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MODIFICATION OF CEMENT PASTES FOR THE REPAIRS OF CONCRETE STRUCTURES

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ABSTRACT

The paper presents results of experiments on the effect of superplasticizer addition on rheological and strength properties of cement paste destined for injection applications. Tested samples were produced with the CEM I 42.5 R Portland cement. The water-to-cement ratio varied from 0.35 to 0.55 and the amount of plasticizing agent varied from 0 to 3% by cement mass. The investigations were performed with the coaxial rotating viscometer. The strength of the matured samples was tested in accordance with valid building codes. The experiments showed that addition of the liquefying admixture effects in simplification of the rheological structure of paste. The strength of matured paste samples with the superplasticizer addition was considerably increased.

Key words: rheology, cement paste, superplasticizer.

INTRODUCTION

Plasticizers have been successfully applied in concrete technology since the thirties of XX age. The effect of plasticizers addition on properties of concrete mix as well as hardened concrete has been recognized and described well in general. However some new trends occurred during last twenty years, like for example self-compacting concrete [19] or high and ultrahigh strength concretes. Structural durability of concrete against the environmental aggression replaced the former usage of shielding layers and coating materials. The mentioned factors resulted in more detailed investigation of various aspects of plasticizers usage. The research on the general aspects of rheological behavior of cement composites is being continued still. Today's tendencies in research covers among others: new types of plasticizers, effect of mineral and organic fillers [3] especially in field of recycling and municipal waste utilization, effect of plasticizers on cement hydration [18], compatibility of plasticizers and cements, effectiveness of plasticizers in presence of fine, ultrafine and nano- powders [21], relations between the chemical structure of plasticizers and their efficiency [10], effect of plasticizers on the chloride ions migration in concrete and on the structure, strength and durability of hardened structural concrete [17], including air-containing concretes and architectural concretes.

Injection technologies are widely used, both in repairs and in caulking any building structures. The areas of their application include, first of all, hydrotechnical structures [6], bridges [15], general construction, underground structures [9], concrete structures [16], walls [4] and stone structures [2]. Repairs refer mostly to horizontal, vertical and ceiling surfaces of elements of concrete structures that require strengthening, gluing, monolithisation or caulking [1]. Injection also allows to strengthen or caulk the soil behind the structure under construction, particularly in underground, general or special purposes construction [9]. Apart from specialist injection materials created basing on various chemical components, such as epoxide or polyurethane resins [8], grouts produced basing on cement pastes are also widely used.

The introduction of chemical admixtures to cement mortars and pastes allows to use them more widely in injection pastes for concrete structures as it changes their workability and plasticity. This is particularly important when the repair method consisting in the injection of cement pastes is used [20].

Injection technologies include mainly gravity and pressure injection. Pressure injection refers to a very wide scope of applications

of low-pressure injection, in particular with respect to the strengthening and caulking of concrete structures. In this case, the grout should be introduced at the lowest working pressure possible.

The scope of works encompasses the preparation of injection paste and the injection thereof with use of special packers powered by a pressurized hydraulic installation. This requires the knowledge of basic technical parameters of the injection material (density, setting time, strength) and of rheological properties that influence the parameters of hydrotransport of pastes [7].

Purpose

The aim of the study was to determine selected standard parameters and rheological properties of cement pastes and their changeability in the course of the modification process conducted with use of a liquefying admixture based on polycarboxylates in the aspect of their application for low-pressure injection i.e. for performing the injection at the lowest possible working pressure.

MATERIALS AND METHODS

The tests were conducted on cement pastes prepared with use of Portland cement CEM I 42.5 R, compliant with the PN-EN 197-1:2002 standard, for various water to cement ratios W/C, varying within the range from 0.35 to 0.55 and the addition of a liquefying admixture in the amount corresponding to 0.4–3% of the cement weight. Basic parameters of the analysed cement are presented in Table 1.

