

# Influence of Curing Conditions on Long-Term Compressive Strength of Mortars with Accelerating Admixtures

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**Abstract.** One of disadvantages of accelerating admixtures usage is possibility of significant decline of long-term compressive strength of concrete in comparison to non-modified one. Described tests were intended to define scale of lowered long-term compressive strength of mortars caused by accelerating admixtures in different curing conditions. Portland cement and blended cement with ground granulated blast furnace slag (GGBFS) addition and four types of non-chloride accelerating agents were used. Compressive strength was tested after 7 up to 360 days. Curing conditions were designed to simulate probable conditions close to reality. Such conditions are simulation of internal concrete elements, external elements cast on start of summer and external elements cast on start of winter. Results had shown that it is invalid to state that every accelerating admixture will cause drop of long-term compressive strength in every conditions and for every cement type. Change of curing conditions even after a long time (in this case half of the year) leads to significant differences in compression strength.

## 1. Introduction

Shortening of setting and hardening time of concrete is beneficial due to many reasons. Construction elements may be demoulded earlier what leads to faster building process and cost reduction of formworks rent.

First way to achieve this effect is usage of Portland cement which is known to show the fastest rate of gaining early strength of all commonly used cements [1, 2]. Although Portland cement does not fit sustainable technology. Manufacturers more often use blended cements with ground granulated blast furnace slag, fly ash or other mineral additives [3].

Accelerating admixtures are agents that are intended to enhance strength gaining rate. Action of some types of them provides also lowering freezing point of pore water and protect fresh concrete against splitting [4 – 6]. Usage of set and hardening accelerating admixtures have also disadvantages. One of them is possibility of significant lowering long-term compressive strength of concrete in comparison to non-modified one [7]. Requirements are given in standard EN-934-2 [8]. It states compressive strength after 28 days to be at least 80% of compressive strength of reference concrete and at least 28<sup>th</sup> day compressive strength after 90 days. Compressive strength of concrete modified with hardening accelerating admixtures is demanded to be not less than 120% of compressive strength of reference concrete after 24 hours in 20°C and at least 90% of one after 28 days. Another drawbacks of accelerating agents usage is higher reinforcing steel and concrete corrosion risk [4, 9]. Danger of corrosion may be lowered by blended cement usage.



Next possibility is reduction of water-cement ratio. Compressive strength is in inverse proportion to water quantity. Slag addition may help in preserving of consistency [1, 10]. Although plasticizers may be needed and they can cause delay of initial setting time by its secondary ingredients but summary hydration heat in first 41 hours is enlarged by usage of such admixtures [6, 11].

## 2. Experimental

### 2.1 Range and target

Experiments were intended to define scale of lowered long-term compressive strength of mortars caused by accelerating admixtures in different curing conditions. Portland cement and blended cement with ground granulated blast furnace slag (GGBFS) addition were used. Compressive strength tests were conducted after 7, 28, 90, 180 and 360 days.

### 2.2 Materials

Portland cement CEM I 52.5R from one of the Polish cement plants and blended cement with regulated GGBFS content (S) were used. Amount of GGBFS in mortars were 6%, 20% and 35%. This is the normative range of CEM II/A-S and CEM II/B-S. Chemical composition and Blaine's specific surface of constituents are given in table 1.

Sand for mortars preparation was standard graded, accordingly to EN 196-1.

**Table 1.** Chemical composition and specific surface of CEM I and GGBFS.

Constituent	CEM I 52.5R	GGBFS
Ignition losses	1.95	-
Unsolved parts	0.42	-
SiO <sub>2</sub>	20.54	37.35
Al <sub>2</sub> O <sub>3</sub>	5.14	7.30
Fe <sub>2</sub> O <sub>3</sub>	2.63	1.22
CaO	64.12	43.90
MgO	1.36	5.73
SO <sub>3</sub>	2.69	0.62
Na <sub>2</sub> O	0.17	-
K <sub>2</sub> O	0.81	-
Cl	0.06	0.03
Blaine surface [cm <sup>2</sup> /g]	4230	3870

