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Influence of Steel Fibers Content on Selected Mechanical Properties - Experimental Tests

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The concrete, as material commonly used in construction, has been the subject of research for many years in order to improve the properties. One way to improve is to use the steel fibers. In the paper a comparative analysis of selected mechanical properties for concrete and fiber-reinforced concrete, e.g. compressive strength and Young's modulus, was presented. It was checked how the value of Young's modulus and the compressive strength of concrete change depending on the content of steel fibers. Three types of samples were prepared and tested: 1 - concrete, 2–fiber-reinforced concrete containing 0.25% of steel fibers, 3–fiber-reinforced concrete containing 0.50% of steel fibers. The conducted research was to show composition of which sample is the most advantageous and how many fibers should be used to obtain the mechanical properties, in this case compressive strength and Young's modulus, the best. The research covered the preparation of concrete samples, their curing and seasoning, measurements of Young's modulus and compressive strength with the use of a strength press, as well as the analysis and interpretation of the obtained results. As the analysis has shown, the greater number of steel fibers is not directly proportional to the increase in its compressive strength or the value of Young's modulus.

Keywords: concrete, fiber-reinforced concrete, compressive strength, Young's modulus

1 Introduction

The continuous development of construction due to the great needs of society and industry, the need to build newer and more durable buildings have meant that scientists all the time look for new opportunities to improve the quality of materials used in this field. Above all, concrete, as material commonly used in construction, has been the subject of research for many years in order to improve the properties. Already in antiquity there were the first attempts to modify the building material with fibers. Initially, they were organic fibers. However, the first patent dates from 1874, when A. Bernard patented the idea of strengthening concrete with steel filings [1]. Then, attempts were made to strengthen the concrete with long steel fibers, which was done by H. Alfsen in 1918.Further researches led N. Zitkiewic to test the strength and impact toughness of concrete with the use of pieces of mild steel wire [2]. Steel fibers in concrete were used for the first time by Romuladi and Baston in 1963.

The rapid development of technology in terms of digitization and automation of processes, the increasing development of the economy, the unemployment rate and the level of remuneration of the population, but also human mobility, environmental awareness, or demographic factors influence the need to build new production buildings, public utility buildings, residential buildings, etc. [3]. Anaman and Osei-Amponsah [4] claim that there are significant relationships between the growth rate of the construction industry and the rate of macroeconomic growth of developing countries. Other sectors of the economy depend heavily on the construction industry, for example the construction of production halls, office buildings, roads, infrastructure, water and power lines can increase the production of goods and services while being an important means of increasing employment. That is why this sector is so important.

In Poland, the construction industry is still an undeveloped part of the market. A lot is being built here, and the costs are relatively lower than a few years ago. Due to innovation in various technologies, it is possible to implement more and more demanding investments. At the same time, the requirements of customers who want to buy flats and houses characterized by a higher level of aesthetics and functionality have also increased. Understanding that the market belongs to them today, customers have more and more requirements and are increasingly looking for competitive solutions. They pay attention not only to construction costs, but also to the quality of the buildings and structures they buy, like in case of any other product [5-6].

Despite its productive form, construction industry is the most often treated as the service sector. Nevertheless, the scope of activities undertaken within this department makes it very close to the production industry and it is with it that it is often combined in various classifications. After all, a specific product is created during construction, in the form of a building or structure [7-9].

It should be remembered that due to construction, not only the necessary infrastructure, engineering facilities, buildings and structures used in all areas of life are created. Construction industry creates a new job, but it also contributes to accelerating the pace of economic growth, which closes development loops. The development of construction industry directly influences the growth of industrial production, including the metallurgical industry (production of reinforcing steel), furniture industry, chemical industry (e.g. production of carpets and floor coverings), cement industry, wood processing or production of construction machinery. Therefore, when the construction industry is in crisis, these sectors of the economy are also in a difficult position [10-12].

The construction industry, however, is facing many challenges, including the situation on the labor market (outflow of Polish qualified workers) and the rising prices of energy and building materials. So it affects the cost of construction and often sought savings.

The use of appropriate solutions in this area allows not only to speed up the construction process, but also improves the durability of the buildings under construction. The development of technology, as well as in the field of construction, means that also in this area new solutions are sought or the already existing ones are improved.

