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Research paper

The effect of shrinkage reducing admixture and expansive admixture on properties of mortars with Portland and slag cement

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Abstract: Both shrinkage reducing admixtures (SRA) and expansive admixture (EXP) can be used to reduce the risk of cracking in concrete. Synergistic effect of using both of those admixtures simultaneously was a was found, however little information can be found on the effects of using both EXP and SRA on the properties of mortars and concrete other than shrinkage. Therefore in this paper, effect of adding both EXP and SRA on properties of mortars outside of their effect on shrinkage is researched. Mortars with Portland cement CEM I were modified by adding EXP and SRA in amount of full dose recommended by the producer, and half of the recommended dose. Research consisted of tests of properties of fresh mortars (consistency, initial setting time, hydration heat) and hardened mortars (compressive strength and drying shrinkage). It has been found that using both SRA and EXP admixtures leads to maintaining the same setting time which can be prolonged if only SRA is used, decreased compressive strength, possibility of increased consistency. Synergistic effect on shrinkage was also confirmed.

Keywords: concrete technology shrinkage, shrinkage reducing admixtures, admixtures

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1. Introduction

Durability of concrete is one of the most important issues in modern concrete technology. One of the main issues that can cause the loss of durability of concrete is cracking connected to its shrinkage. The phenomena of concrete shrinkage is one of the most prevalent in concrete technology, due to the fact that there are many mechanisms of shrinkage that happen simultaneously in concrete at different times of its maturity, and different types of shrinkage require different methods of its minimization. Moreover, Shrinkage types in concrete consist of, in order of possible appearance: plastic shrinkage, chemical and autogenous shrinkage, and drying shrinkage [1–3]. Among those types of shrinkage, plastic and drying shrinkage are connected to the loss of water due to evaporation [4]. In case of plastic shrinkage, the dimension change is linked to the loss of water itself, causing sedimentation of still plastic concrete mix, and thus dimension change [1]. Plastic shrinkage is considered to be the easiest to control, due to the fact that good curing and proper formwork can decrease or stop the water loss at this stage of concrete setting.

The mechanism of drying shrinkage is much more complicated. At least four different effects can contribute to the occurrence of drying shrinkage in concrete: capillary stress due to water evaporation, changes in surface free energy (sometimes called Gibbs-Banhgam effect), disjoining pressure and movements of interlayer water [5,6]. The relative magnitude of those effects is dependent on the relative humidity of the environment, as in relative humidity under 40% changes in surface energy play the greatest part in the drying shrinkage, while for relative humidity of over 40%, the capillary stress and disjoining pressure have the greatest effect [7, 8]. It should be noted, that for the concretes with w/c ratios higher than 0.4, the drying shrinkage is the highest and most prevalent form of shrinkage in concrete [2, 3, 9].

Chemical shrinkage and autogenous shrinkage are often discussed simultaneously, as the latter is oftentimes the effect of the former. Chemical shrinkage is the effect of the difference in the volume of the products and substrates of the reaction of hydration [5, 10]. As the water is consumed during hydration of cement phases, it creates voids within the emerging matrix, and if no water is available to fill those spaces, autogenous shrinkage occurs [1, 9, 11]. The autogenous and chemical shrinkage are considered to be so interconnected, that their names are often used interchangeably. It should be noted however, that while chemical shrinkage is dependent on the cement hydration, autogenous shrinkage depends on the w/c ration of the concrete, and can vary significantly depending on the composition of the concrete mix [9]. Autogenous shrinkage is the higher, the lower w/c ratio, therefore it has become one of the main issues for low w/c ratio concretes, especially High Performance Concretes (HPC) or Ultra High Performance Concretes (UHPC) as the w/c ratio in those concretes is low, usually set at 0.20–0.30 [12, 13].

To try and contain the shrinkage, many methods were devised: surface curing, use of expansive cements, introducing expansive agents, or using shrinkage reducing admixtures (SRA). Expansive agents are used to offset the shrinkage in first hours of the hydration, which in most cases is caused by chemical and autogenous shrinkage [9]. Most popular expansive agents promote creation of ettringite in the early stages of hydration process, utilizing expansiveness of ettringite compounds [14,15]. That effect lowers the shrinkage of mortars and concretes, sometimes even introducing an expansion of the samples [18–20]. Ettringite is obtained either by introducing alumina phases to the concrete, or by introducing calcium oxide and using C_3A phase present in cement as the substrates for ettringite production [9, 16, 17]. The effects of expansive admixtures on properties of mortar and concrete have been tested by Nagataki and Gem [18], whose test results showed that the compressive strength of concrete with expansive admixture can be similar or lower than in case of ordinary concrete, depending on the expansion rate of the admixture, while carbonation and water permeability were comparable between the two concretes. Effect of lowered strength was observed by Jackiewicz-Rek et al. [21], who used alumina powder as an expansive admixture, while Maltese at al. [16] did not observe any changes in compressive strength of concrete with 3% c.m. of expansive admixture. Latter research also showed a slight shortening of setting time in the presence of expansive agent, most likely due to the quick ettringite formation.