**Table 2.** Characteristics of admixtures.

Symbol	Characteristics	Dosage range [% c.m.]	Dry mass [%]
CF	Calcium format based hardening accelerating admixture	0.2 – 5.0	50
CSH	CSH crystal seeds based hardening accelerating admixture	2.0 – 4.0	20
CN	Calcium nitrate based hardening accelerating admixture	1.0 – 3.0	< 5
TEA	Trietanolamine based hardening accelerating admixture	1.0 – 2.0	< 5

Water-cement ratio was 0.5 for mortars without admixtures. Amount of water was reduced due to water content in admixtures in mortars modified with admixtures. 4 types of non-chloride accelerating admixtures were used. They were added in quantity of 50 and 100% of manufacturer recommended dosage. Characteristics of accelerators are given in table 2.

Exact composition of mortars is given in table 3.

**Table 3.** Mortars composition.

Cement	GGBFS content	Admixture type	Adm. quantity [% c.m.]	w/c ratio
	-	-	-	
	6, 20, 35%	-	-	
CEM I	-	CF, CSH, CN, TEA	50%	0.5
52.5R	-	CF, CSH, CN, TEA	100%	
	35%	CF, CSH, CN, TEA	50%	
	35%	CF, CSH, CN, TEA	100%	

### 2.3 Methods

Examinations were provided in accordance to standard EN 196-1:2006 Methods of testing cement, determination of strength.

Curing conditions were designed to simulate probable conditions close to reality. Curing conditions were divided into three groups:

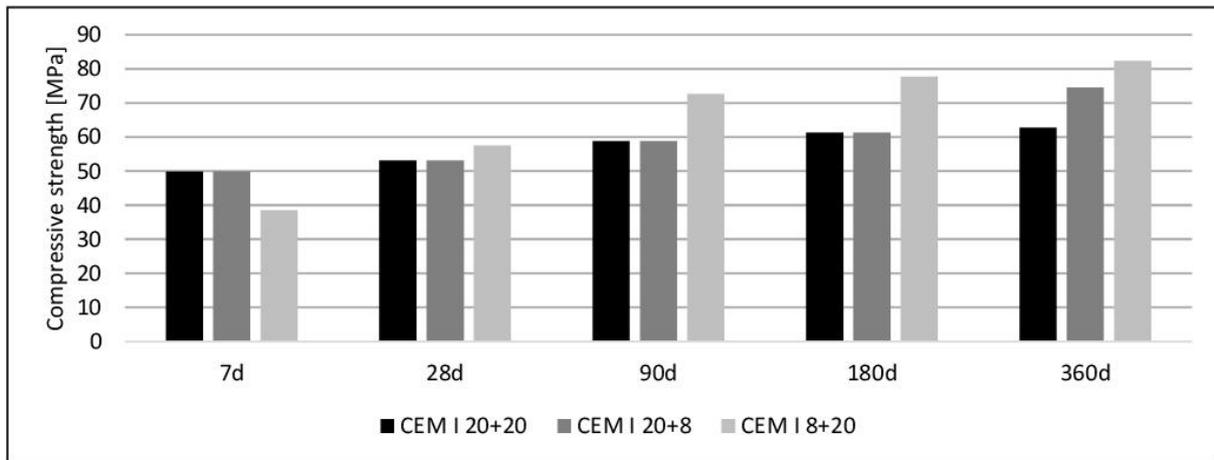
1. Components and surrounding temperature during samples forming was stable and equal to  $20 \pm 1^\circ\text{C}$ . Specimens were cured in stable conditions of climatic chamber. Air temperature was equal to  $20 \pm 1^\circ\text{C}$  and relative humidity was equal to 60%. Curing conditions were stable during whole year.
2. Components and surrounding temperature during samples forming was stable and equal to  $20 \pm 1^\circ\text{C}$ . For first half of the year specimens were cured in climatic chamber. Air temperature was equal to  $20 \pm 1^\circ\text{C}$  and relative humidity was equal to 60%. After half of the year specimens were moved to water bath with temperature of  $8^\circ\text{C}$ .
3. Components and surrounding temperature during samples forming was stable and equal to  $8 \pm 1^\circ\text{C}$ . For first half of the year specimens were cured in water bath at temperature of  $8 \pm 1^\circ\text{C}$ . After half of the year specimens were moved to climatic chamber. Air temperature was equal to  $20 \pm 1^\circ\text{C}$  and relative humidity was equal to 60%.