Table 1. Basic parameters of the cement CEM I 42.5 R

Parameter	Value
Density [g/cm ³]	3.050
Normal consistency [%]	27
Initial setting time [min]	85
Final setting time [min]	180
Compressive strength [MPa] after 28 days	56.6
Flexural strength [MPa] after 28 days	8.08

The cement pastes were modified with use of a highly efficient liquefying admixture based on modified polycarboxylates. Liquefiers based on polycarboxylate ether open new possibilities in concrete technology, both with reference to regular concrete and self-compacting types of concrete. The main task of the liquefiers is the deflocculation of cement paste by means of increasing the degree of dispersion of cement grains. This allows for the regulation of the consistency of cement paste regardless of the water to cement ratio W/C.

Rheological tests were conducted with use of the Haake VT550 rotational viscometer, equipped with a measurement system consisting of co-axial cylinders of the MV2P system, according to the methodology presented in the work [11]. All measurements were conducted at ambient temperature $t = 20^{\circ}\text{C}$. The scope of analysed water to cement ratio of cement pastes varied in the range of $W/C = 0.35\text{--}0.55$. For each water to cement ratio level liquefying admixture was added in an amount varying within the range 0.4–3.0% in relation to the cement weight. Pseudo-curves of flow obtained as a result of the measurements were then approximated to actual curves of flow, pursuant to the methodology presented by Krieger, Maron and Elrod [12–14] proposed by Czaban [5].

Investigation of effect of liquefying agent on strength properties of CEM I 42,5R cement was performed on $4\times4\times16$ cm beam samples, in accordance with PN-EN 196-1:2006. The amount of additive varied from 0 up to 3% of mass of cement. Fresh mortars were tested also to determine the effect of superplasticizer on consistency of mortar. The measurements were performed with the flow table method, in accordance to the PN-EN 1015-3:2000 standard. The compressive and flexural strength tests were performed with the ToniNorm strength frame, fulfilling the requirements of the PN-EN 196-1:2006 standard.

RESULTS

Flow curves of plain cement paste are shown on Figure 1. Flow curves of cement paste of $W/C=0,35$ with various doses of polycarboxylate fluidizing admixture are shown on Figure 2.

The flow curves exhibit distinct yield stress and are characteristic for the viscous-plastic body for all tested concentrations.

