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Original article

Analysis of the impact of high temperature on the change in tensile strength of cement mortars with or without polypropylene fibres added

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ABSTRACT

When evaluating concrete, its strength is the most important feature from the practical point of view. In compliance with technological requirements, the strength of concrete depends primarily on its composition, mainly on the content and strength of cement slurry. This is because this concrete component is most susceptible to changes in working conditions in a construction, including high temperature impact on concrete during the fire. The paper presents the results of tests performed on the cement mortar with and without the addition of polypropylene fibers. This treatment allowed for the elimination of the effect of the coarse aggregate by reason of the accuracy of the tested strength characteristics. The studies concerned the impact of high temperature on the change in tensile strength of cement mortars modified with the addition of polypropylene fibers. The analysis of available literature shows that one of the main causes of concrete's thermal spalling is seen in high tensile stresses. The results of many tests prove that the addition of polypropylene fibers can have a positive effect on the behavior of concrete structures at high temperatures and help reduce spalling. The polypropylene fibers present in a composite may also positively influence the increase in tensile strength. This article discusses the purpose and scope of research, research methods, the experiment plan, test benches, and test results as well. The conclusions of the study were formulated in the final part of the article.

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KEYWORDS

cement composites, cement mortars, tensile strength, mechanical properties, high temperature impact, thermal spalling, concrete, concrete reinforced with polypropylene fibers

Introduction

Currently, a number of products designed to increase the required fire resistance of building components are available on the construction market. Products of this type occur primarily in the form of mortars for fire-retardant plasters or fire protection boards used for enclosures of construction elements. There are also known other methods to improve the performance of concrete exposed to high temperatures. These are primarily: aeration of concrete, as well as the use of polypropylene fibers as an additive in concrete and fire retardant plasters [Abramowicz et al. 2012; Bednarek et al. 2012; Drzymala and Bednarek 2011; Gawin et al. 2006; Kosiorek 2005; Kus et al. 2014].

The high temperatures evoke destructive physicochemical processes in concrete, occurring in individual concrete components [Grabiec 1987; Kosiorek et al. 1988; Neville 2012]. These processes have a significant impact on the behavior and strength of concrete structures during a fire [Gawin et al. 2003]. The most important ones include [Piasta and Piasta 1997]: chemical decomposition reactions, phase transformations and volumetric changes. With the increase in temperature and its longer impact, the utility value of concrete decreases and in the case of accident an object may fail.

Cement slurry is the concrete component in which the majority of complex and unexplained physical and chemical processes occur. Heating the slurry to 300°C does not cause major changes to its sructure. However, a clear increase in the number of microcracks has already been observed at 400°C in the contact zone: slurry – non-hydrated clinker grains. Whereas, at the temperature of 500°C, apart from the microcracks, the internal destruction of large non-hydrated cement grains also appears in the contact zone. Phases occurring in the hardened cement slurry are characterized by very different heat deformations [Bednarek et al. 2009; Piasta and Piasta 1997]. Despite the high content of the coarse aggregate in relation to the slurry in 1 m^3 of concrete mix, the cement slurry decides on the expansion of concrete (depending on the moisture conditions).

For many years the Main School of Fire Service (SGSP) has conducted numerous research projects on the impact of high temperature on the change in strength parameters of normal-strength concrete (NSC) and high-strength concrete (HSC) as well as polypropylene fiber-reinforced concrete (PFRC) composites. Currently, SGSP has also carried out research on the optimization of the addition of polypropylene fibers to reinforced composites [*Optymalizacja ilosci*… 2014-2016].

The article deals with the effect of high temperature on changing the tensile strength of cement mortars. This treatment allowed for eliminating the influence of the coarse aggregate on the accuracy of the test characteristics. The polypropylene fibers present in a composite may also have a positive effect on the increase in tensile strength.

The list of major symbols and indications

f_{ti} – unit value of tensile strength [MPa],

f_{tm} – average value of tensile strength [MPa],

$f_{tm1.8F}$-f_{tm0F} – difference in strength between samples without and with the addition of polypropylene fibers [MPa],

$f_{tm, max}$ – maximum average of tensile strength [MPa],

$f_{tT}/f_{t20°C}$ – the relation of the tensile strength of heat-soaked samples at a given temperature to the tensile strength of non-heat-soaked samples [%],

$f_{tT}/f_{t20°C, Z0F}$ – the relation of the tensile strength of heat-soaked samples at a given temperature to the tensile strength of samples without the addition of non-heat-soaked fibers [%],

$f_{tT}/f_{t20°C, Z1.8F}$ – the relation of the tensile strength of heat-soaked samples at a given temperature to the tensile strength of the samples with non-heat-soaked fibers [%],

Z0F – the cement mortar specimen without added polypropylene fibers,

Z1.8F – cement mortar sample with added polypropylene fibers in the amount of 1.8 kg/m^3.

1. The impact of high temperature on concrete constructions

1.1. Thermal spalling of concrete

The basic mechanism of physical destruction of the concrete structure, when exposed to high temperature, is the process of the so-called thermal splintering (chipping) of its surface fragments. This phenomenon in foreign literature is referred to as *thermal spalling* (*abplatzung* in German) [Bednarek and Drzymala 2008]. There are currently two main theories about the mechanism of spalling [Bednarek and Drzymala 2010; Gawin et al. 2003; Phan and Carino 2001]. According to the first of them (recognized mainly by European researchers), the main reason for this is: high gas pressure resulting from evaporation of moisture in the near-surface layer of the structure acting together with the decrease in the concrete strength, which causes 'peeling' of subsequent layers of material that sometimes has an explosive character. The second theory (developed mainly by American scientists), the primary cause of spalling, is seen in high tensile stresses that can exceed the tensile strength of concrete, reduced as a result of high temperatures. Consequently, the accumulated potential energy of the distortion can be freed, often in a violent way when it exceeds the value of the material's cracking.

Thermal spalling of concrete fragments can be caused by several phenomena occurring in heat-soaked concrete. The most important ones include:

Water vapor flow inside the structure of the concrete – under the influence of high temperatures the water contained within the structure of concrete begins to evaporate. Water vapor under high pressure moves inside the concrete's structure, causing tension stresses on its walls. After the local exceedance of the tensile strength of the concrete, its fragments begin spalling [Gawin et al. 2006; Kosiorek 2005].