SRA introduce into the mortar or concrete amphiphilic molecules, which get absorbed on the liquid-vapor threshold, thus lowering the surface tension of the water and preventing moisture loss [8, 22, 23]. While SRA can influence early shrinkage, their effect is mostly used in connection to the drying shrinkage [24]. The mechanism of SRA decreasing drying shrinkage is usually explained by several simultaneous effects caused by low surface tension: lowered capillary tension [25] and structure with smaller pores, what allows to maintain high relative humidity [26]. Some research also reported possibility of expansion following the SRA addition to mortars and cements, due to the increased rate of portlandite crystallization [27–29]. It should be noted that with the increase of the amount of SRA in the mortar or concrete, the drying shrinkage decreases [29–31]. SRA has been found to have a significant impact on the hydration of Portland clinker [22]. Tests by Eberhard [32] and He at al. [33] showed that in presence of SRA the setting is delayed, and early microstructure development is severely hindered. This can be attributed to the lowered surface tension hindering the availability of water for the hydration process, and reduced alkali content leading to slower C_3S hydration [33, 34]. The effect of SRA admixture on the workability and consistency is not as clear, with some research indicating an increase in workability with the increase of SRA content [35, 36], while others show a decrease [37, 38]. The research into compressive strength of concrete containing SRA conducted by Güneyisi et al. [39] and Quangphu et al. [40] showed that with the increase in SRA content, compressive strength decreases. SRA content in concrete was found to have a positive effect on the freeze-thaw resistance [41] and chloride resistance [42].

As expansive admixtures are most useful for early shrinkage connected with autogenous and chemical shrinkage, and SRA is mostly effective for drying shrinkage, attempts were made to combine the two admixtures. Research by Oliveira et al. [43], Zaichenko et al. [34, 44], Corinaldesi [45] and Maltese et al. [16] had shown this to be a viable strategy, as the two admixtures show synergistic effect in terms of shrinkage reduction. Combination of SRA and expansive admixture had shown significantly higher shrinkage reduction than if only one of those admixtures was used [16]. It should be noted, however, that other than the effect on the shrinkage, very little research was done in relation to of use of the both admixtures on other properties of mortars and concretes. Maltese et al. [16] tested the compressive strength as well as initial and final setting time of mortars. The strength of mortars with both admixtures was lower than in case of mortar with no admixtures and only expansive admixture, but higher than for the mortars with SRA. Similar effect was observed in research by Meddah et al. [44], where both the early and 28 day compressive strength of concrete with mix of SRA and expansive admixture was lower than compressive strength of concrete with no admixtures. The possibility of interaction between two admixtures is therefore something that should be investigated further.

Therefore, following paper presents the inquiry into effects of using both expansive admixture (EXP) and SRA on properties of mortars outside of their effect on shrinkage, to see if any adverse side effect can be expected. Mortars with Portland cement CEM I and slag cement CEM III/A were modified by adding commercially available EXP and SRA in amount of full dose recommended by the producer, and half of the recommended dose. The test were conducted both on mortars with just one of the admixtures, and on the combination of the two. Research consisted of tests of properties of fresh mortars (consistency, initial setting time, hydration heat) and hardened mortars (compressive strength and drying shrinkage).

2. Materials and methods

2.1. Materials

All tests were conducted on the ordinary Portland cement CEM I 42.5R (OPC) and slag cement CEM III/A 32.5N-LH/HSR/NA (SC). Composition and properties of the cements are shown in Table 1 and Table 2, respectively.

Table 1. Composition of Portland cement CEM I 42.5R

Cement	Constituent [%]									Phase composition [%]				
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Na_2O_{eq}	C_3S	C_2S	C_3A	C_4AF	Slag
OPC	20.6	4.7	2.8	64.4	1.2	2.8	0.2	0.4	0.46	60.7	11.6	11.9	8.2	–
SC	30.0	6.37	1.81	52.6	4.05	2.7	0.3	0.61	0.69	28.4	4.8	3.7	3.8	51

For the tests which were conducted on the mortars, standard sand was used according to the European standard EN 196-1:2016-07 [46]. The composition of base mortar was always based on the composition of standard mortar according to EN 196-1:2016-07 [46], consisting of 450 g of cement, 225 g of water, and 1350 g of standard sand.

Shrinkage Reducing Admixture (SRA) used in the research is a commercially available agent, intended for use in both mortars and concrete. Expansive admixture (EXP) used in the research is also a commercially available product, based on the lime. Admixtures were added both separately and simultaneously to the mortar in the amount of a full dose recommended by the producer (0.5% of mortar mass for SRA, amounting to 10.125 g, and

Table 2. Properties of Portland cement CEM I 42.5R

Cement property	Unit	OPC	SC
Initial setting time	min	260	294
Soundness of cement, by Le Chatelier's method	mm	0.4	0.3
Compressive strength after 2 days	MPa	28.65	9.79
Compressive strength after 28 days	MPa	52.66	39.66
Specific surface area	cm^2/g	4400	4624

8% of cement mass for EXP, amounting to 36 g), and half that dose. The dosing was chosen in order to best show the effect of the admixture, and therefore full dose of admixture was used, with half of a recommended dose as a midpoint to better gauge the effects of mixing the admixtures. All mortar compositions are shown in Table 3.