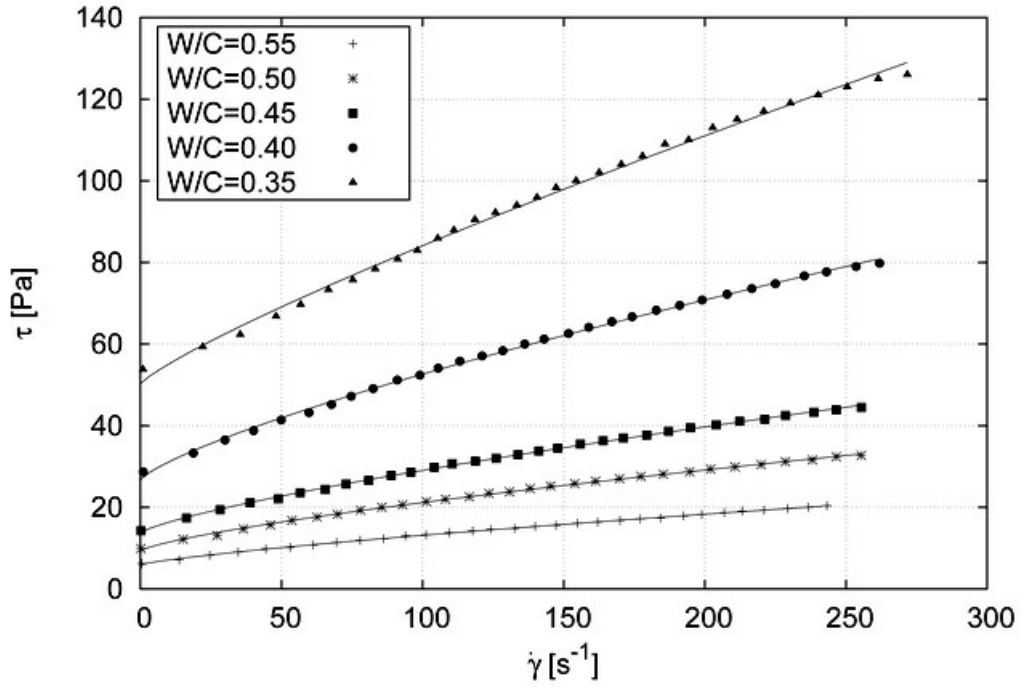


Fig. 1. Actual curves of flow of cement CEM I 42.5 R

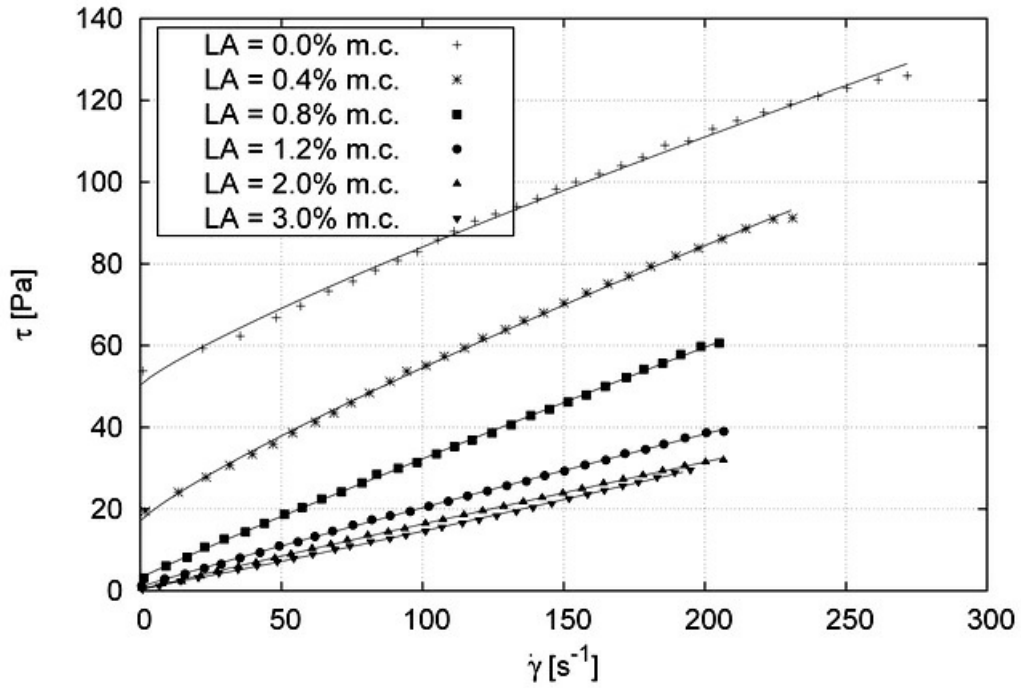


Fig. 2. Actual curves of flow of cement CEM I 42.5 R of water to cement ratio W/C = 0.35 with a polycarboxylate-based liquefying admixture

Actual curves of flow were approximated with use of the tri-parametric, generalised Herschel-Bulkley rheological model (1).

$$\begin{aligned} \tau &= \tau_0 + k \dot{\gamma}^n \text{ for } \tau > \tau_0 \\ \dot{\gamma} &= 0 \text{ for } \tau \leq \tau_0 \end{aligned} \quad (1)$$

Model (1) transforms to the two-parameter Bingham model (2), in case of simplification of cement paste structure

$$\begin{aligned} \tau &= \tau_0 + \eta_{pl} \dot{\gamma} \text{ for } \tau > \tau_0 \\ \dot{\gamma} &= 0 \text{ for } \tau \leq \tau_0 \end{aligned} \quad (2)$$

and to the one-parameter Newton model (3), in case of absence of yield stress

$$\tau = \eta \dot{\gamma} \quad (3)$$

where:

k – consistency [Pa·sⁿ],

n – power law (flow behaviour) index [–],

$\dot{\gamma}$ – shear rate [s⁻¹],

η – viscosity [Pa·s],

η_{pl} – plastic viscosity [Pa·s],

τ – shear stress [Pa],

τ_0 – yield stress [Pa].

The obtained values of rheological parameters τ_0 , k and n , as a function of the water to cement ratio W/C and the amount of liquefying admixture LA are presented in Table 2 and in a graphic form, on Figures 3–5.

