Effect of Plasticizing and Retarding Admixtures on the Properties of High Strength Concrete

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Abstract. From year to year the Earth's temperature increases due to global warming resulting in new challenges in the concrete industry. It still remains very important branch of the modern economy. Concrete is the material which is used widely. Due to the temperature rising, the transportation of fresh concrete in hot weather becomes complicated, especially high strength concrete, which contains higher amount of cement in comparison with traditional concrete. In spite of this the fresh concrete should be delivered in plastic state to provide proper placing and compaction. That's why it is compulsory to use retarders and plasticizers if high strength concrete is designed. In this article the influence of plasticizers and retarder on properties of cement paste, fresh and hardened concrete was studied, because it is important to enhance the workability and slump retention of such concrete under hot weather. The setting time and compressive strength of cement paste with different dosages of polycarboxylate and lignosulphonate based plasticizers with retarding effect and retarder on the basis of sodium gluconate (SG) were studied. Experimental researches were carried out to determine the optimum dosage of plasticizing and retarding admixtures and their effect on compressive strength of concretes. The influence of optimal amount of polycarboxylate based plasticizer and SG on slump loss and compressive strength of concrete was established as well. The obtained results show that correlation between setting time of cement paste and slump loss isn't observed, but rational technical decisions allow to obtain designed properties both fresh and hardened concretes.

Keywords: High strength concrete · Fresh concrete · Retarder · Plasticizer · Slump loss · Compressive strength

1 Introduction

The significant changes have taken place since the beginning of the industrial revolution. The global warming causes the permanent temperature increase and results in new challenges in the concrete industry, which remains very important branch of the modern economy. Concrete is still the material, which is used widely to satisfy the human needs. The new types of concretes such as high strength concrete (HSC), ultra high strength concrete (UHSC), self-compacting concrete (SCC), high performance

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concrete (HPC) become very popular nowadays and are more often used in construction industry to achieve sustainability [1–6]. HSC is used to put the concrete into service earlier (for example opening the road traffic at 3 days), to build structures by reducing cross section area (high-rise buildings), to build superstructures such as long-span bridges and bridge desk with enhanced durability. It can be also used to satisfy the specific needs of special application such as flexural strength, modulus of elasticity and durability. Portland cements with higher compressive strength class is used as a rule to manufacture HSC. Due to the higher temperature caused by global warming, the problems related with the transportation of fresh high strength concrete in hot weather are more often risen. The transportation of high strength concrete becomes more and more complicated in such conditions, because it usually contains higher amount of cement with the higher activity in comparison with traditional concrete and as a result more heat is released when fresh concrete is delivered due to cement hydration causing its quick stiffening. Though, it is well known that ready-mixed concrete should be delivered to the construction site in plastic state to provide proper placing and compaction. That's why the effective retarders, air entraining agent, different modifiers and both plasticizer or superplasticizer are used in contemporary concrete technologies, including HSC production, to improve the technological properties of fresh and mechanical and durability characteristics of hardened concretes [7–12]. As a result, it is compulsory to use plasticizers and retarders when such concretes are designed. There are several types of commercially available superplasticizers such as lignosulphonates, naphthalene-based, melamine-based, and modified polycarboxylates and different retarding admixtures [13].

Runova et al. [14] revealed the slump loss problem in hot weather if SNF-based superplasticizer is used for ready-mixed concrete production. Multifunctional chemical admixture was developed consisting of sulfonated naphthalene formaldehyde condensate in combination with the lignosulphonate based retarder and sodium borate to prevent rapid slump loss. Many researchers also study the efficiency of such organic retarder as sodium gluconate [15–17]. SG is commonly used in real concrete production resulting in the significant retarding effect and rather good compatibility with different superplasticizers. Ma et al. [15] concluded that SG results in the formation of AFt at early stage of hydration if the dosage is less than 0.03 mass%. On the contrary, SG slows down the formation of AFt if the dosage is more than 0.05 mass%. Most researchers study the setting time of cements containing retarders at normal temperature, but the influence of SG on setting time of cement at higher temperature is rarely discussed [16]. Lv et al. [17] shows that sodium gluconate has positive influence on the compressive strength at the dosage which is less than 0.15 mass% and if it is exceeded, the negative effects are observed. That's why the aim of this researches is to study the effect of dosage different types of plasticizers and retarder on properties of fresh and hardened concrete.

2 Materials and Methods

Commercially available Portland cement CEM II/A-S 42,5R was used in this study.
The physical and mechanical properties of Portland cement are presented in Table 1.