Table 3. Mortar composition

Symbol of the mortar	Constituents [g]				
	Cement	Water	Sand	SRA	EXP
OPC or SC	450	225	1359	–	–
OPC or SC + 0.5 SRA				5.06	–
OPC or SC + 1.0 SRA				10.125	–
OPC or SC + 0.5 EXP				–	18.0
OPC or SC + 1.0 EXP				–	36.0
OPC or SC + 0.5 SRA + 0.5 EXP				5.06	18.0
OPC or SC + 0.5 SRA + 1.0 EXP				5.06	36.0
OPC or SC + 1.0 SRA + 0.5 EXP				10.125	18.0
OPC or SC + 1.0 SRA + 1.0 EXP				10.125	36.0

2.2. Methods

Two of the tests were performed on cement paste –initial setting time and hydration heat. Initial setting time was measured according to the EN-196-3:2016-12 [47]. The cement paste was prepared by mixing 500 g of cement with set amount of SRA and/or EXP, and adjusting the amount of water to obtain standard consistency. The setting time measurement was conducted in the automated Vicat apparatus.

Another test performed on cement paste was hydration heat measurement, done in a isothermal calorimeter Tam-Air with internal mixing, allowing for the constant measurement from the moment of adding water to cement. The measurement was done on cement paste samples consisting of 5g of cement, 2.5 g of water, with SRA and EXP added as per

Table 3 in amounts of 0.5 SRA – 0,019 g, 1SRA – 0,037 g, 0.5EXP – 0.02 g and 1EXP – 0.04 g. Quartz sand was used as the reference, in amount calculated to have equal heat capacity as the sample. The measurement lasted 72 h.

Consistency of mortars was measured by flow table (EN 1015-3:1999 [48]) and by plunger penetration (EN 1015-4:1999 [49]). Both measurements were conducted on the mortar from the same batch.

Compressive strength of the mortars was tested according to the standard EN 196-1:2016-07 [47]. After forming, the samples were kept in a climatic chamber for the first 24 hours, and afterwards in water of temperature 20°C. Tests were conducted after 1, 2, 3, 7 and 28 days of curing. For each mortar and each test date 2 prismatic samples were made, giving 4 compressive strength samples.

Drying shrinkage was also tested, according to the standard PN-84/B-06714/24 [50]. Prismatic samples were prepared, with metal socket at each end. A measurement of changes in the length of the sample was conducted with Graf-Kaufman apparatus. First measurement, which serves as reference length of the sample, was done 24 h after mixing; then the measurements were repeated after 2, 6, 14 and 28 days, and changes in length were calculated. The samples were cured in a climatic chamber in tempertaure 20^{o}C and humidity of 60%, as metal sockets make it impossible to keep samples in higher humidity.

3. Results and discussion

3.1. Initial setting time

The results of tests of initial setting time are shown in Fig. 1.

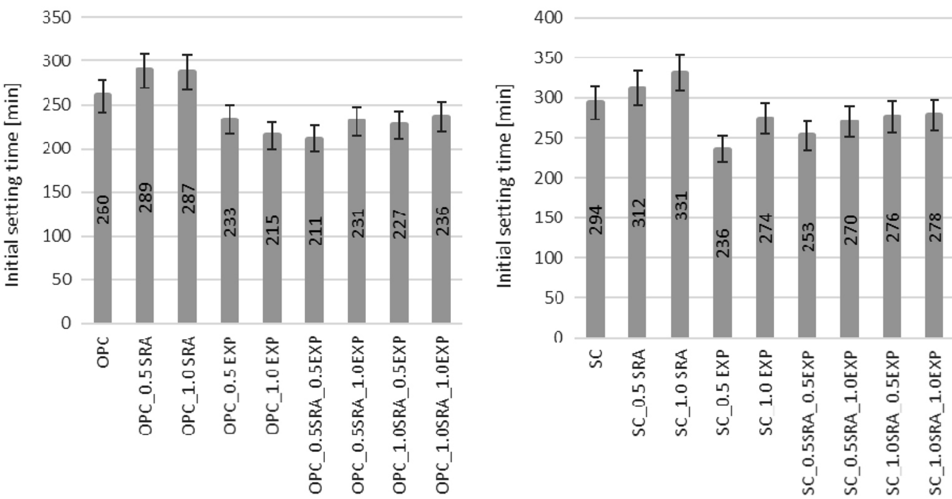

Fig. 1. Initial setting time of OPC (left) and PSC (right) cement pastes with SRA and EXP

In the case of both OPC and SC, the addition of EXP reduces the initial setting time, while the addition of SRA, prolongs it. The effect of EXP can be linked to a high CaO content, as its high concentration can result in C_3A phase reacting with CaO, creating increased amounts of expansive ettringite [16]. Some research also points to the possibility of hydration of CaO occurring, which results in portlandite $Ca(OH)_2$ production [3, 51]. Therefore, in case of EXP admixture, fast ettringite reaction can lead to a quicker stiffening of the cement paste, leading to the measurement showing faster setting time. The average shortening of initial setting time similar in case of OPC and SC, as it's ~10%. The effect of SRA may be in turn linked to the lowered surface tension hindering hydration process by decreasing water availability [22, 34]. The amount of SRA did not affect the setting time in case of both OPC and SC.