High water pressure in the zone of the so-called 'moisture clog' – a phenomenon that results from the thermodiffusion of moisture to cooler areas of the heated element behind the zone of rapid water evaporation at its surface. As a result, the pores of the concrete are saturated with high-pressure water, which can cause ripping of the concrete [Gawin et al. 2006].

Thermal stresses inside the concrete – caused by a sudden change in the concrete's volume, uneven thermal expansion of its components, the lack of freedom for distortion and uneven temperature distribution in the cross section. As a result of these factors, self-induced stresses are generated, which contributes to scratches causing spalling [Gawin et al. 2006; Kosiorek 2005].

The presence of minerals in aggregates – high temperatures leads to a series of physicochemical processes that contribute to loosening the concrete's structure.

These abovementioned factors are heavily dependent on the amount of water contained in the concrete. Research shows that the limit of moisture content in the concrete is 2-3%, below which 'spalling' does not pose a threat to its structure. It also appears that there is no explosive spalling in completely dry elements. The speed of heat-soaking the concrete also affects the spalling. The danger of the phenomenon occurrence increases as the heating speed grows. Therefore, the thin-walled components in which the temperature rises very quickly are most prone to thermal spalling. Another factor directly affecting the intensity of the concrete's spalling is the type of aggregate used. When heat-soaked, the quartzite aggregate rapidly increases its volume. Aggregate crystals are characterized by uneven enlargement along geometric axes. When the temperature exceeds 500°C, their volume changes periodically. All described factors lead to the formation of states of stresses in planes lying parallel to outer surfaces. The spalling phenomenon occurs when the water vapor pressure locally exceeds the tensile strength of the concrete. Most often, 'spalling' is the result of several phenomena occurring simultaneously, in particular the flow of water vapor and the formation of thermal stresses [Gawin et al. 2006; Kosiorek 2005].

The thermal spalling is most closely related to the concrete with the low water-cement index (w/c), the high compressive strength, and the compact cement matrix as in the case of the high-strength concrete HSC [Han et al. 2005]. The 'spalling' phenomenon poses a major threat to rescuers and lowers the strength of a construction by exposing very high temperature-sensitive reinforcing bars, which can result in the structure damage [Bednarek 2010; Gawin et al. 2006].

1.2. The effect of the addition of polypropylene fibers to the cement composite

The polypropylene that the fibers are made from belongs to thermoplastics, which means that it softens and melts at the elevated temperatures. When heat-soaked in the first phase, after exceeding the softening temperature it becomes softened and thermally distorted. Subsequently polypropylene undergoes thermal decomposition and pyrolysis, and its chemical composition changes. As the temperature rises a number of reactions occurs that produce flammable and non-flammable gases, liquids and solid particles. Due to the thermal decomposition of the fibers, a significant loss of their mass is observed. It has been observed in the studies that the loss of polypropylene mass during the thermal decomposition is much slower in the non-oxidizing atmosphere than with an oxidant involved. In effect, the thermal distortion of fibers inside the cement slurry structure will also be slower than in the oxidizer-rich atmosphere [Drzymala and Polka 2011]. In this case the essence of polypropylene fibers' impact is to improve the so-called percolation of the concrete's structure, i.e. structural connections. The percolation of the system depends primarily on the type of concrete. In normal concrete it is usually provided by the presence of strongly porous contact areas and the porosity of the cement matrix itself. In high-quality concretes, due to the presence of the small number of pores, percolation is significantly reduced. The full percolation of the concrete takes place at the porosity close to n = 20%. Polypropylene fibers added to the concrete, after melting at high temperature, leave the ducts connecting local, isolated pores. This phenomenon enables the percolation within the whole element. Moreover, the melted prolypropylene fibers directly affect the porosity as well as the specific permeability of the concrete. The presence of fibers in concrete has little effect on its thermal properties. The occurrence of those phenomena results in the decreased maximum values of water vapor pressure in heat-soaked concrete, which in turn reduces the occurrence of thermal spalling [Abramowicz et al. 2012; Bednarek and Drzymala 2012; Witek and Gawin 2005].

The mechanism of the effect of polypropylene (PP) fibers in the fibre concrete during fire assumes that at the elevated temperature (above 160°C) the PP fibers soften and then melt, leading to the reduction in the volume of individual fibers. The resulting cavities form ducts through which water vapor comes out under high pressure. As a result, internal stresses do not reach a critical point and no concrete spalling occurs [Kalifa et al. 2001; Kitchen 2004].

Numerous studies have shown that the addition of polypropylene fibers to concrete as structural ‘reinforcement’ can improve the resistance of concrete structures to high temperatures. The presence of polypropylene fibers in concrete limits the likelihood of ‘spalling’ at fire temperatures. This is also confirmed by the Channel Tunnel Rail Link research report and the UPTUN project results [Gawin et al. 2006; Kitchen 2004]. The addition of PP fibers also affects the strength properties of concrete both in normal and at high temperatures [Bednarek and Drzymala 2008; Bednarek and Drzymala 2008a; Bednarek et al. 2009; Bednarek and Drzymala 2012; Behnood and Ghandehari 2009; *Badanie wplywu*… 2008; *Wplyw temperatur*… 2008].

PP fibers are also used as an additive to the concrete mix so as to improve the resistance of the new concrete to the damaging effects of shrinkage stresses. The PP fibers used are very thin and have a high tensile strength, which has a decisive influence on reducing the scratch formation of the cement matrix in the first hours after the element is cemented. In the first hours of concrete hardening, these fibers transfer tensile stresses, and later in the cement hydration phase the cement matrix achieves the strength sufficient enough to avoid damage. This is confirmed by Brandt [Brandt 2000], who mentions PP fibers as a way to protect new concrete from the formation of shrinkage scratches. After the hydration, synthetic fibers induce the improvement of many other features of concrete such as [Jasiczak and Mikolajczyk 1997]: crack resistance to bending, significant improvement of impact strength and fatigue load resistance, resistance to corrosion and temperature changes, increased wear resistance, reduced water absorption and water permeability and reduction of the amount of secreted cement wash.