Such conditions are simulation of internal concrete elements (1), external elements cast on start of summer (2) and external elements cast on start of winter (3).

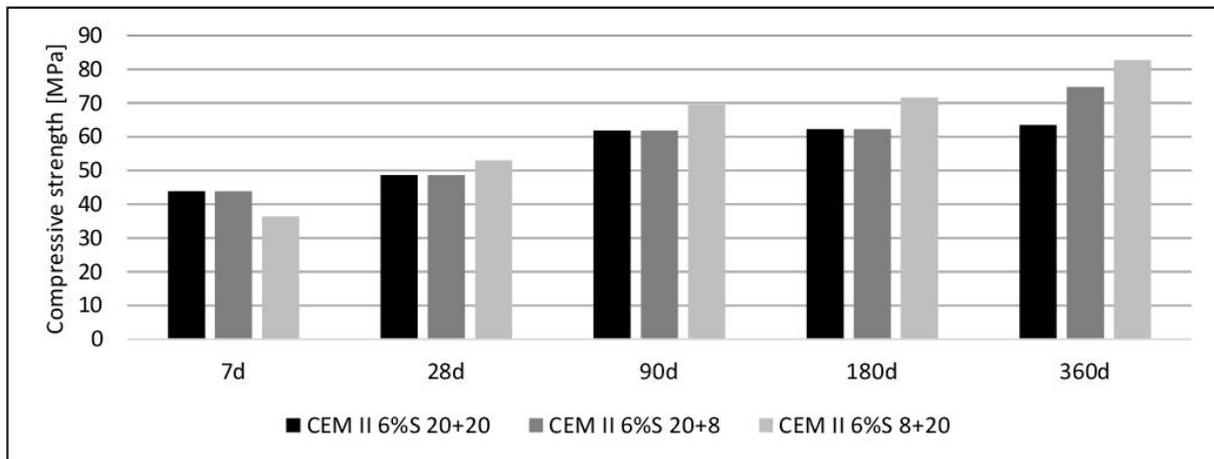
### 3. Results and discussion

At first, mortars made of Portland cement and blended cements with 6-35% of ground granulated blast furnace slag without admixtures were examined. More slag added to mortars results with compressive strength drop after 7 and 28 days. After 90<sup>th</sup> day mortars made of cements with 6 and 20% of GGBFS shown similar compressive strength to Portland cement. Those made of cement with 35% of slag achieved lower compressive strength. Results above are suitable for all curing conditions separately (figures 1-4).