Work and research in order to improve the building system are ongoing. Most of them have led to the creation of modern materials that can even perform several functions at once. New technologies in construction are aimed at ensuring care for the natural environment and the economical use of raw materials by [13-14]:

- reduction of negative health effects caused by the use of unsuitable materials,
- reduction of pollutant emissions to the environment,
- refraining from using materials that have a negative impact on the environment and people's health,
- use of renewable energy sources,
- use of natural vegetation as a building envelope,
- limitation of the production of waste and pollution as well as protection against negative impact on the natural environment,
- increasing the productivity and protecting the health of workers and residents.

New technologies penetrate the construction industry, arouse the interest of producers of building materials and elements, developers and other participants of the entire investment process. However, these changes do not apply to new, innovative materials and design solutions. It is also about the entire technology of manufacturing and erecting buildings, modern management processes, the possibility of individualizing products depending on the customer's needs, wide use of ITC techniques, modern ordering and sales systems, interactive participation in the design process, etc.

When designing or implementing various construction projects, various undesirable situations may occur, which are caused by various reasons, e.g. natural phenomena, socio-political conditions, for technical reasons and due to the mistakes of inexperienced workers, etc. [15]. There may also be problems with the use of unsuitable building material.

The problem of the structural failures is inextricably linked with the construction industry. A structural failure can be defined as the unintentional, violent destruction of a building object or its part, as well as structural elements of scaffolding, forming elements, sheet piling and excavation linings. Structural failures always entail financial and environmental losses that cause a big problem for companies. The analysis of the structural failures allows to indicate the causes that led to them, but also to introduce actions to help avoid them or decrease their appearance in the future [16]. The solutions that will improve the quality of the building should be looked for. Modern construction materials with increased strength deserve special attention [17-18].

As already mentioned, one of the important areas of research in the field of improvement is the search for methods to strengthen concrete. One of the solutions is the use of different types of fibers (glass or steel) to improve the mechanical properties of the concrete. Fibers added to the concrete improve its strength and eliminate the formation of shrinkage cracks. Formerly it was a solution reserved for industry. Currently, reinforcing fibers are used more and more for the needs of individual construction such as housed or block of flats.

However, the first patent dates from 1874, when A. Bernard patented the idea of strengthening concrete with steel filings [1]. Then, attempts were made to strengthen the concrete with long steel fibers, which was done by H. Alfsen in 1918. Further researches led N. Zitkiewic to test the strength and impact toughness of concrete with the use of pieces of mild steel wire [2]. Steel fibers in concrete were used for the first time by Romuladi and Baston in 1963.

The concept of using fibers to improve the mechanical properties of concrete has been known for several decades. The most intensive research and development in this field began in the 1970s of the last century [19].

Concrete which, apart from the basic components (cement, aggregate, water), contains short reinforcing fibers evenly distributed throughout the entire volume of concrete, is called the fiber-reinforced concrete. The fiber concrete belongs to the group of special concretes, i.e. those that have a special purpose and are characterized by appropriate properties [20]. An important mechanism caused by the addition of fibers is the reduction of stress concentration - in particular tensile stresses. Fibers evenly dispersed in the concrete bridge its discontinuous structure, which results from microcracks or scratches in the matrix. In the case of unreinforced concrete, a high concentration of stresses is observed within the crack, which negatively affects the strength of this zone. The presence of the fibers allows the forces resulting from the loads to be transferred from one side of the crack to the other, which significantly reduces the stress concentration at the edge of the crack. This phenomenon makes it possible to limit the transformation of micro-scratches into larger cracks, which preserves the integrity of the fiber-reinforced concrete element after scratching. The fiber-reinforced concrete, unlike concrete, does not behave like a brittle material, but exhibits quasi-plastic properties. After scratching, the fiber-reinforced concrete elements are able to carry loads and deform [21]. Fibers in concrete subjected to external loads change the manner of concrete failure and improve its strength properties [22-23]. The concrete exhibits high explosive behavior due to water content in fire conditions. In case of a fire, there is an immediate change of water concentration which leads to high pressure and concrete splashes. Due to the use of polypropylene fibers, their melting point is significantly low, due to which, under the influence of temperature increase, the fibers melt and leave vacuum voids in which the pressure caused by water exits.

The aim of the laboratory research was to assess the influence of steel fibers on selected mechanical properties of concrete - compressive strength and modulus of elasticity (Young's modulus). Three types of samples were prepared and tested by the authors: 1 - concrete, 2 – fiber-reinforced concrete containing 0.25% of steel fibers, 3 – fiber-reinforced concrete containing 0.50% of steel fibers.