2. The research program and methods

2.1. The purpose and scope of research

The purpose of the research was to determine the impact of high temperature on the change in tensile strength of cement mortars with and without the addition of polypropylene fibers. The work was decided to investigate the effect of high temperature on the tensile strength of the cement mortar with polypropylene fibers added to eliminate the effect of the coarse aggregate on the strength parameters of the composite. The heterogeneity of the coarse aggregate and its sensitivity to the temperature rise could significantly impair the results obtained.

The scope of the tests carried out was to in particular show how the addition of polypropylene fibers to the cement mortar affects the change in the tensile strength. The study concerned tensile strength because the analysis of available literature proves that this strength parameter has a strong influence on limiting the 'spalling' phenomenon. Among other things, the addition of polypropylene fibers limits the possibility of its occurrence. Some studies emphasize that polypropylene fibers increase, to a certain extent, the tensile strength of concrete. The phenomenon of thermal spalling appears when the tensile stresses occurring within the concrete's structure are exceeded. The greater the tensile strength of the concrete, the less likely it is to be destroyed by thermal chipping. As a result, any increase in concrete tensile strength at elevated temperatures will also result in an increase in the rest of its mechanical properties. The research was conducted at the Main School of Fire Service and at the Warsaw University of Technology.

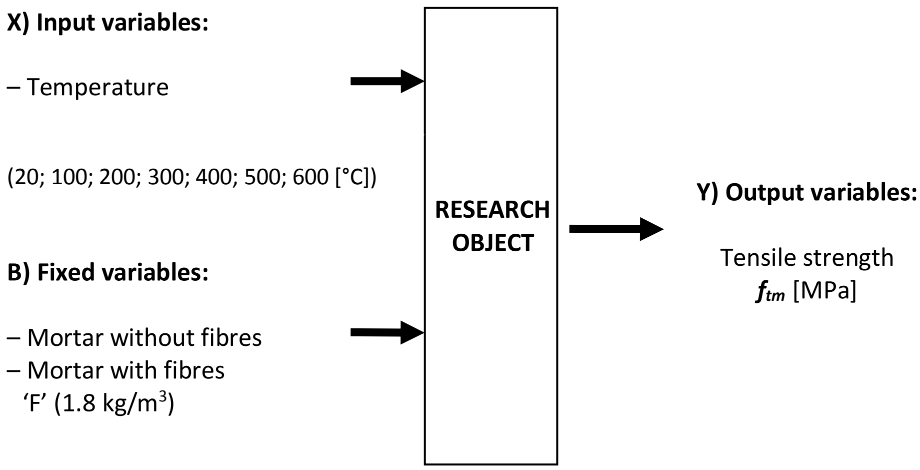

Fig. 1. The research program for determining the tensile strength f_{tp}
Source: [Own study].

The identification of the tensile strength f_{tm} (R_r) was performed on the mortar octal specimens in accordance with the norm PN-B-04500:1985: 'Building mortars – evaluation of physical and strength characteristics' [PN-B-04500:1985]. For testing purposes the 'F' (Fortatech® Fiber High Grade) polypropylene fibers were used as the addition. Comparative studies were carried out on octal specimens with no fibers added and with 1.8 kg/m^3 of fibers added. Test temperatures ranged from 20 to 600°C. Specimens were heat-soaked in the furnace at six test temperatures (100, 200, 300, 400, 500 and 600°C). During the tests, the temperature distribution over time was similar to thermal conditions of a standard fire. After heating in the furnace and cooling, the samples were subjected to tensile strength tests each time. At each measuring point seven samples were examined.

Figure 1 shows the test program for determining the tensile strength of mortar samples with and without the addition of polypropylene fibers [*Optymalizacja ilosci*… 2014-2016].

2.2. The characteristics of the cement mortar used

The CEM I 42.5 cement from the Małogoszcz cement plant was used to produce mortar samples. The cement used for the research purposes complied with the manufacturer's declaration of satisfying the requirements of the norm PN-EN 197-1:2002 ‘Cement. Part 1: Composition, specifications and conformity criteria for common cements’ [PN-EN 197-1:2002]. The w/c index for mortar samples was below 0.3. The laboratory tests were carried out based on the developed plan of the experiment. The summary of the components for the preparation of mortar samples needed to complete the approved experiment plan is given in Table 1 [*Optymalizacja ilosci*… 2014-2016].

Table 1. The summary of the components for the preparation of cement mortar samples needed for the completion of the approved experiment plan

Components	**Z0F (composition without fibres)**	**Z0F (composition without fibres)**
Cement CEM I 42,5 R, [kg/m^3]	846	846
Microsilica	84.6	84.6
Sand, [kg/m^3]	1249	1249
Optima Plasticizer 190, [% m.c.]	2	2
Water, [dm^3]	215	215
‘F’ fibres, [kg/m^3]	–	1.8

Source: [Optymalizacja ilosci… 2014-2016].

2.3. The characteristics of the fibers used

The ‘F’ polypropylene fiber, trade name Fortatech® Fiber High Grade, was used to produce mortar samples. As described by the manufacturer this is a fibrillated, of higher quality, beam fiber used as a structural reinforcement in concrete. The rough surface of the fibers enables that they are effectively anchored in concrete and fast and threedimensionally placed in the matrix while mixing the concrete mix components. 'F' fibers prevent plastic shrinkage and also increase the impact strength of concrete. Fibers further limit the sedimentation of the concrete mix components and increase the concrete's resistance to structures exposed to aggressive water. Figure 2 shows the fibers used to make mortar samples.

Fig. 2. The polypropylene fibers Fortatech® Fibre High Grade
Source: [Own study].

2.4. The preparation of test samples

The samples for the strength tests were made at the Warsaw University of Technology in the Laboratory of the Department of Building Materials Engineering. The mortar mix without the addition of polypropylene fibers was prepared in a laboratory mixer. First, a weighed portion of fine aggregate and cement were dry mixed together for two minutes. Then, after two minutes, the water was added and the mixture was stirred for another minute. Immediately after the mixing process, octal specimens were formed.

