	343000	523550	1
Pozzolan concrete C30- 28 days	4	78500	314000	400	820	328000	642000	1.226
Pozzolan concrete C30- 42 days	3.75	78500	294375	385	820	315700	610075	1.165
Pozzolan concrete C30- 56 days	3.5	78500	274750	355	820	291100	565850	1.081
Pozzolan concrete C30- 90 days	3.2	78500	251200	345	820	282900	534100	1.020

With cost price comparison of Pozzolan concrete in various ages and concrete containing cement type 2, the economic optimum age of concrete class 30 MPA will be determined as follow.

The comparison of Pozzolan concrete with strength determination criterions of 90 days and concrete type 2 with strength determination criterion of 28 days shows that the cost price of Pozzolan concrete is about 1.02 times more than ordinary concrete. It means, it is still 2% more expensive and it is likely that if this trend increases, in ages above 100 days, its price will be equal to ordinary concrete.

On the other hand, the slower trend of getting compressive strength up to 28 days leads to increased cement content in mixing scenarios similar to ordinary concrete. Thus, in this study, it becomes clear that in case the criterion for determination of compressive strength of Pozzolan concrete is 28 days, the cost price of its mixing scenario will be more expensive than ordinary concrete.

In this study, concerning the increasing trend of strength of concrete containing Pozzolan cement, precise measurement of the increase of compressive strength has been done from age 28 days to ages 42, 56 and 90 days. Moreover, by deducing the increased strength value from early special strength, new special strength has been defined. The basis for preparation of new mixing scenarios is that in age 28 days, it achieves new special strength (lower) and with the increase of concrete age and strength in certain higher ages, the special strength of the scenario should be achieved. By performing this task and reducing the additives and cement in mixing scenarios, it becomes clear that if the criterion age of concrete mixing scenario preparation and its compressive strength determination become 45 days for c20, 56 days for c25 and 90 days for c30, the cost price of Pozzolan concrete in the proposes ages becomes equal to cost price of concrete containing cement type 2 that is proposed based on 28 days. It worth noting that if the ages above mentioned values become criterion, the price of Pozzolan concrete becomes less than ordinary concrete.

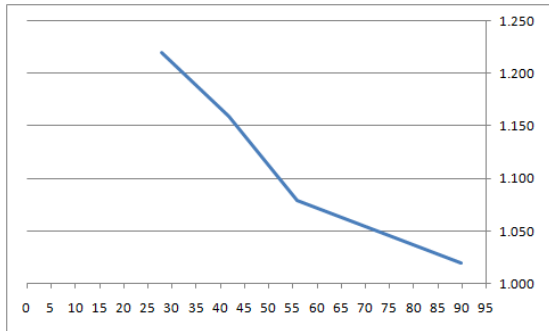


Fig. 6: Age- cost percent graph of concrete c30

8. Conclusion

Although special Pozzolan cement in factory is cheaper than cement type 2, if the criterion age is 28 days, for preparation of mixing scenario of concrete and determination of compressive strength, the price of concrete constructed from it will be higher than ordinary concrete for two reasons. First, the higher special level of this cement compared to ordinary cement leads to attraction of more water for preparation of cement plastic that by keeping the water to cement ratio constant, this leads to consumption of more lubricant materials for determination of similar efficiency that leads to increased price of Pozzolan concrete.

References

Kader, GF., AlGabbani, AM and Abid, SM. "Mathematical model for the prediction of cement compressive strength at the age of 7 and 28 days within 24 hours" Mater.struct.36, 2003, 693-701.

Kasmatka, A. Panares, V. (2003). Design and Control of Concrete Mixtures. Translated by Khalou, A.

Ramezanyanpour, A., Tahouny, Sh., Peydayesh, M.
(2003). Manual of Concrete Working.

Tadyn, M. (2003). "Application of Pozzolanic
Portland Cement and special Pozzolan concrete"