Table 2. List of the rheological parameters of the Herschel-Bulkley model for cement pastes made from cement CEM I 42.5 R with a liquefying admixture

LA [% m.c.]	τ_0 [Pa]	k [Pa·s ⁿ]	n [–]	Rheological model
W/C = 0.55				
0	5.89	0.2038	0.7758	H-B
0.4	1.31	0.0793	0.9373	H-B
0.8	0.42	0.0243	1.0947	B
1.2	0.14	0.0287	1	B
2	0.009	0.0248	1	N
3	0	0.0212	1	N
W/C = 0.50				
0	9.3	0.3907	0.7413	H-B
0.4	1.83	0.1834	0.8515	H-B
0.8	0.49	0.0758	0.9396	H-B
1.2	0.2	0.0435	0.9862	B
2	0.31	0.0254	1.0917	B
3	0.19	0.0147	1.1819	B
W/C = 0.45				
0	13.66	0.4681	0.7586	H-B
0.4	4.06	0.2	0.9114	H-B
0.8	1.32	0.1408	0.9377	H-B
1.2	0.87	0.0716	1.0149	B
2	0.45	0.0051	1.0303	B
3	0.23	0.0484	1.0826	B
W/C = 0.40				
0	26.63	0.7695	0.7644	H-B
0.4	11.42	0.4777	0.882	H-B
0.8	3.46	0.2193	0.9891	H-B
1.2	2.24	0.247	0.9471	H-B
2	1.4	0.1238	0.9978	B
3	0.78	0.0918	1.0441	B
W/C = 0.35				
0	50.23	0.6942	0.8441	H-B
0.4	16.99	0.7673	0.8449	H-B
0.8	3.16	0.3603	0.9539	H-B
1.2	0.91	0.2477	0.9472	H-B
2	0.15	0.1993	0.9547	H-B
3	0.68	0.0926	1.0885	B
H-B – Herschel-Bulkley model				
B – Bingham model				
N – Newton model				

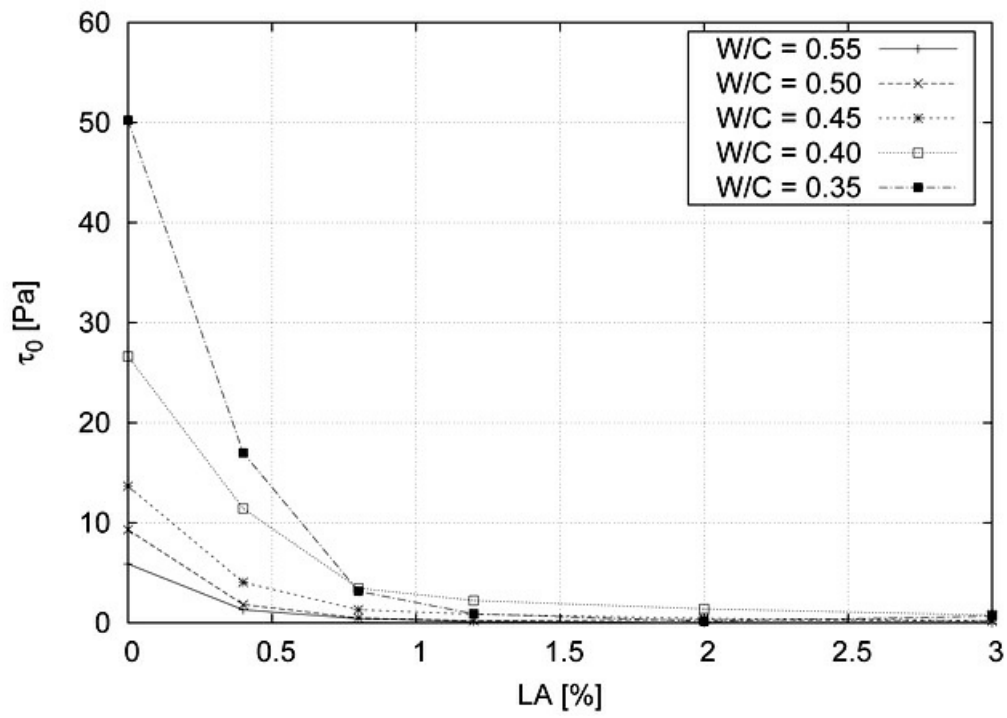


Fig. 3. Dependence between yield stress and the water to cement ratio W/C and the amount of liquefying admixture