The mortar mix with polypropylene fibers was prepared in a similar manner. First, a weighed fine aggregate was mixed for two minutes, and then polypropylene fibers were gradually added. After that, the cement was added and the mixture was dry stirred for another two minutes. Next, water was added to the mixer, followed by a superplasticizer after approximately thirty seconds. In the end all the ingredients were stirred for another two minutes. Immediately after the mixing process, octal specimens were formed. All types of samples were finally formed by volume concentration on a vibrating table. After disforming, the samples were stored for 28 days in a climate chamber with the humidity of RH = 99% and the temperature of 20°C. The octal specimens prepared in this way were tested after the period of 6 months since their preparation. The octal specimens were formed in special, demountable steel molds (Fig. 3) meeting the requirements of the norms.

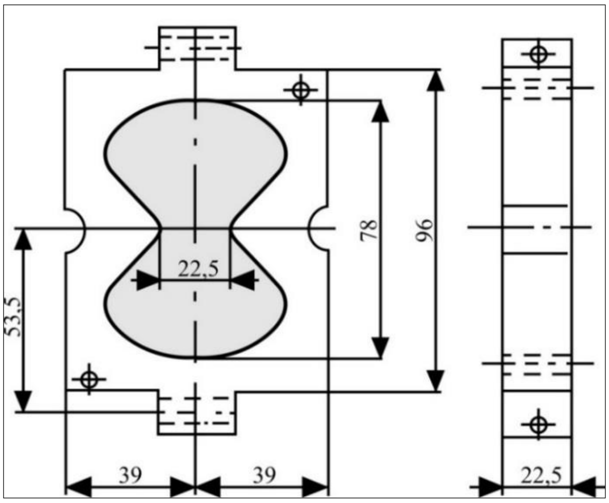

Fig. 3. The steel mold for the preparation of octal specimens for testing
Source: [Own study based on: PN-B-04500:1985]

2.5. The construction of research posts

2.5.1. The bench for heating the samples

The heat soaking of samples was conducted at the Laboratory of Applied Mechanics at the Main School of Fire Service. The heating was carried out on the test bench with the PK1100/5 medium temperature electric furnace. The measurement station also includes a PC with appropriate software to control the furnace operation and temperature recording during the heating of the samples. Figure 4 shows the sample heating station.

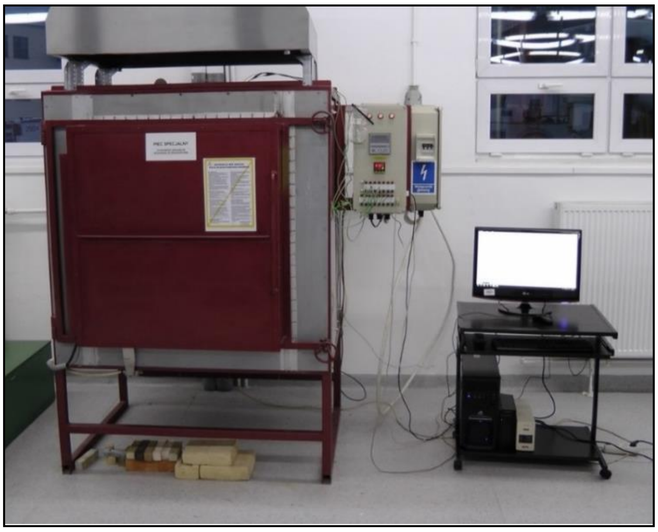

Fig. 4. The bench for heating the samples
Source: [Own study].

Four measuring thermocouples were used to indicate the temperature during the samples' heating process: the thermocouple (TR) measuring the temperature inside the furnace and three thermocouples measuring the temperature on the sample (T1, T2, T3). Two thermocouples (T1, T2) were attached to the sample wall, and one (T3) was placed in the drilled channel – the thermocouple end was halfway through the sample's thickness. Each time a batch of 15 samples was baked (7 samples without fibers added, 7 samples with fibers added, and an additional sample on which the temperature was measured using thermocouples T1, T2, T3).

Figure 5 shows the distribution of the batch of samples to be tested in the oven and the sample on which the temperature was measured. Each test sample was digitally coded according to the following scheme: (**Z1.8F** – samples with fibers and **Z0F** samples without fibers), e.g. '0F100/1' means the number '1' sample without fibers added, heat-soakeded at 100°C.

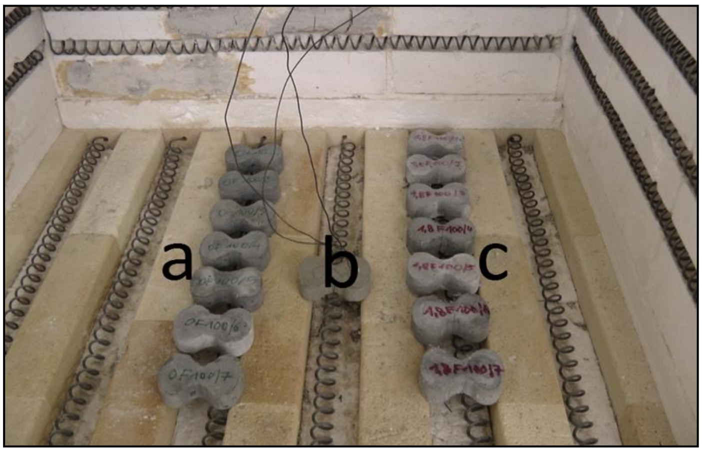

Fig. 5. The bench for heating the samples:
a – samples without fibres added; **b** – the sample for measuring the temperature distribution; **c** – samples with fibres added
Source: [Own study].

Each time after heating the furnace was switched off and cooled to a safe temperature (about 100°C), then it was opened and the samples were cooled for about 24 hours to a temperature of about 20°C. After cooling, the samples were subjected to the strength test, according to the established research procedure. Figure 6 depicts the exemplary curve showing the actual temperature distribution at the locations of the measuring thermocouples.