When used simultaneously, the SRA and EXP admixtures also shorten the initial setting time, to the similar degree as just EXP admixture, in case of both OPC and SC.

3.2. Hydration heat

The results of hydration heat test results are shown in Figs. 2 and 3.

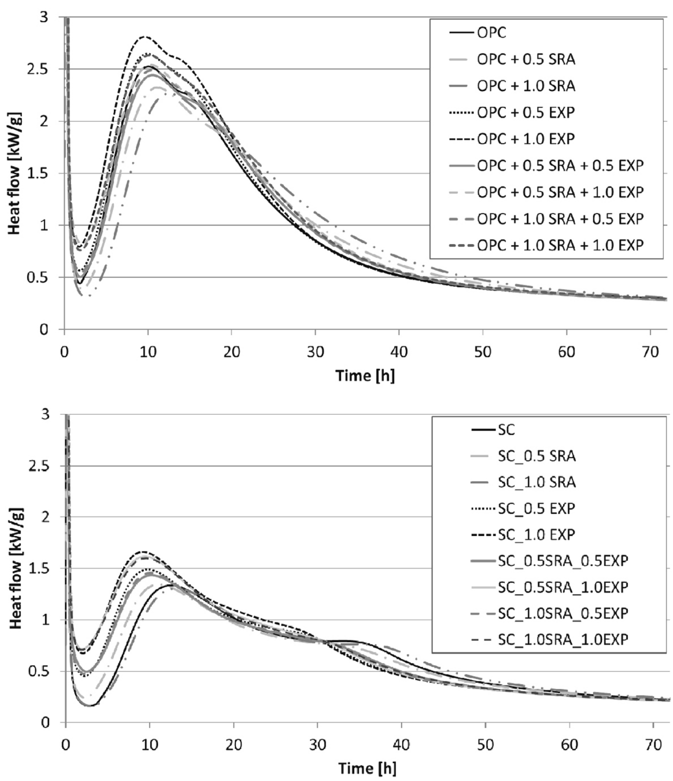

Fig. 2. Hydration heat evolution of OPC (top) and SC (bottom) cement pastes with SRA and EXP

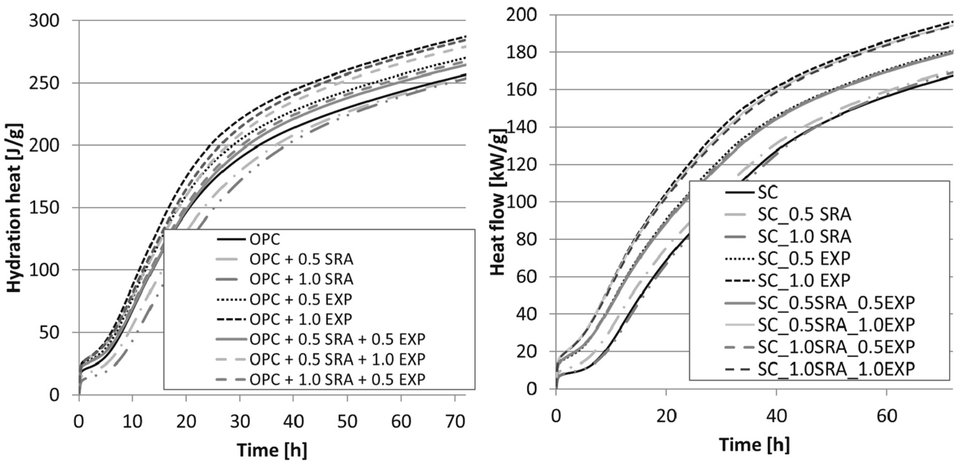

Fig. 3. Hydration heat of OPC (left) and SC (right) cement pastes with SRA and EXP

In case of both OPC and SP, addition of SRA and EXP results in a significant changes in hydration heat evolution. With the increase in SRA content in the cement paste, the hydration heat released in the first 40 hours of hydration decreases. A significant extension of the induction period as well as delayed main reaction peaks can be also observed. This indicates slower reaction rates in presence of SRA, what is consistent with the research by Eberhard [32] and He at al. [33]. The effect of slowed hydration has been observed in the test of initial setting time (Fig. 1). As previously mentioned, this effect can be explained by the lowered surface tension hindering hydration process by decreasing water availability [34]. While the hydration heat differs significantly in the first 40 h, after 72 hours from adding water to OPC and SC cement, the there was no difference between reference cement paste hydration heat and hydration heat of cement paste with SRA.

Addition of EXP to the cement paste, on the other hand, increased the heat of hydration by up to 12% in comparison to the reference sample of OPC paste and 17% in case of SC paste. A significant increase in the rate of hydration heat released can also be observed both during the induction period and in the post-induction period. Those phenomena can be attributed to the ettringite formation due to the introduction of CaO, and its reaction with C_3A [52, 53]. It should be noted, that while more heat has been released during first 20 h of hydration of cement paste with EXP, there is no change to the hydration speed, with the induction period and main hydration peaks occurring at the same time as in the reference OPC and SC pastes. This would indicate that EXP addition does not affect the hydration speed of Portland clinker. While the initial setting time results presented in Fig. 1. show decrease in setting time, what could be linked to an increased hydration rate, it can be also linked to the reaction of EXP admixture and subsequent ettringite production, which in turn could affect the measurement [3, 51].