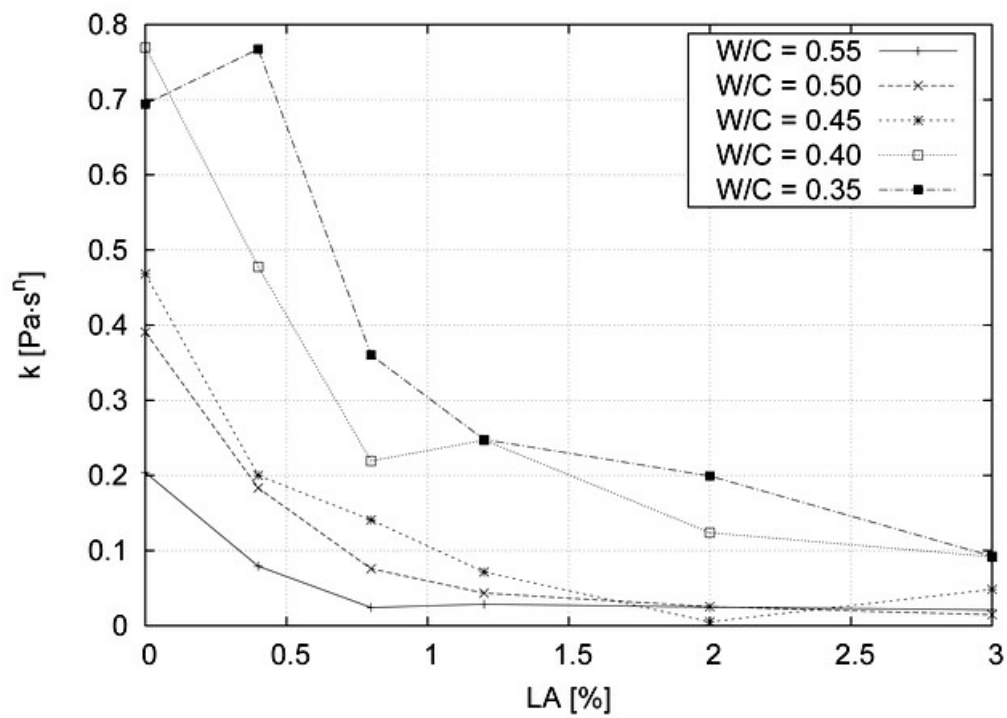


Fig. 4. The dependence between the consistency index and the water to cement ratio W/C and the amount of liquefying admixture