2.5.2. The bench for testing the tensile strength

The strength tests were carried out at the Department of Building Materials Engineering at the Warsaw University of Technology. Tensile strength was tested on the suitably fitted INSTRON 5567 testing machine with the measuring range of 0-30 kN. The machine was equipped with tensile strength testing equipment (arc-shaped chucks for mounting octal samples) and a PC with software for recording results. Figure 7 shows a photo of the tensile strength test bench.

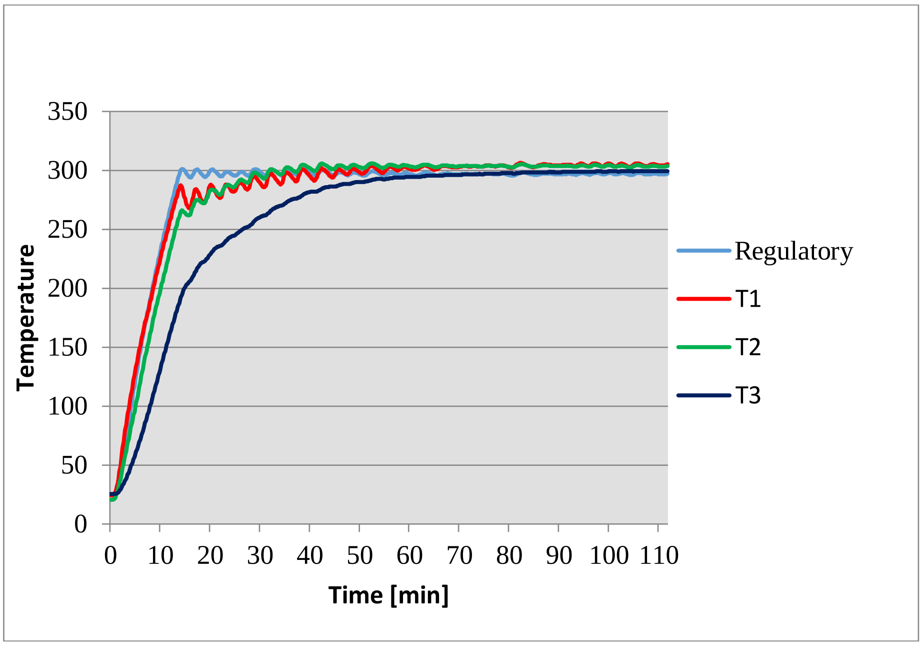

Fig. 6. The heat-soaking process – the temperature of 300°C
Source: [Own study].

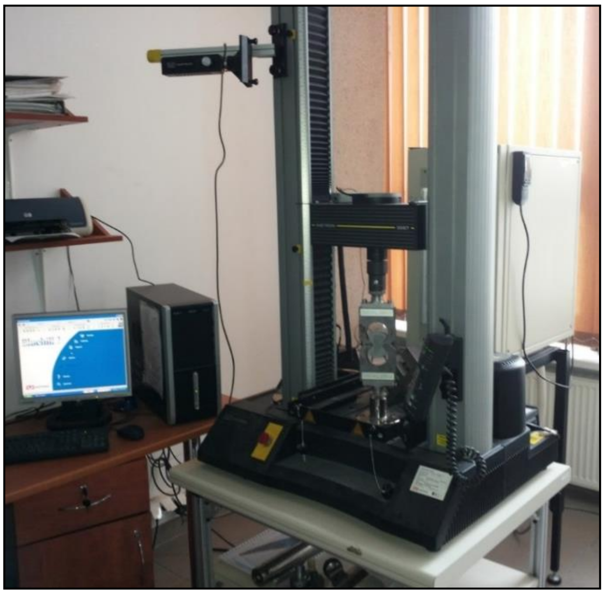

Fig. 7. The bench for testing the tensile strength
Source: [Own study].

3. Results of the studies conducted

Tables 2 and 3 present the comparison of the average tensile strength values f_{tm} of the mortar samples without and with the addition of polypropylene fibers, depending on the soaking heat [*Optymalizacja ilosci*… 2014-2016]. Table 2 contains the values of the strength decrease at a given temperature (expressed as a percentage) in relation to the strength of the non heat-soaked sample $f_{tT}/f_{t20°C}$. The tensile strength of the fiberless sample at 20°C was assumed to be 100% for the identification of the strength decrease of the samples both without and with the fibers added. Table 3 contains values of the strength decrease at a given temperature (expressed as a percentage) relative to the strength of the non heat-soaked sample $f_{tT}/f_{t20°C}$. In this case, the value of the tensile strength at the temperature of 20°C was assumed to be 100% separately for the samples without and with the addition of polypropylene fibers. The negative results listed in Tables 2 and 3 in the percentage change in the strength indicate its reduction.

Table 2. Average values of the tensile strength of the mortar with and without fibers added, depending on soaking heat together with percent changes in strength (non heat-soaked fibreless sample – 100%)

	Tensile strength f_{tm} [MPa]							
		20 [°C]	**100 [°C]**	**200 [°C]**	**300 [°C]**	**400 [°C]**	**500 [°C]**	**600 [°C]**
Without fibres (Z0F)	f_{tm} [MPa]	3.96	3.23	2.46	2.23	2.22	0.76	0.42
	$f_{tT}/f_{t20°C, Z0F}$ [%]	**100**	**81.42**	**61.96**	**56.23**	**55.98**	**19.08**	**10.65**
	Change in strength [%]	0	-18.58	-38.04	-43.77	-44.02	-80.92	-89.35
With fibres (Z1,8F)	f_{tm} [MPa]	4.62	4.00	3.75	2.43	2.36	1.36	0.52
	$f_{tT}/f_{t20°C, Z0F}$ [%]	**116.56**	**100.92**	**94.62**	**61.32**	**59.60**	**34.40**	**13.23**
	Change in strength [%]	16.56	0.92	-5.38	-38.68	-40.40	-65.60	-86.77

	Tensile strength f_{tm} [MPa]							
		20 [°C]	**100 [°C]**	**200 [°C]**	**300 [°C]**	**400 [°C]**	**500 [°C]**	**600 [°C]**
Without fibres (Z0F)	f_{tm} [MPa]	3.96	3.23	2.46	2.23	2.22	0.76	0.42
	$f_{tT}/f_{t20°C, Z0F}$ [%]	**100**	**81.42**	**61.96**	**56.23**	**55.98**	**19.08**	**10.65**
	Change in strength [%]	0	-18.58	-38.04	-43.77	-44.02	-80.92	-89.35
With fibres (Z1,8F)	f_{tm} [MPa]	4.62	4.00	3.75	2.43	2.36	1.36	0.52
	$f_{tT}/f_{t20°C, Z0F}$ [%]	**100**	**86.58**	**81.18**	**52.60**	**51.13**	**29.51**	**11.35**
	Change in strength [%]	0	-13.42	-18.82	-47.40	-48.87	-70.49	-88.65

Source: [Own study].