When EXP and SRA are used simultaneously, their effects overlap. All samples with maximum EXP dose used have higher heat flow during the induction phase, however presence of SRA lowers the main peaks of hydration heat evolution. It should be noted, however, that simultaneous use of EXP and SRA may stop the effect of delayed hydration, as none of the cement pastes with mixed admixtures exhibited prolonged induction phase or delayed main hydration peaks that was present when using only SRA.

3.3. Consistency

The results of consistency tests are shown in Fig. 4.

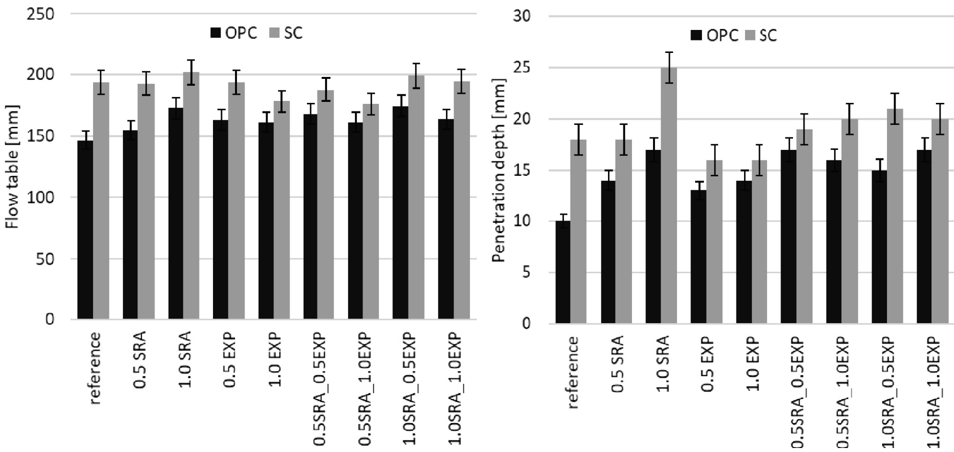

Fig. 4. Consistency measured by flow table (left) and plunger penetration (right) of OPC and SC mortars with SRA and EXP

The flow table test shows no significant effect of EXP or lower dose of SRA on the consistency of the mortars, with only an addition of a maximum dose of SRA resulting in the increased flow in comparison to the reference sample of OPC. Significant differences can be observed however in case of plunger penetration test, where addition of EXP slightly increased plunger penetration depth, while SRA had a significant effect, and with increasing SRA content, the penetration depth increased. The difference in the results can be attributed to the difference in the actual physical values measured by the two tests. Plunger penetration test, due to the very blunt end of the plunger is partially dependent on viscosity of fresh mortar, while flow table diameter can be linked to its yield stress [54]. This may mean, that seeing as SRA affect the surface tension of the pore solution in mortar, and thus influence its viscosity [55], while the yield stress is not affected to the same degree. Tests of rheological behavior conducted by Corinaldesi have shown decrease in viscosity in presence of SRA, while yield stress was not affected [45].

It should be noted that in case of using both SRA and EXP, the results of consistency test are similar to the results of adding only SRA admixture. Therefore it stands to reason that in case of mixing the two admixtures, one should be aware of the possible consistency change, however there is no indication that there is any interaction between SRA and EXP in terms of consistency changes.

3.4. Drying shrinkage

The results of tests of drying shrinkage are shown in Fig. 5.

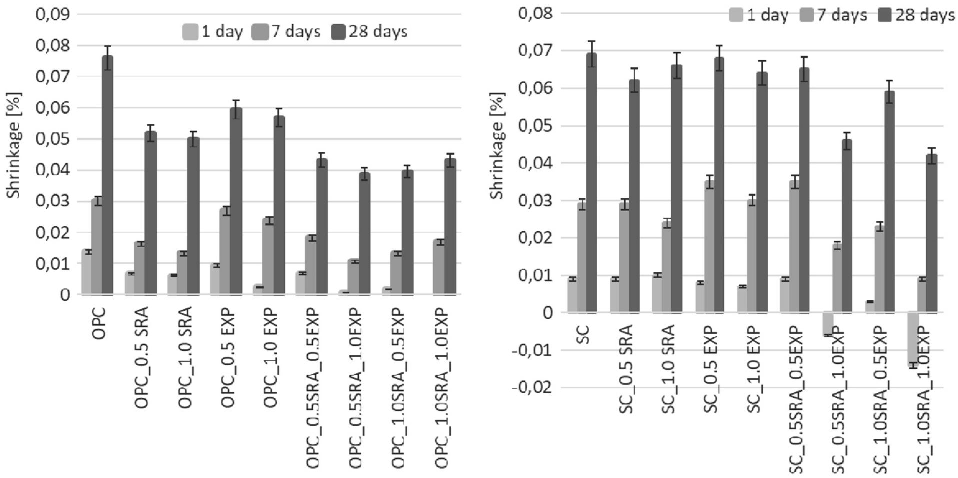

Fig. 5. Drying shrinkage of mortars with SRA and EXP

As it could be expected, addition of SRA and EXP reduced the shrinkage of the OPC and SC mortars, both in the early stages (first 48 h) and at the later stages (28 days) [22]. Addition of SRA significantly decreased the shrinkage of the sample both in the beginning, and after 28 days, and no significant difference was observed between the shrinkage reduction after using half of the maximum dose, and maximum dose of the admixture. This may be the sign that there is an optimal amount of SRA required for the mortar and over which there is no improvement of the properties [56].