Table 1. Physical and mechanical properties of Portland cement.

Specific surface, m^2/kg	Residue on sieve 008, %	Water demand, %	Setting time, min		Compressive strength, MPa	
			Initial	Final	2 days	28 days
380	0.4	29.5	180	290	31.8	52.7

The tests of both Portland cement and aggregates properties were carried out according to Ukrainian standards [18–22]. The results of aggregates' investigations are shown in Table 2.

Table 2. Aggregates' properties.

Aggregate type	Density, (g/cm^3)	Bulk density, (kg/m^3)	Voidage, (%)	Dust and clay particles, (%)	Fineness modulus
Fine	2.64	1321	50.0	1.5	1.49
Coarse (5–20 mm)	2.70	1408	43.7	0.5	–

Commercially available polycarboxylate (PCE-RE) and lignosulfonate (LS-RE) based superplasticizers with retarding effect as well as traditional retarder on the basis of sodium gluconate (R-SG) were used in researches.

The concrete mix designed was carried out according to DSTU B V.2.7-214:2009 [23]. The mathematical planning of experiments was carried out to determine the optimal amount of plasticizing and retarding admixtures [24]. Compressive strength of concrete was determined according to DSTU B V.2.7-214:2009 [25].

3 Results and Discussion

At first stage the researches were focused on the study of the influence of plasticizing and retarding admixtures on the properties of cement paste and both fresh and hardened concretes. As seen from the Fig. 1, cement paste containing plasticizer with retarding effect and retarder results in extending the hydration induction period and thereby lengthening the setting times. It should be noted that the use of plasticizers with secondary retarding effect is one of the most effective method to improve fresh and hardened concrete properties. The addition of LS-RE and PCE-RE delay the initial and final setting time of cement pastes by approximately 100 and 140 min respectively compared to control cement paste without admixtures. The setting time of cement paste incorporating R-SG shows the tendency of gradual significant increasing with the dosage growth from 0.2 to 0.3 mass%. Thus, the initial and final setting time for cement containing 0.3 mass% of SG extend by 380 min compared to control cement paste. However, the interval time between initial and final time is rather short and ranges between 80–110 min.

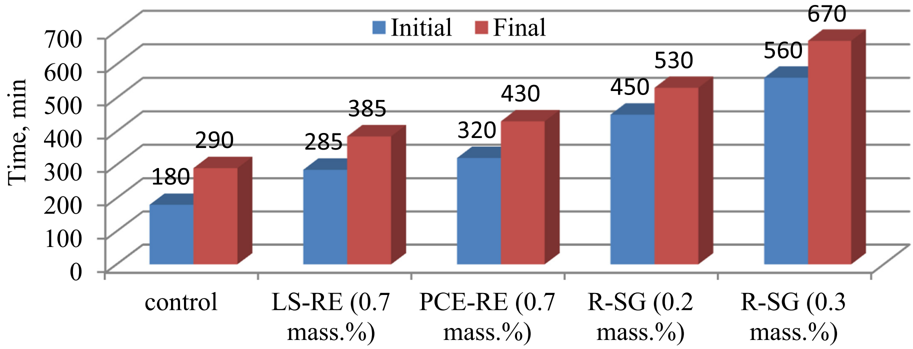

Fig. 1. Setting time of cement pastes.

The compressive strength of cement paste (paste 1:0, samples-cubes 2 × 2 × 2 cm) containing plasticizing and retarding admixtures is discussed in this part and the results are given in Table 3. The water demand of cement pastes added with LS-RE and PCE-RE decreases by 8 and 9% respectively, but cement paste containing different dosages of SG present the tendency of increasing by 3%. The compressive strength of cement pastes incorporating LS-RE and different dosages of R-SG decreases at early age (after 1 and 7 days) of cement paste hardening in comparison with control paste without admixtures. The highest decrease (16 and 25.6%) is observed for cement paste with 0.3 mass% of R-SG after 1 and 7 days of hardening respectively. It should be noted that compressive strength of cement pastes incorporating LS-RE, R-SG (0.2 mass%) exceeds the compressive strength of control paste by 8 and 4% respectively, except cement paste containing 0.3 mass% of R-SG where 8% decrease is observed after 28 days of hardening.

Table 3. Effect of admixtures on compressive strength of cement paste.