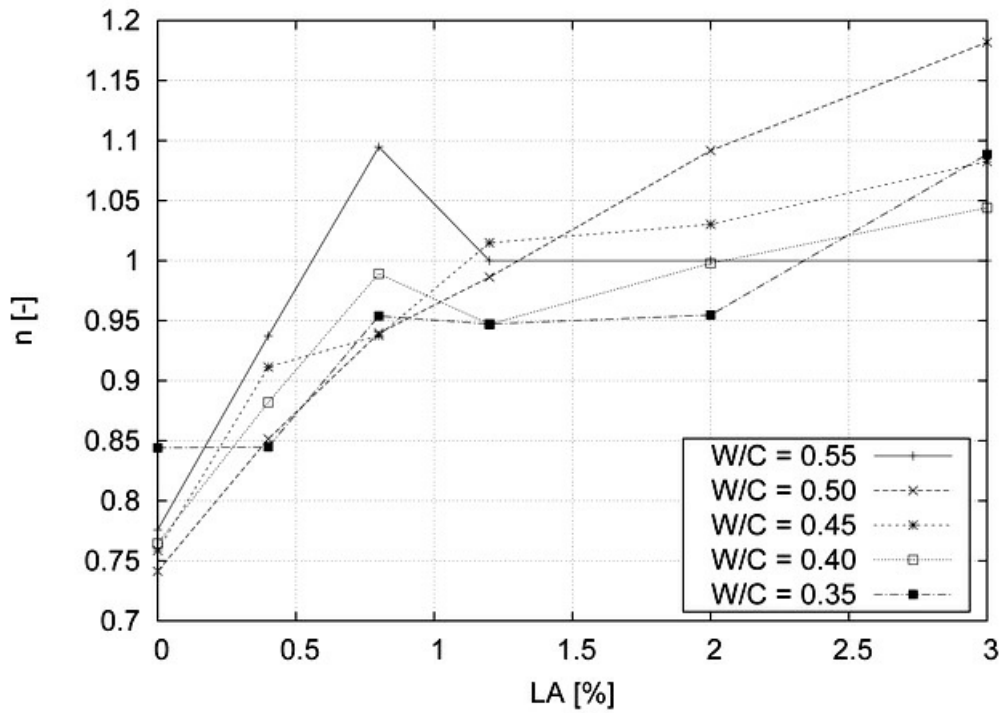


Fig. 5. The dependence between the flow behaviour index and the water to cement ratio W/C and the amount of liquefying admixture

Table 3 presents results of tests of absolute and relative flexural strength f_{ct} and compressive strength f_c of standard mortars, depending on the amount of applied liquefying admixture LA, with values of statistical parameters, such as standard deviation ($s_{f_{ct}}$, s_{f_c}) and coefficient of variation ($V_{f_{ct}}$, V_{f_c}). In Table 3 are presented also values of consistence of fresh mortar (D) achieved by the flow table method. Generally, an increasing tendency has been observed for flexural strength, compressive strength and for consistence. This is clearly visible on Figure 6 presenting the relative changes in standard mortar strength and consistence depending on the amount of the liquefying admixture. The increase in strength (for LA = 3%) amounts to 49% for compressive strength and 15% for flexural strength, in relation to standard mortar without the addition of liquefier.

Table 3. Absolute and relative changes in flexural strength f_{ct} , compressive strength f_c and consistence by flow table D of standard mortars, depending on the amount of applied liquefying admixture LA.

LA [%]	f_{fc} [MPa]	$s_{f_{ct}}$ [MPa]	$V_{f_{ct}}$ [%]	f_c [MPa]	s_{f_c} [MPa]	V_{f_c} [%]	$f_{ct,LA}/f_{ct,0}$	$f_{c,LA}/f_{c,0}$	D[mm]	D_{LA}/D_0
0	4.12	0.136	3.31	31.9	1.92	6.05	1	1	123	1
0.4	4.4	0.156	3.55	37.8	1.94	5.27	1.07	1.18	160	1.30
1.2	4.1	0.232	5.66	44.9	0.72	1.61	1	1.41	210	1.71
3	4.72	0.206	4.36	47.5	1.35	2.85	1.15	1.49	230	1.87