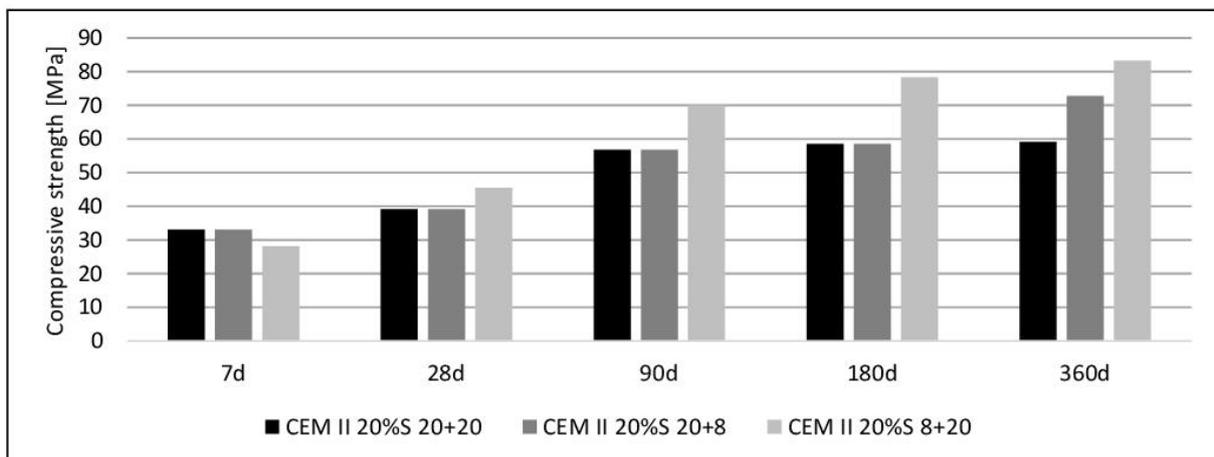
In case of mortars cured at first in  $20^\circ\text{C}$  at 60% RH and then at  $8^\circ\text{C}$  in water (conditions 2) the compressive strength after 360 days is significantly higher in comparison to those cured whole year in  $20^\circ\text{C}$  at 60% RH (conditions 1) (figures 1-4).



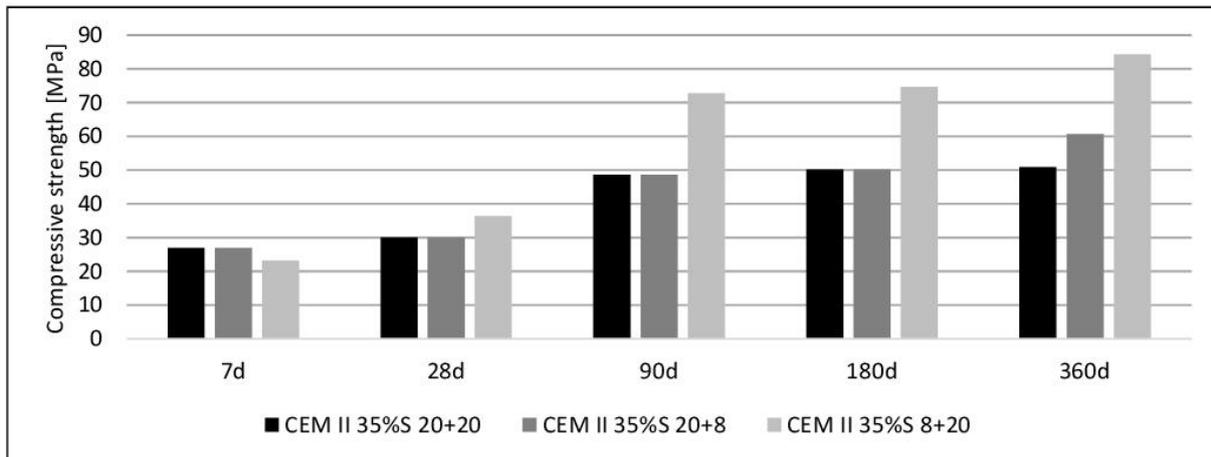
**Figure 1.** Compressive strength of CEM I non-modified mortars.