Age, days	Compressive strength, MPa				
	Control	LS-RE (0.7 mass%)	PCE-RE (0.7 mass%)	R-SG (0.2 mass%)	R-SG (0.3 mass%)
1	16.4	15.5	16.6	14.8	13.8
7	36.3	35.0	37.0	27.5	27.0
28	60.0	65.0	67.5	62.5	55.0

The compressive strength of cement paste containing PCE-RE has shown permanent increase for 28 days of hardening. The PCE-RE and R-SG were used for further researches such as these admixtures show the best plasticizing and retarding effect respectively.

The optimization of the content of PCE-RE and R-SG was carried out using the mathematical planning of experiments. The results are presented in Fig. 2.

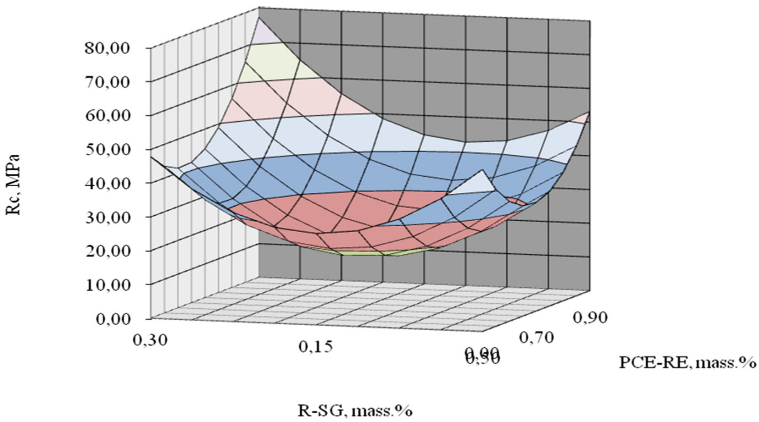

Fig. 2. Compressive strength of concretes after 1 (a) and 28 (b) days of hardening.

The optimum dosage of PCE-RE and R-SG are found on the basis on the highest ultimate compressive strength of fine-grained concrete (Cement:Sand = 1:2). The results are presented at the age of 28 days. Dosage with lower content of PCE-RE than this optimum value reduces the compressive strength and higher is not recommended by producer, because can cause negative effect related with the over dosage of plasticizer. The content of R-SG will depend on the workability retention of fresh concrete and compressive strength of hardened concrete.

The concrete mix design was done according to Ukrainian standard to study the influence of optimal amount on plasticizing and retarding admixtures on slump loss and compressive strength of concrete. The following mix-proportion has been obtained: C = 408 kg/m^3, S = 600 kg/m^3, G = 1138 kg/m^3, W = 246 kg/m^3, PCE-RE (0,9 mass%), R-SG (0,3 mass%). Consistency class of concrete mixes was S4.

The results of slump loss determination are shown in Fig. 3. The data show the relation between dosages of R-SG and slump loss. The results show that slump reduces with time. More R-SG (0.9 mass%) than designed (0.3 mass%) was added to retain the concrete in liquid state for a longer time and, as a result, it would reduce the slump loss during the transportation of concrete to the construction site. According to Fig. 3, the designed consistency class S4 is retained during the test and the conclusion can be made that retarder R-SG (0.9 mass%) is more effective in comparison with plasticizer with retarding effect PCE-RE in retaining the slump of the high strength concrete.

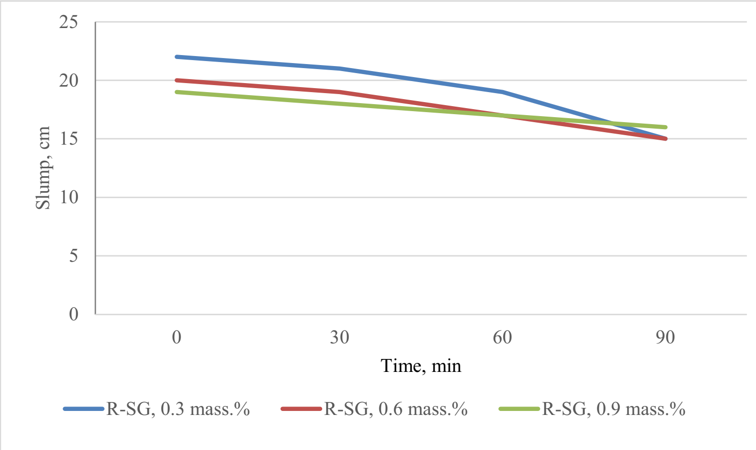

Fig. 3. Slump loss of fresh concretes.