In this paper a third group of samples has been added - without steel fibers. So far, the authors have compared samples containing 0.25% and 0.50% steel fibers, without comparing their properties with ordinary concrete. They focused on the conditions of seasoning. The conducted research was to show composition of which sample is the most advantageous and how many fibers should be used to obtain the mechanical properties, in this case compressive strength and Young's modulus, the best. For the authors, the obtained results are the starting point for further research in order to check at which level of fiber content the selected mechanical properties are the most optimal, and when these parameters decrease. It would be worth checking values between 0.25% and 0.50%.

The fibers used in concrete can be of various materials, have a different shape and length. The amount of fibers contained is also of great importance for the properties of the material obtained. The research was limited to the use of steel fibers 60 mm long and 1 mm in diameter. The authors conducted research aimed at analyzing how the amount of steel fibers affects the mechanical properties of the fiber-reinforced concrete, in which proportions the effect is the best, the most optimal. The aim was to find out about the limitations and problems associated with too much fiber used. The research is developmental and involves many variants resulting from the physical properties of the fibers used. The aim of the next tests will be to compare the obtained results with fibers of a different length and shape.

2 Literature review

2.1 Concrete – characteristics, properties

Concrete is the most popular building material in construction. Its main ingredients are cement, aggregate and water. Over time, the composition of concrete has evolved and nowadays its composition is modified, e.g. replacing cement with other binders and using enriching additives. The composition of concrete may vary, as shown in Fig. 1.

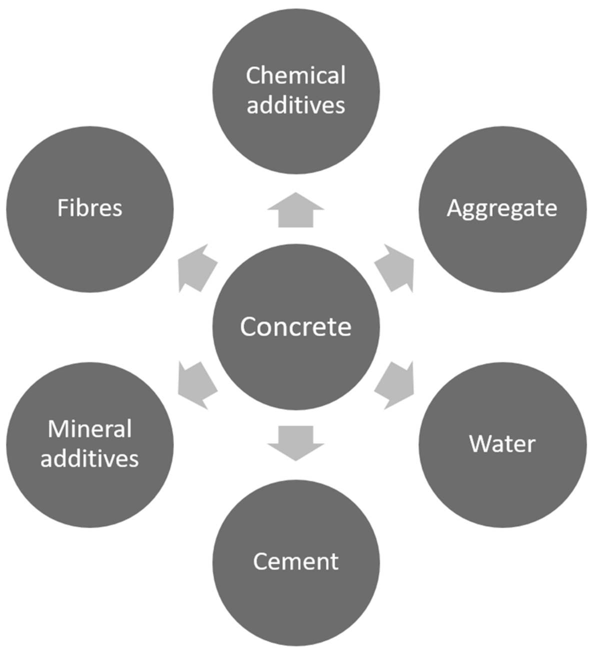

Fig. 1 *Concrete composition (own study based on 24)*

Standard PN-EN 206+A2:2021-08 [25] specifies the requirements for:

- concrete components;
- properties of concrete mix and hardened concrete and their verification;
- restrictions on the composition of concrete;
- concrete specification;
- deliveries of concrete mix;
- production control procedures;
- compliance criteria and conformity assessment.

Concrete properties are a group of all physical, mechanical, rheological and environmental properties. The properties of the concrete are important depending on its use. It is possible to distinguish four main groups of properties that are presented in Tab. 1.

Tab. 1 *Concrete properties and their groups [20, 26]*

Physical properties	**Mechanical properties**
– specific and volumetric density, – porosity, – water absorption, – water resistance, – frost resistance, – thermal conductivity, – shrinkage.	– compressive strength, – tensile strength, – shear strength, – torsional strength, – resistance to local pressure, – biaxial compressive strength, – triaxial compressive strength, – impact resistance (impact strength), – resistance to dynamic influences, – modulus of elasticity.
Rheological properties	**Resistance to the influence of the environment**
Deformability under the influence of permanently acting external stimuli, especially under the influence of: – force loads, – temperature changes, – changes in humidity.	– to high temperature, – to low temperature, – to chemical aggression.

Concrete is characterized by high compressive strength and a much lower tensile strength. The strength of concrete depends on many factors, primarily the grain size and quality of aggregate, the quantity and quality of cement and water, as well as the production technology, maturation conditions and age of the concrete. The brittleness of concrete causes scratches, cracks and other serious design defects. As a material that independently transfers tensile stresses, it is not a perfect material and research is still ongoing to improve the properties of concrete. Concrete parameters can be improved by applying fiber reinforcement evenly distributed in the concrete mix [27-29].