The results of the tests performed are presented in Figures from 8 to 10 [*Optymalizacja ilosci*… 2014-2016]. Figures 8 and 9 show the average tensile strengths of mortar samples without and with the addition of polypropylene fibers, depending on the annealing temperature. The difference in the average tensile strength is shown in Figure 10.

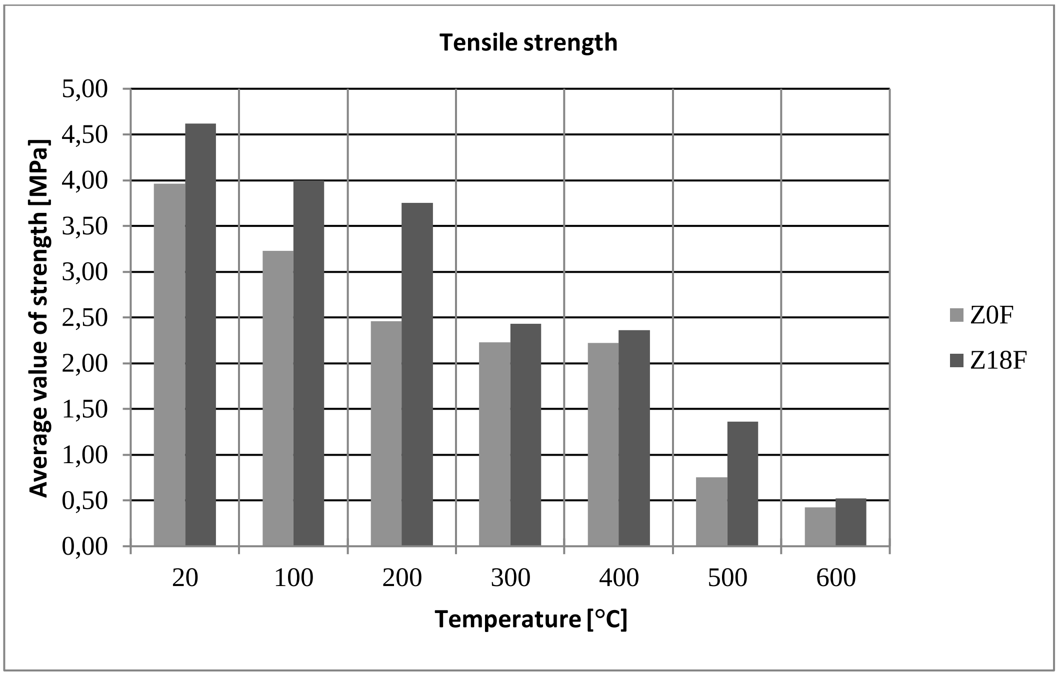

Fig. 8. The summary of average tensile strengths of concrete samples without and with the addition of polypropylene fibers at different temperatures
Source: [Own study].

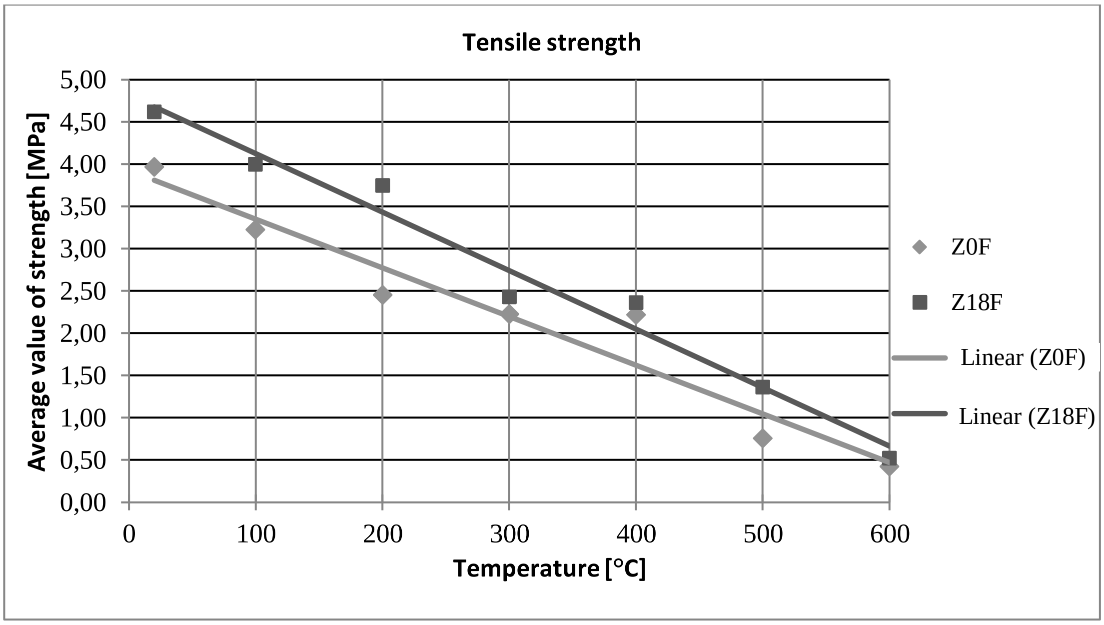

Fig. 9. The summary of average tensile strengths of mortar samples without and with the addition of polypropylene fibers at various temperatures (a graph with the trend line)
Source: [Own study].