With the increased amount of EXP admixture, the early shrinkage also decreases significantly. The decrease can be also observed after 28 days, however the difference between the samples with 0.5 of maximum dose and a maximum dose is not significant, and the shrinkage is higher than in case of using SRA admixture. It should be noted that for the 0.5 of maximum EXP addition to OPC mortars, the early shrinkage was slightly higher than in case of use of SRA admixture. In case of SC, the effect on 1 day shrinkage is similar for both SRA and EXP admixtures.

When using both SRA and EXP admixtures, a clear synergistic effect can be seen both in terms of early shrinkage and 28 day shrinkage, as in both cases the shrinkage is lower than in case of using either of those admixtures on their own. In case of SC with SRA and 1% addition of EXP, even some expansion may be observed, possibly due to the slower hydration rate of SC, and lower early shrinkage. Similar synergistic effect was obtained in research by Yuan et al. [57], and Zaichenko et al. [34]. The synergistic effect between the two admixtures could be possibly explained by expansion introduced by EXP compensating for shrinkage caused by lowered surface tension of the pore fluid during the first two weeks of cement hydration, and thus significantly altering the early shrinkage [44]. It should be noted that the best results for early shrinkage were obtained for the maximum dose of EXP admixture, where the 1 day shrinkage was almost nonexistent, however after 28 days there were no significant differences between the shrinkage of all mortars with both SRA and EXP admixtures.

3.5. Compressive strength

The results of compressive strength tests of mortars after 1, 3, 7 and 28 days are shown in Fig. 6.

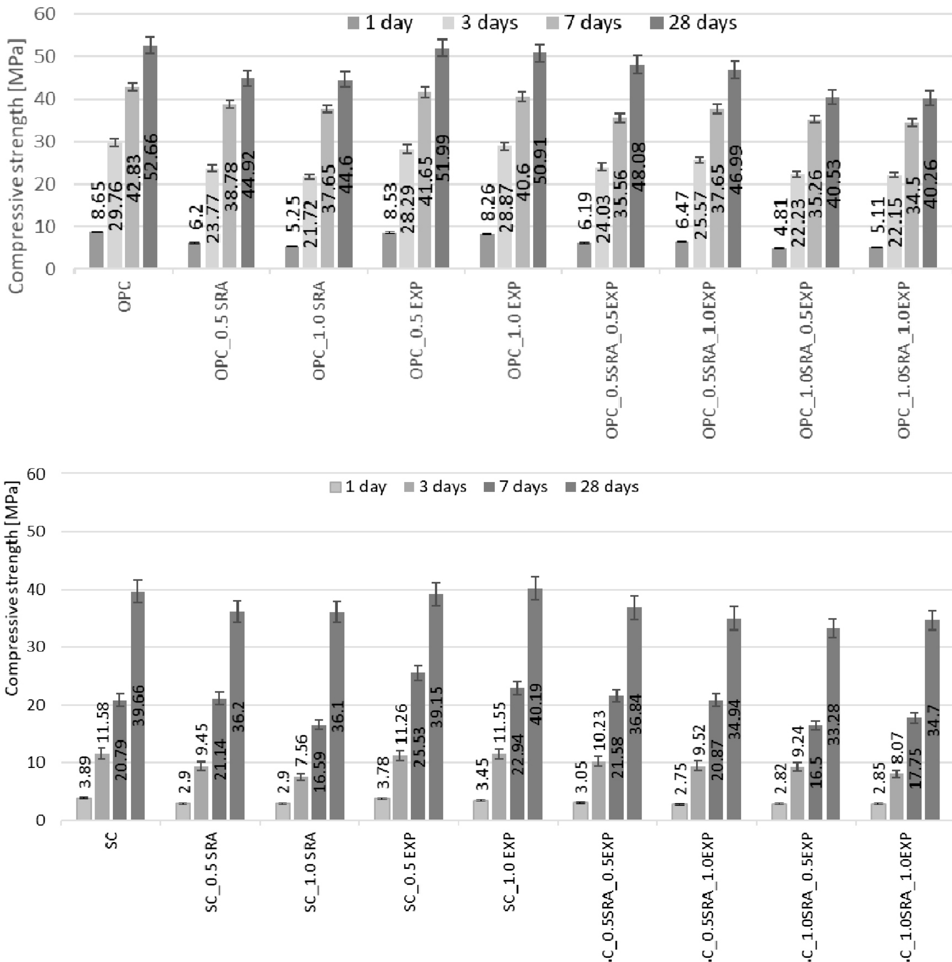

Fig. 6. Compressive strength of mortars with SRA and EXP after 1, 3, 7 and 28 days of OPC (top) and SC (bottom) mortars