2.2 Fibers used in concrete – characteristics, properties

The purpose of using fibers in concrete is to improve its properties [30]. The most common additive found in the fiber-reinforced concrete are steel fibers [31], but due to the research carried out in this field, this group also includes fibers such as: glass, carbon, basalt and artificial materials. The requirements for steel fibers include different standards [32-33].

In the literature different authors give many reasons for the use of fibers in concrete. Among them, it is possible to distinguish [22, 34]:

- reduction of shrinkage cracks in the entire section thickness,
- elimination of surface plastic cracking by increasing concrete tensile strength,
- greater tightness,
- greater frost resistance and fire resistance (they prevent concrete spattering during a fire),
- greater mechanical strength of concrete, including crushing and abrasion, as well as corrosion and fatigue,
- better response to dynamic loads due to a greater degree of energy absorption,
- better workability,
- homogeneity and less segregation of ingredients at the production stage,
- in foundation, ceiling and base slabs, the fibers replace traditional steel anti-shrink mesh, they are much more effective than them, because they are dispersed throughout the

thickness of the cross-section, and not only concentrated in the subsurface zone,

- in some cases, after an accurate calculation, the use of fibers allows to reduce the thickness of the concrete cross-section.

Among the most commonly used fibers, steel, polypropylene and glass fibers can be distinguished.

a) b) c)

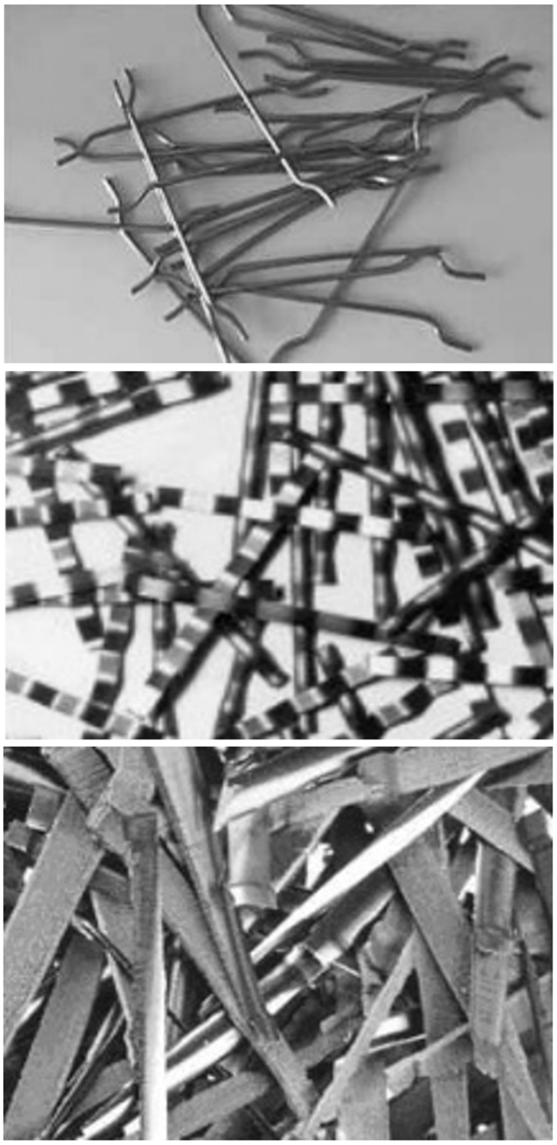

Fig. 2 *Tipes of fibres a) from wire, b) sheet metal, c) cut [35]*

Steel fibres can be produced from wire (fig. 2a), sheet metal (fig. 2b), steel block by cutting (fig. 2c). Steel fibers and sheet metal fibers can be wavy or hooked.

The main material for the production of steel fibers in the fiber-reinforced concrete is steel with high plasticity in the range from 500 to 2400MPa. This product is manufactured using various technologies, but the most popular is bent fragments of cold drawn wire. The appearance of steel fibers is significantly varied with different shapes, dimensions and diameters [36]. Straight fibers are an example of the shape of steel fibers, but the most common in practice are fibers with characteristic bends at the beginning and end. It is possible to find completely corrugated steel fibers or with formed thicker ends in order to obtain very high strength of the fiber-reinforced concrete and high efficiency of anchoring, which are made of steel with increased strength of 2300MPa. Years of experience have revealed four most efficient types of steel fibers (Fig. 3). This performance is related to the effectiveness in the concrete matrix and affects its price.