Figures 8 and 9 illustrate the higher strength of PP fiber mortar samples over the entire range of soaking temperatures. The highest increase in strength was observed at 100°C and 200°C, a noticeable growth also occurred at 500°C. The results also prove that the addition of fibers to the samples elevated the strength of the non heat-soaked mortars.

It can be seen from the graphs that the tensile strength of the fiber-reinforced mortar samples at each temperature point is higher than that of the fiber-free samples. Table 4 shows the percentage difference in the strength between samples with and without fibers.

Table 4. Differences in strength between samples without and with the addition of polypropylene fibers

	Differences in tensile strength [%]							
		20 [°C]	**100 [°C]**	**200 [°C]**	**300 [°C]**	**400 [°C]**	**500 [°C]**	**600 [°C]**
$f_{tm18F} - f_{tm0F}$ [%]	f_{tm} [MPa]	16.56	19.50	32.66	5.09	3.62	15.32	2.58

Source: [Own study].

The difference in the mean tensile strength at a given temperature for the samples tested is shown graphically in Figure 10.

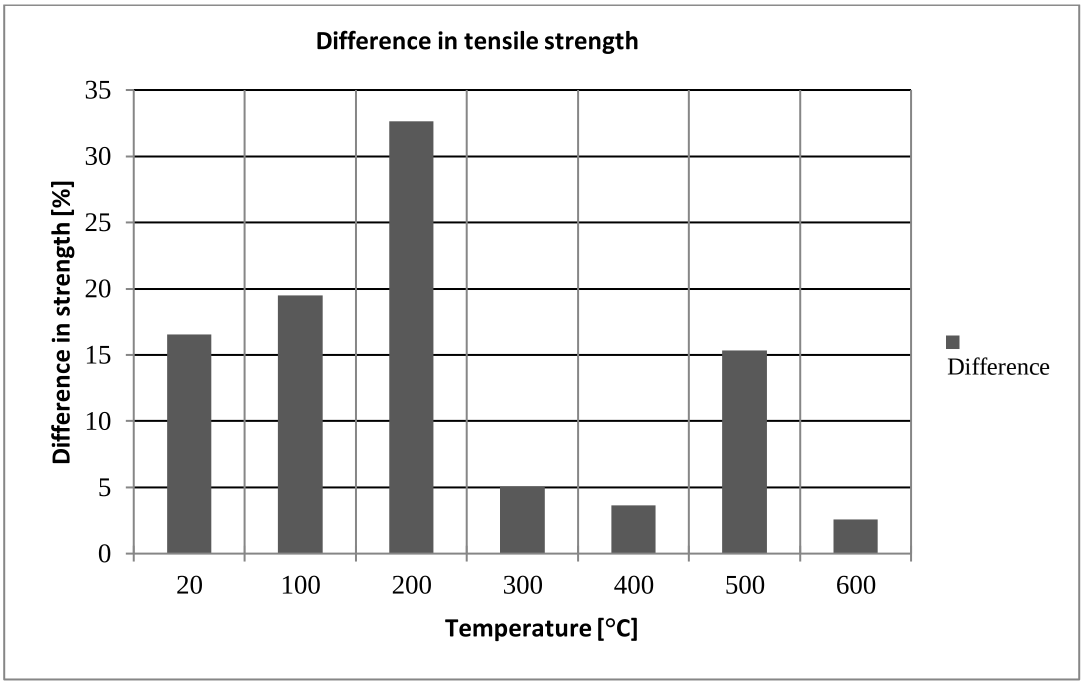

Fig. 10. Differences in strength between samples without and with the addition of polypropylene fibers
Source: [Own study].

The largest difference in tensile strength was 33% (200°C) and the lowest one less than 3% (600°C).

Conclusion

Based on the conducted tests concerning the tensile strength of cement mortars with and without added polypropylene fibers, the following conclusions were made:

1. The addition of polypropylene fibers to non heat-soaked mortar samples increased their tensile strength by approximately 16.5%.
2. Heating mortar samples without and with the addition of polypropylene fibers resulted in a marked decrease in their tensile strength as the temperature rose. The fall was observed at each soaking temperature but was not uniform.
3. The greatest drops in tensile strength of the samples without and with fibers added were observed at temperatures of 500 and 600°C. For samples without fibers the strength reduction was 81% at the temperature of 500°C and about 90% at the temperature of 600°C compared to the tensile strength of the non-heated samples. As regards fiber-reinforced samples, their strength decreased by more than 70% at the temperature of 500°C and by more than 88%, at the temperature of 600°C in relation to the tensile strength of the fiber-filled non-heated samples.
4. The addition of polypropylene fibers to the mortar samples increased their tensile strength after heating at any temperature.
5. The highest increase in tensile strength caused by the addition of polypropylene fibers was noted at the temperatures of 100, 200 and 500°C. The strength with respect to samples without added polypropylene fibers increased successively by 19.5% (100°C), 32.5% (200°C) and 15% (500°C).
6. In the source literature there is little information on the residual tensile strength of cement mortars containing different amounts of polypropylene fibers. There is therefore a need to continue research. In the general case, it can be shown that the addition of 1.8 kg/m^3 of PP fibers can apparently improve the residual mechanical properties of cement mortars with regard to tensile after heat-soaking at elevated temperatures. With this in mind, this treatment can contribute to the limitation of thermal spalling of concrete.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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References

Abramowicz, M., Drzymala, T. and Kowalski, R. (2012). *Praktyczne aspekty wplywu wysokiej temperatury na beton oraz fibrobeton z dodatkiem wlokien polipropylenowych*. Materialy konferencyjne "Dni Betonu", Wisla.

Badanie wplywu temperatur wystepujacych podczas pozaru na wytrzymalosc fibrobetonu. (2008). Research work BW/E-422/8/2008. Scientific director Drzymala, T. Warszawa: Szkola Glowna Sluzby Pozarniczej.

Bednarek, Z. and Drzymala, T. (2008). Wplyw temperatur wystepujących podczas pozaru na wytrzymalosc na sciskanie fibrobetonu. *Zeszyty Naukowe Szkoly Glownej Sluzby Pozarniczej*, no. 36, pp. 61-84.