SRA admixture had a significant influence on the compressive strength of the mortars. With the introduction of SRA, compressive strength of mortars decreases. This effect is much more pronounced in case of OPC than SC. The difference in compressive strength is starkest in relation to the early strength, as the decrease in compressive strength of mortars with SRA in relation to the OPC reference sample is ~30–40%, and in third day reaches around 30%, while in case of SC samples its respectively 35% and 20%. After 7 and 28 days the difference is lower, but still significant, as it is around 15% for OPC and 10% for SC. Strength decrease can be explained by the fact that SRA can hinder the hydration process by decreasing the availability of water by lowered surface tension, and reduced alkali content leading to slower C_3S hydration [33, 34]. Moreover, lowered surface tension of pore solution introduces air into the matrix, increasing porosity of the mortar, and additionally lowering the compressive strength [58]. Lesser negative effect of SRA in case of SC mortar may be connected to the smaller sizes of pores in presence of slag [59].

Addition of EXP admixture did not influence the compressive strength of mortars, as in all tested instances the compressive strength of mortars with EXP is comparable to the reference sample. The compressive strength was the same for the samples with maximum dose or 0.5 of maximum dose recommended by the producer of the admixture. It can therefore be concluded, that the early expansion did not affect the strength development of mortars. Similar results were obtained by Nagataki, confirming the obtained results [18].

In case of mortars with both SRA and EXP admixtures, a decrease in strength in relation to the reference sample can be observed. The decrease in strength is comparable to the decrease caused by the addition of SRA admixture. The only exception are the mortars with 0.5SRA and EXP after 28 days, which compressive strength is slightly higher than strength of mortars with only 0.5SRA, however it still is lower than the compressive strength of reference sample. It may be therefore concluded, that the addition of EXP admixture to the mortar does not provide any effect on the strength decrease caused by the SRA addition, and no synergistic effect was observed.

4. Conclusions

Performed research on the properties of mortars with SRA and EXP admixtures leads to the following conclusions:

– Both SRA and EXP have a significant effect on the initial setting time and hydration process. While SRA addition to mortar delays the setting and prolongs the hydration process, EXP addition to mortar increased the heat released during the first several hours of hydration due to rapid C_3A reaction with CaO, however did not affect the setting. Mixing SRA and EXP admixtures allowed to mitigate the issue of prolonged setting and hydration in the presence of SRA.
– The effect of SRA and EXP on consistency is depends on the test used, as no significant difference in consistency of all tested mortars was observed when flow table method was used, however in plunger penetration tests, SRA use showed improvement in consistency both when used on its own and with EXP admixture.

– Both early shrinkage and shrinkage after 28 days is reduced by using EXP and SRA. Synergistic effect can be observed when using both of those admixtures simultaneously. Possible explanation can be connected to expansion introduced by EXP which can compensate for shrinkage caused by lowered surface tension of the pore fluid.
– EXP addition to mortar does not affect the mortar strength, while addition of SRA significantly lowered the compressive strength due to slowed hydration and possible higher porosity. When SRA and EXP are used simultaneously, the compressive strength is lowered to the similar extend as with only SRA admixture, showing no interaction between EXP and SRA in relation to compressive strength.
– Effect of using SRA and EXP admixture is similar for mortars with OPC and SC, with the only difference being smaller negative effect of SRA admixture on the strength of mortars, possibly due to the different pore distribution in SC.

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Wpływ domieszki redukującej skurcz i domieszki ekspansywnej na właściwości zapraw z cementem portlandzkim i żużlowym

Słowa kluczowe: domieszki, właściwości zapraw, domieszki przeciwskurczowe, domieszki ekspansywne

Streszczenie:

Jednym z głównych problemów mogących powodować spadek trwałości betonu jest pękanie związane z jego skurczem. Zjawisko skurczu betonu jest jednym z częściej podnoszonych problemów w technologii betonu, ze względu na fakt, że w dojrzewającym betonie występuje wiele mechanizmów skurczu jednocześnie w różnych okresach, a różne rodzaje skurczu wymagają różnych metod jego redukcji. Aby spróbować ograniczyć skurcz, opracowano wiele metod, m.in. stosowanie środków ekspansywnych lub stosowanie domieszek zmniejszających skurcz (SRA). Środki ekspansywne służą do kompensacji skurczu poprzez pobudzenie reakcji tworzenia ekspansywnego etryngitu w pierwszych godzinach hydratacji, tak by kompensować redukcję objętości w wyniku skurczu chemicznego i autogenicznego. Mechanizm działania SRA jest natomiast łączony głównie z redukcją skurczu wysychania, ze względu na jego dział anie związane z kilkoma równoczesnymi efektami zachodzącymi w jego obecności: obniżenie napięcia kapilarnego na skutek niskiego napięcia powierzchniowego oraz stworzenie struktury z mniejszymi porami pojawiającymi się na skutek obniżonego napięcia powierzchniowego, co pozwala na utrzymanie wysokiej wilgotności względnej. W celu lepszej redukcji skurczu podjęto próby stosowania obydwu domieszek jednocześnie, otrzymując bardzo dobre wyniki redukcji skurczu; problemem w powszechniejszym zastosowaniu tej metody jest niewielka ilość informacji o wpływie stosowania domieszki SRA i ekspansywnej na raz na inne właściwości betonów i zapraw.