The dosage of R-SG presents different behavior on the compressive strength of modified high strength concrete (Fig. 4). At early age, the addition of extra amount (0.6 and 0.9 mass%) of R-SG is not able to increase the compressive strength of concrete. On the contrary, the strength significantly reduces from 43.5 MPa (0.3 mass% of R-SG) to 18,6 MPa (0.9 mass% of R-SG), because the addition of the extra amount of retarder to the concrete delays the reaction of C3S and C3A and, as a result, the strength development is low. The situation changes only after 7 days from casting, compressive strength of high strength concrete containing R-SG slightly improves and exceeds the compressive strength of concrete incorporating 0.3 mass% of R-SG. As seen from the graph, continuous strength gain is observed with age and compressive

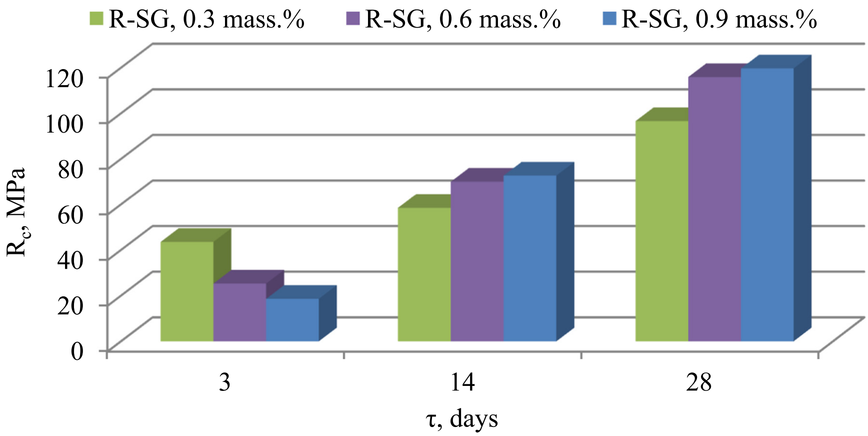

Fig. 4. Compressive strength of concretes.

strength of HSC containing 0.6 and 0.9 mass% of R-SG exceeds the compressive strength of concrete incorporating 0.3 mass% of R-SG by 20 and 24% respectively, because the reaction between the cement particles and water is active.

4 Conclusion

The efficiency of different type of chemical admixture was studied. The obtained results show that correlation between setting time of cement paste and slump loss isn't observed. It was established that incorporation rationally selected plasticizing and retarding admixtures in high strength concrete and optimization of their dosage allows obtaining fresh concrete with designed workability retention and compressive strength. The obtained properties of fresh and hardened high strength concrete allow transporting it longer and opening up a gate towards wider market, including construction of high-rise buildings. Use of this structurally safe and environmental friendly material enables to realize concept and idea of vertical cities.

References

1. Sanytsky, M., Marushchak, U., Olevych, Y., Novytskyi, Y.: Nano-modified ultra-rapid hardening Portland cement compositions for high strength. In: Lecture Notes in Civil Engineering, vol. 47, pp. 392–399 (2020)
2. Solodkyy, S., Markiv, T., Sobol, K., Hunyak, O.: Fracture properties of high-strength concrete obtained by direct modification of structure. In: MATEC Web of Conferences, vol. 116, p. 01016 (2017)
3. Kew, H., Donchev, T., Petkova, D., Iliadis, I.: Behaviour of high strength concrete (HSC) under high temperatures. In: 5th International Conference on Concrete Repair Concrete Solutions Proceedings, Belfast, Northern Ireland, pp. 493–497 (2014)
4. Dvorkin, L., Bezusyak, A., Lushnikova, N., Ribakov, Y.: Using mathematical modeling for design of self compacting high strength concrete with metakaolin admixture. Constr. Build. Mater. **37**, 851–864 (2012)
5. Markiv, T., Hunyak, O., Sobol, Kh., Blikharskyy, Z.: The effect of active mineral additives on properties of HSC in different hardening conditions. In: IBAUSIL. 20 Internationale Baustofftagung, Band 2, Weimar, Germany, pp. 851–857 (2018)
6. Stechshyn, M., Sanytsky, M., Poznyak, O.: Durability properties of high volume fly ash self-compacting fiber reinforced concretes. Eastern Eur. J. Enterp. Technol. **3**(11), 49–53 (2015)
7. Tolmachov, S., Brazhnik, G., Belichenko, O., Tolmachov, D.: The effect of the mobility of the concrete mixture on the air content and frost resistance of concrete. IOP Conf. Ser. Mater. Sci. Eng. **708**, 012109 (2019)
8. Kropyvnytska, T., Sanytsky, M., Rucinska, T., Rykhlitska, O.: Development of nanomodified rapid hardening clinker-efficient concretes based on Portland composite cements. Eastern Eur. J. Enterp. Technol. **6**(6), 38–48 (2019)
9. Runova, R.F., Gots, V.I., Rudenko, I.I., Konstantynovskyi, O.P., Lastivka, O.V.: The efficiency of plasticizing surfactants in alkali-activated cement mortars and concretes. In: MATEC Web of Conferences, vol. 230, p. 03016 (2018)