Bednarek, Z. and Drzymala, T. (2008a). *Wytrzymalosc na sciskanie fibrobetonu z dodatkiem wlokien polipropylenowych w warunkach termicznych pozarow*. Międzynarodowa Konferencja "Bezpieczenstwo Pozarowe Budowli". Warszawa.

Bednarek, Z. and Drzymala, T. (2010). Zagrozenie wystepowania eksplozyjnego odpryskiwania betonu w czasie pozaru w tunelach komunikacyjnych. *Logistyka*, no. 6, pp. 1231-5478.

Bednarek, Z. and Drzymala, T. (2012). *Analiza wplywu wysokiej temperatury na zmiane wybranych parametrow wytrzymalosciowych fibrobetonu z dodatkiem wlokien polipropylenowych*. Materialy konferencyjne "Bezpieczenstwo Pozarowe Obiektow Budowalnych". Warszawa.

Bednarek, Z., Krzywoblocka-Laurow, R. and Drzymala, T. (2009). Effect of high temperature on the structure, phase composition and strength of concrete. *Zeszyty Naukowe Szkoly Glownej Sluzby Pozarniczej*, no. 38, pp. 5-27.

Behnood, A. and Ghandehari, M. (2009). Comparison of compressive and splitting tensile strength of high-strength concrete with and without polypropylene fibers heated to high temperatures. *Fire Safety Journal*, vol. 44, no. 8, pp. 1015-1022.

Brandt, A.M. (2000). *Zastosowanie wlokien jako uzbrojenia w elementach betonowych*. Konferencja "Beton na progu nowego Milenium". Krakow, pp. 433-444.

Drzymala, T. and Bednarek, Z. (2011). Wybrane kierunki zastosowan fibrobetonu z dodatkiem wlokien polipropylenowych poddanego oddzialywaniu wysokiej temperatury. *Logistyka*, no. 6, pp. 743-755.

Drzymala, T. and Polka, M. (2011). Analiza zachowania sie wlokien polipropylenowych stosowanych do fibrobetonu w temperaturach pozarowych. *Zeszyty Naukowe Szkoly Glownej Sluzby Pozarniczej*, no. 42, pp. 53-62.

Gawin D., Witek, A. and Pasavento, F. (2006). O ochronie betonowej obudowy tunelu przed zniszczeniem w warunkach pozarowych – wyniki projektu UPTUN. *Inzynieria i Budownictwo*, no. 11, pp. 622-625.

Gawin, D., Pasavento, F., Majorana, C.E. and Scherefler, B.A. (2003). Modelowanie procesu degradacji betonu w wysokich temperaturach. *Inzynieria i Budownictwo*, no. 4, pp. 218-221.

Grabiec, K. (1987). Wplyw temperatur pozarowych na bezpieczenstwo konstrukcji budowlanych. *Przegląd Budowlany*, no. 10.

Han, C., Hwang, Y., Yang, S. and Gowripalan, N. (2005). Performance of spalling resistance of high performance concrete with polypropylene fiber contents and lateral con-finement. *Cement Concrete Research*, no. 35, pp. 1747-1753.

Jasiczak, J. and Mikolajczyk, P. (1997). *Technologia betonu modyfikowanego domieszkami i dodatkami. Przeglad tendencji krajowych i zagranicznych*. Poznan: Wydawnictwo Politechniki Poznanskiej.

Kalifa, P., Chene, G. and Galle, C. (2001). High-temperature behavior of HPC with polypropyl-ene fibers from spalling to microstructure. *Cement Concrete Research*, no. 31, pp. 1487-1499.

Kitchen, A. (2004). Fibres for passive fire protection in tunnels. *Tunneling & Trenchless Construction*, no. 4.

Kosiorek, M. (2005). *Budownictwo ogolne – fizyka budowli*. Vol. II. Warszawa: Wydawnictwo Arkady.

Kosiorek, M.A., Pogorzelski, J.A., Laskowska, Z. and Pilich, K. (1988). *Odpornosc ogniowa konstrukcji budowlanych*. Warszawa: Wydawnictwo Arkady.

Kus, A., Tomaszewski, M., Jackiewicz-Rek, W. and Drzymala, T. (2014). *Wplyw oddzialywania wysokiej temperatury na wlasciwosci napowietrzonych betonow wysokowartosciowych*. Materialy konferencyjne “Dni Betonu”, Wisla, pp. 919-932.

Neville, A.M. (2012). *Wlasciwosci betonu*. Krakow: Stowarzyszenie Producentow Cementu.

Optymalizacja ilosci dodatku wlokien polipropylenowych do betonu w celu przeciwdzialania eksplozyjnemu odpryskiwaniu betonu w tunelach komunikacyjnych w trakcie pozarow. (2014-2016). Statutory research work S/E-422/18/14/15/16. Scientific director Drzymala, T. Warszawa: Szkola Glowna Sluzby Pozarniczej.

Phan, L.T. and Carino, N.J. (2001). *Mechanical properties of high-strength concrete at elevated temperatures*. NISTIR 6725. Maryland: National Institute of Standards and Technology, Gaithersburg.

Piasta, J. and Piasta, W.J. (1997). *Beton zwykly*. Warszawa: Wydawnictwo Arkady.

PN-B-04500:1985. (1985). *Zaprawy budowlane. Badania cech fizycznych i wytrzymalosciowych*. Warszawa: Polski Komitet Normalizacyjny.

PN-EN 197-1:2002. (2002). *Cement.* Czesc 1: *Sklad, wymagania i kryteria zgodnosci dotyczace cementow powszechnego uzytku*. Warszawa: Polski Komitet Normalizacyjny.

Witek, A. and Gawin, D. (2005). Wplyw wlokien polipropylenowych na degradacje betonu wysokosciowego i zjawiska cieplno-wilgotnosciowe w wysokich temperaturach. *Inzynieria i Budownictwo*, no. 2, pp. 92-94.

Wplyw temperatur wystepujacych podczas pozaru na wybrane parametry wytrzymalosciowe fibrobetonu. (2008). Statutory research work S/E-422/8/2007. Scientific director Bednarek, Z. Warszawa: Szkola Glowna Sluzby Pozarniczej.

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