**Figure 2.** Compressive strength of CEM II (6% S) non-modified mortars.

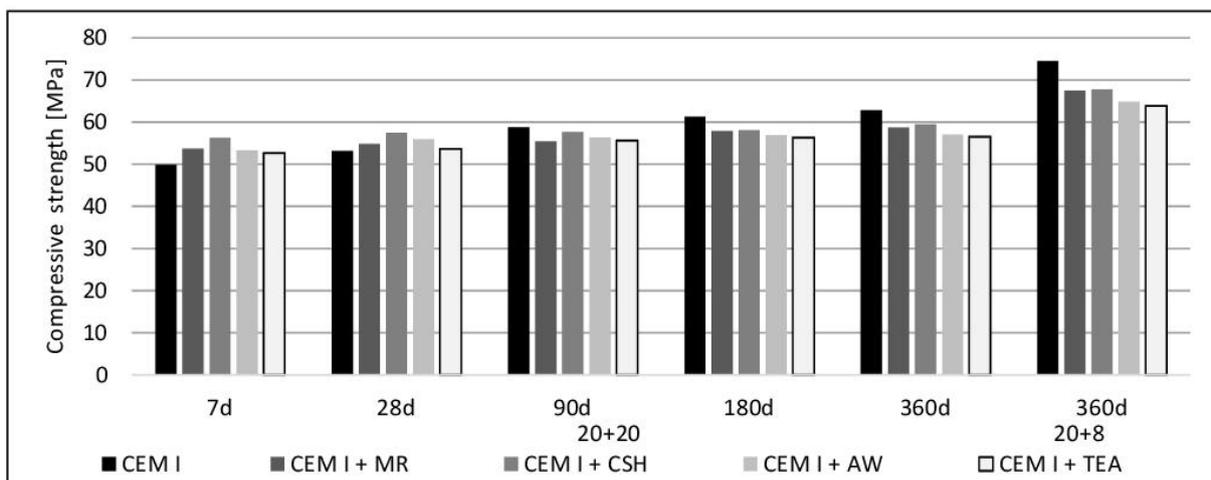


**Figure 3.** Compressive strength of CEM II (20% S) non-modified mortars.



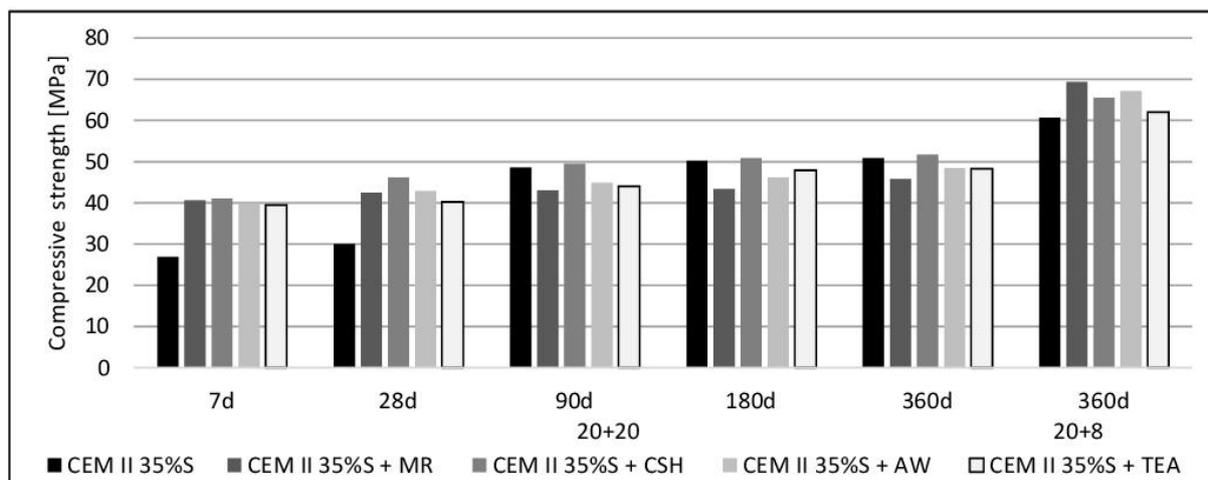
**Figure 4.** Compressive strength of CEM II (35% S) non-modified mortars.

For mortars cured at first at 8°C in water and then at 20°C at 60% RH (conditions 3) the compressive strength up to 7 days is lower than in conditions 1 and 2, after 28 days it is comparable and it rises getting significantly higher after 90<sup>th</sup> day. The greatest difference is visible in case of cement with 35% of slag (ca. 50%). For CEM I and cements with addition of 6 and 20% of slag the difference is about 25%. (figures 1-4). Compressive strength is also higher than for specimens cured in conditions 2 by ca. 30% for blended cement and 10% for Portland cement.