10. Markiv, T., Sobol, K., Petrovska, N., Hunyak, O.: The effect of porous pozzolanic polydisperse mineral components on properties of concrete. In: Blikharskyy, Z., Koszelnik, P., Mesaros, P. (eds.) Advances in Resource-Saving Technologies and Materials in Civil and Environmental Engineering 2019. LNCE, vol. 47, pp. 275–282. Springer, Heidelberg (2019)
11. Turba, Y., Solodkyy, S., Markiv, T.: Strength and fracture toughness of cement concrete, dispersedly reinforced by combination of polypropylene fibers of two types. In: Blikharskyy, Z., Koszelnik, P., Mesaros, P. (eds.) Advances in Resource-Saving Technologies and Materials in Civil and Environmental Engineering 2019. LNCE, vol. 47, pp. 488–494. Springer, Heidelberg (2019)
12. Kroviakov, S., Mishutin, A., Pishev, O.: Management of the properties of shipbuilding expanded clay lightweight concrete. Int. J. Eng. Technol. **7**(3.2), 245–249 (2018)
13. Alsadey, S.: Effects of super plasticizing and retarding admixtures on properties of concrete. In: International Conference on Innovations in Engineering and Technology, pp. 271–274 (2013)
14. Runova, R.F., Kochevyh, M.O., Rudenko, I.I.: On the slump loss problem of super plasticised concrete mixes. In: Admixtures - Enhancing Concrete Performance, pp. 149–156 (2005)
15. Ma, S., Li, W., Zhang, S., Ge, D., Yu, J., Shen, X.: Influence of sodium gluconate on the performance and hydration of Portland cement. Constr. Build. Mater. **5**(91), 138–144 (2015)
16. Li, B., Lv, X., Dong, Y., Zhou, S., Zhang, J.: Comparison of the retarding mechanisms of sodium gluconate and amino trimethylene phosphonic acid on cement hydration and the influence on cement performance. Constr. Build. Mater. **168**, 958–965 (2018)
17. Lv, X., Li, B., Shi, Y., Yang, H.: Comparison of the influence of amino trimethylene phosphonic acid and sodium gluconate on the performance of concrete. In: Proceedings of International Conference on Architectural, Civil and Hydraulics Engineering, pp. 1–8. Atlantis Press, Guangzhou (2015)
18. DSTU B V.2.7-188:2009: Building materials. Cements. Methods of determination of fineness. Ukrarkhbudinform, Kyiv, Ukraine (2010)
19. DSTU B V.2.7-185:2009: Building materials. Cements. Methods of determination of normal thickness, setting time and soundness. Ukrarkhbudinform, Kyiv, Ukraine (2010)
20. DSTU B V.2.7-187:2009: Building materials. Cements. Methods of determination of bending and compression strength. Ukrarkhbudinform, Kyiv, Ukraine (2010)
21. DSTU B V.2.7-71-98: Building materials. Mauntainous rock road-metal and gravel, industrial waste products for construction works. Methods of physical and mechanical tests, Kyiv, Ukraine (1998)
22. DSTU B V.2.7-232:2010: Building materials. Sand for construction work testing methods, Kyiv, Ukraine (2010)
23. DSTU-N B V.2.7-299:2013: Guidelines for appointments of the heavy concrete. Ukrarkhbudinform, Kyiv, Ukraine (2014)
24. Dvorkin, L., Dvorkin, O., Ribakov, Y.: Mathematical experiments planning in concrete technology. Nova Science Publishers, New York (2012)
25. DSTU B V.2.7-214:2009: Building materials. Concrete. Methods of determining the strength of control samples. Ukrarkhbudinform, Kyiv (2010)