Dlatego w niniejszym artykule przedstawiono analizę wpływu stosowania zarówno domieszki ekspansywnej (EXP) jak i SRA na właściwości zapraw. Zaprawy z cementem portlandzkim CEM I 42.5R (OPC) i CEM III/A 32.5N-LH/HSR/NA (SC) modyfikowano dodając dostępne na rynku domiezki EXP i SRA w ilości pełnej dawki zalecanej przez producenta i połowy zalecanej dawki. Testy przeprowadzono zarówno na zaprawach z tylko jedną domieszką, jak i na ich kombinacji. Badania obejmowały badania właściwości zapraw świeżych (konsystencja, czas początku wiązania, ciepło hydratacji) oraz zapraw stwardniałych (wytrzymałość na ściskanie i skurcz wysychania).

Zarówno w przypadku OPC jak i SC dodatek EXP skraca czas początku wiązania, natomiast dodatek SRA go wydłuża. Efekt EXP można wiązać z powstawaniem ekspansywnego etryngitu, co

może prowadzić do szybszego usztywnienia zaczynu cementowego, czyli do szybszego osiągnięcia pomiaru opowiadającego czasowi początku wiązania. Efekt SRA może być z kolei związany z obniżonym napięciem powierzchniowym utrudniającym proces hydratacji poprzez zmniejszenie dostępności wody. Stosowane jednocześnie domieszki SRA i EXP skracają czas początku wiązania, w podobnym stopniu jak domieszka EXP zarówno w przypadku OPC, jak i SC.

Zarówno dodatki SRA, jak i EXP wykazują znaczący wpływ na wydzielanie ciepła hydratacji zarówno w przypadku OPC, jak i SC. Wraz ze wzrostem zawartości SRA w zaczynie cementowym następuje wydłużenie okresu indukcji oraz opóżnienie wystąpienia maksimów wydzielania ciepła. Wskazuje to na wolniejsze tempo reakcji hydratacji w obecności SRA. Dodatek EXP do zaczynu cementowego zwiększa ciepło hydratacji. Istotny wzrost szybkości wydzielania ciepła hydratacji można zaobserwować zarówno w okresie indukcji, jak i w trakcie reakcji hydratacji alitu. Zjawiska te można przypisać powstawaniu ettryngitu w wyniku wprowadzenia CaO i jego reakcji z C_3A. Kiedy EXP i SRA są używane jednocześnie, ich efekty nakładają się, i należy podkreślić, że można w ten sposób mitygować efekt wydłużenia okresu indukcji w obecności SRA.

Wpływ EXP i SRA na konsystencję nie był jednoznaczny, ze względu na wyraźne różnice pomiędzy wynikami otrzymanymi różnymi metodami pomiarowymi.

Przy stosowaniu zarówno domieszek SRA jak i EXP zaobserwowano wyrażny efekt synergiczny zarówno w zakresie skurczu wczesnego, jak i skurczu 28 dniowego, gdyż w obu przypadkach skurcz był znacząco mniejszy niż w przypadku stosowania tylko jednej z tych domieszek. Efekt synergiczny między dwiema domieszkami prawdopodobnie można wyjaśnić ekspansją wprowadzoną przez zastosowanie EXP, które może kompensować skurcz spowodowany obniżonym napięciem powierzchniowym płynu porowego podczas pierwszych dwóch tygodni hydratacji cementu, a tym samym znacząco zmieniając wczesny skurcz.

Domieszka SRA ma istotny wpływ na wytrzymałość zapraw na ściskanie. Wraz ze wzrostem zawartości SRA, wytrzymałość na ściskanie maleje. Spadek wytrzymałości można wytłumaczyć faktem, że SRA może hamować proces hydratacji, zmniejszając dostępność wody przez obniżone napięcie powierzchniowe i obniżoną zawartość alkaliów prowadzącą do wolniejszego hydratacji C_3S. Ponadto obniżone napięcie powierzchniowe roztworu porowego wprowadza do zaczynu powietrze, zwiększając porowatość zaprawy, i dodatkowo obniżając wytrzymałość na ściskanie. Dodatek domieszki EXP nie wpływał na wytrzymałość zapraw na ściskanie. W przypadku zapraw z domieszką bot SRA i EXP można zaobserwować spadek wytrzymałości w stosunku do próbki referencyjnej. Spadek wytrzymałości jest porównywalny ze spadkiem spowodowanym dodaniem domieszki SRA.

Należy jednocześnie zauważyć, że wpływ SRA i EXP na właściwości zapraw byłporównywalny w przypadku zarówno cementu hutniczego CEM III/A, jak i cementu portlandzkiego CEM I.

Podsumowując, jednoczesne stosowanie domieszek SRA i EXP może prowadzić do wyrażnego obniżenia skurczu dzięki synergistycznemu efektowi działania obydwu domieszek. Stosowaniem domieszki ekspansywnej można także mitygować opóżniający wpływ SRA na czas wiązania i szybkość reakcji hydratacji, natomiast negatywny wpływ SRA na wytrzymałość zapraw jest także obecny w przypadku stosowania domieszki EXP.

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