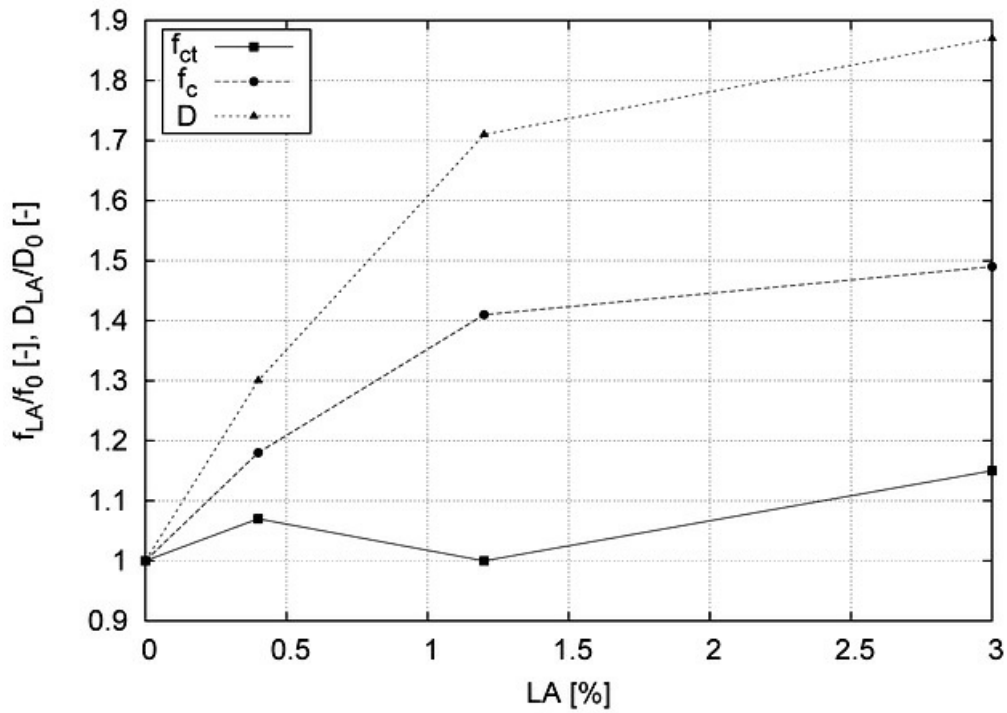


Fig. 6. Relative changes in standard mortar strength and consistence depending on the amount of the liquefying admixture

DISCUSSION

The analysis of standard parameters of cement pastes modified by the addition of liquefier has shown an increasing tendency in compressive and flexural strength. This is a desirable result in the context of practical applications.

Rheological studies confirmed that the analysed cement pastes without added liquefier behave like a viscoplastic mixture with a clearly visible yield stress τ_0 and changeable plastic viscosity η_{pl} . This requires the application of a tri-parametric, general rheological model, e.g. the Herschel-Bulkley model [11].

Analysis of the course of curves of flow $\tau(\dot{\gamma})$ of cement pastes with addition of liquefier shows a noticeable simplification of the internal structure of cement pastes, whose rheological behaviour changes initially into that of a viscoplastic mixture characterised by constant plastic viscosity η_{pl} ($n = 1$, $k = \eta_{pl}$, Bingham model) and then into a Newtonian mixture ($n = 1$, $\tau_0 = 0$, $k = \eta$, Newton model). This conclusion is confirmed by the values of rheological parameters presented in Table 2. Mixture of cement paste characterised by the lowest water to cement ratio W/C 0.35 may be simplified only to the Bingham model at the amount of admixture LA = 3%, while for W/C = 0.55 the transition into the Bingham model is observed as early as at LA = 0.8% and into the Newton model at LA = 2%.

Analysing the influence of liquefier agent on the rheological parameters of cement pastes (Fig. 3–5) it should be stated that the optimum dose of liquefier, resulting in the highest dynamics of changes in the rheological parameters τ_0 , k and n is the amount corresponding to 1.2% of cement weight.

As it has been already mentioned, the addition of liquefier leads to the simplification of the internal structure of cement pastes, which in turn causes a decrease in pressure loss when flowing through the gap in the rotational viscometer. This flow is analogous to laminar flow inside a pipeline. Actual curves of flow $\tau(\dot{\gamma})$ are characterised by a course similar to the graphs of pressure loss in a pipeline $I(v)$, within the scope of laminar flow. Lowering the diagram of pressure loss results in a simultaneous lowering of the operating point of the hydraulic system for cement paste injection and thus the operation of the pump and pipeline system is established at decreased operational pressure. It has been proved that this can be achieved by means of adding liquefier in the effective dose amounting to 1.2 of cement weight to the injection cement paste.

CONCLUSION

The analyses of modified cement pastes in the aspect of their applications in widely understood repair works conducted with use of pressure injection fully confirmed the possibility of such application.

Basic standard parameters based on the determination of flexural and compressive strength parameters are subject to a beneficial increase with the addition of liquefier, respectively, in the amount of 15–49%. This results from a decrease in porosity and higher compaction of the sample during the homogenisation of the mixture. These changes are beneficial from the point of view of practical applications.

On the other hand, rheological analyses confirmed the possibility to lower the operating pressure of the pump and pipeline

system of the injection installation and to perform the injection at the lowest possible required operational pressure.

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