**Figure 5.** Compressive strength of CEM I mortars modified with accelerating admixture (conditions 1 and 2).

For both cements (CEM I and blended one) after 360 days of curing at 20°C (conditions 1) compressive strength of mortars modified with accelerating admixtures is similar or lower in comparison to non-modified ones (figure 5 and 6). In case of curing conditions 2 (180 days at 20°C and next 180 days at 8°C) 360 days compressive strength of CEM I modified mortars is also lower in comparison to reference one but for blended cement with 35% of GGBFS 360 days compressive strength is higher than reference one (figure 6).

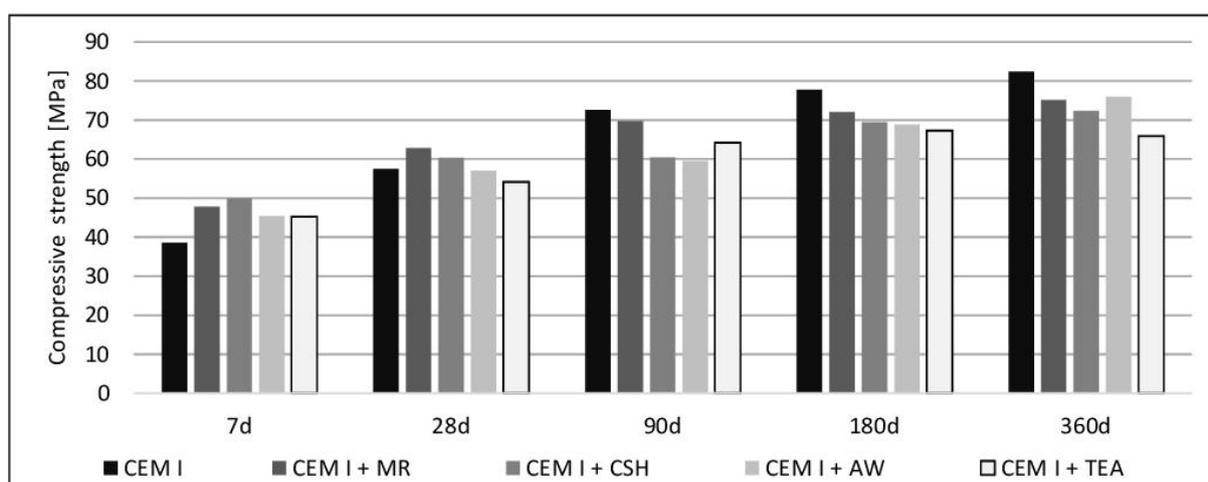


**Figure 6.** Compressive strength of CEM II (35%S) mortars modified with accelerating admixture (conditions 1 and 2).

Also for modified mortars cured at first at 8°C in water and then at 20°C at 60% RH (conditions 3) the compressive strength up to 7 days is lower than in conditions 1 and 2, after 28 days it is comparable but it rises getting significantly higher after 90<sup>th</sup> day.

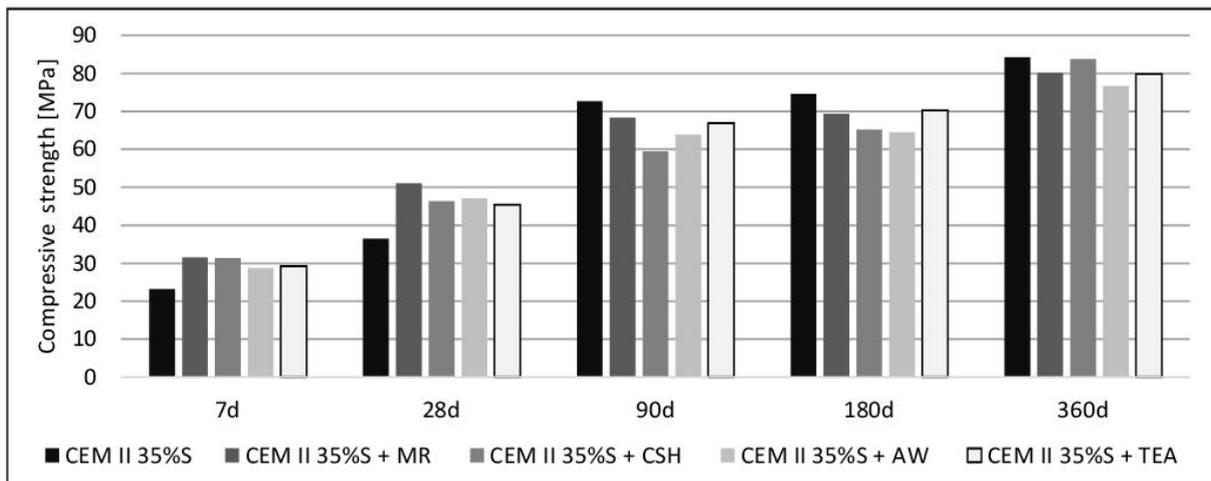
In case of Portland cement drop of long-term (>90 days) compressive strength caused by accelerating admixtures occurs in every case but it is not significant drop and depends on admixture type (figure 5). For blended cement with 35% of GGBFS such drop does not occur for admixture based on CSH crystal seeds (figure 6).

In conditions 2 (half of the year at 20°C at 60% RH and other half at 8°C in water) modified Portland cement mortars achieve higher compressive strengths than in stable conditions at 20°C although the drop in comparison to reference non-modified mortar is greater in conditions 2 (figure 5). Modified blended cement mortars achieve higher compressive strengths than in stable conditions at 20°C and also achieve improvement in comparison to reference non-modified mortar (figure 6). According to results above it is invalid to state that every accelerating admixture will cause drop of long-term compressive strength in every conditions and for every cement type.



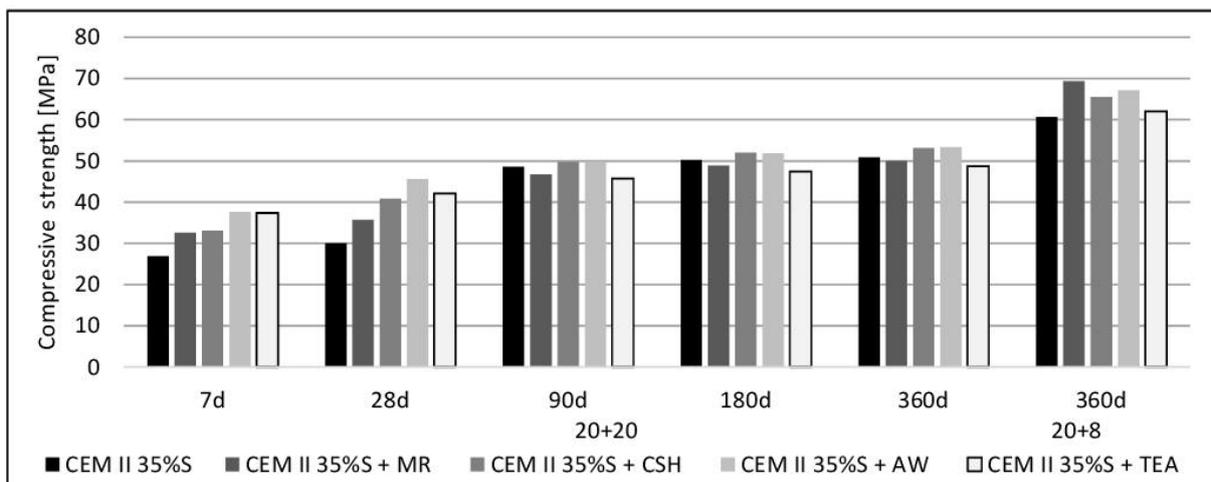
**Figure 7.** Compressive strength of CEM I mortars modified with accelerating admixture (conditions 3).

In conditions 3 (half of the year at 8°C in water and other half at 20°C at 60% RH) accelerating admixtures cause rise of compressive strength in comparison to non-modified mortar made of CEM I up to 7<sup>th</sup> day. After 28 days rise is noticed only for calcium formate and CSH crystal seeds based admixtures. In longer term all admixtures cause decline of compressive strength (figure 7). For blended cement with 35% of slag accelerators give greater compressive strength up to 28<sup>th</sup> day and decline after 90<sup>th</sup> (figure 8).

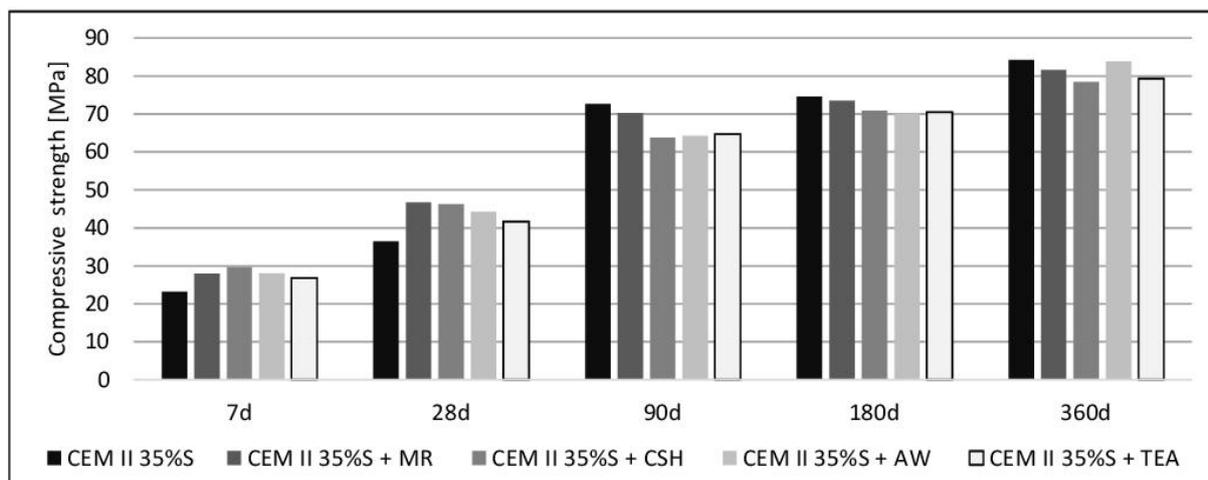


**Figure 8.** Compressive strength of CEM II (35%S) mortars modified with accelerating admixture (conditions 3).

Quite similar situation occurs for mortars modified with admixtures in half of maximal dosage given by manufacturer. It is shown on example of cement with addition of 35% of slag – for conditions 1 and 2 at figure 9 and for conditions 3 at figure 10. The only differences are visible in values but general statements are appropriate for both dosages of used hardening accelerating admixtures.



**Figure 9.** Compressive strength of CEM II (35%S) mortars modified with half of maximal dosage of accelerating admixture (conditions 1 and 2).



**Figure 10.** Compressive strength of CEM II (35%S) mortars modified with half of maximal dosage of accelerating admixture (conditions 3).

#### 4. Conclusions

Conducted examinations led to following conclusions:

- In case of CEM I 52.5R decline of long-term (>90 days) compressive strength caused by accelerating admixtures occurs in every case but it is not significant drop and depends on admixture type.
- In case of cement with slag addition the decrease of compressive strength does not occur after modification by accelerator based on CSH crystal seeds.
- According to results above it is invalid to state that every accelerating admixture will cause drop of long-term compressive strength in every conditions and for every cement type.
- Change of curing conditions even after a long time (in this case half of the year) leads to significant differences in compression strength.

#### References

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