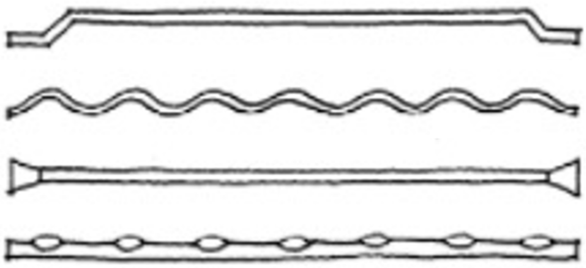

Fig. 3 *Examples of shapes of steel fibers (Hooked, Crimped, Coned, and Mechanically Deformed) [37]*

The wide use of the fiber-reinforced concrete with steel fibers meant that this material is used in: industrial floors, road and airport surfaces, elements exposed to dynamic loads (i.e. elements of bridges, hydrotechnical facilities, breakwaters, foundations for machines with impact action), elements of complex shape, tunnel linings.

Polypropylene fibers are produced as yarn staple fibers (Fig. 4a) or film chopped fibers (fibrillated) (Fig. 4b).

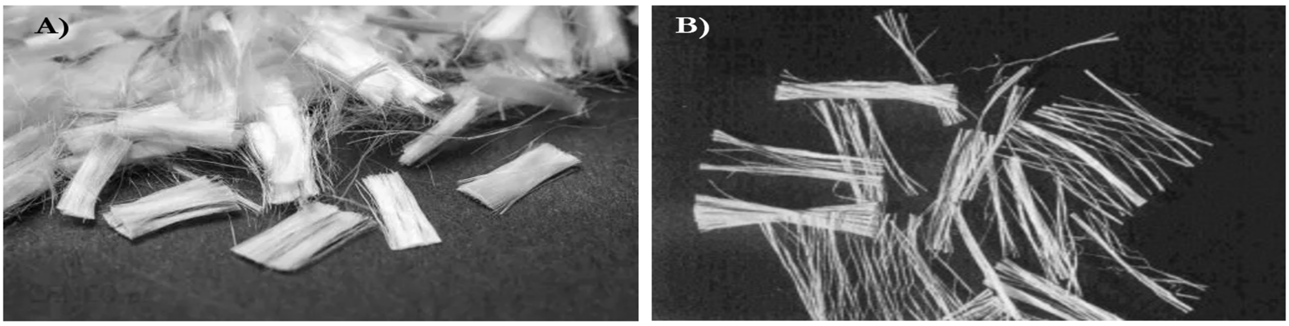

Fig. 4 *Polypropylene fibers a) yarn staple, b) fibrillated [35, 38]*

Due to their scratch resistance, the fiber-reinforced concrete with polypropylene fibers are used to make: thin-walled façade elements, pavements, pedestrian paths, "small architecture" elements, repair layers of reinforced concrete elements. Chemical resistance of polypropylene fibers determines their use as an additive in concrete structures such as: monolithic water tanks and elements of a sedimentation tank in a sewage treatment plant. The chemical resistance of polypropylene fibers determines their use as an additive in concrete structures such as: monolithic water tanks and elements of a sewage treatment plant sedimentation tank.

Polypropylene fibers also have surprising properties that improve the fire resistance of concrete, they are characterized by the protection of concrete against sudden detachment of concrete fragments at high temperatures, leading to the exposure of reinforcement elements, which in turn leads to deterioration of the load-bearing properties of the reinforced concrete element.

Glass fibers are obtained by dragging molten glass through 12-20 μm holes. Glass fibers replaced asbestos fibers that were withdrawn from the market, which were harmful to health.

Polypropylene and glass fibers are characterized by low modulus of elasticity, they are added to protect the element against cracks, due to which this concrete is perfect as an architectural material that looks great and ensures durability of the product for years [35].

Typically, the fibers with a length of two to four times the maximum grain size of the aggregate are used. The workability of the fiber-reinforced concrete mix is strongly influenced by the fiber content, their shape and slenderness as well as the proportions of the remaining components of the mix. Observations carried out with the help of the fall of the cone, a decrease of the fall with the increase in the content of steel fibers is observed, it can be expected that the fall of the cone will be reduced by approx. 25-100 mm compared to the concrete mix without the fibers. The most advantageous method to prevent this are fluidizing admixtures. It is better not to add water or adding other ingredients to liquefy the mixture.

Pictures of the microstructures of the samples without the content of steel fibers (a) and with the content of steel fibers (b), taken with a scanning microscope, are presented in Figure 5.

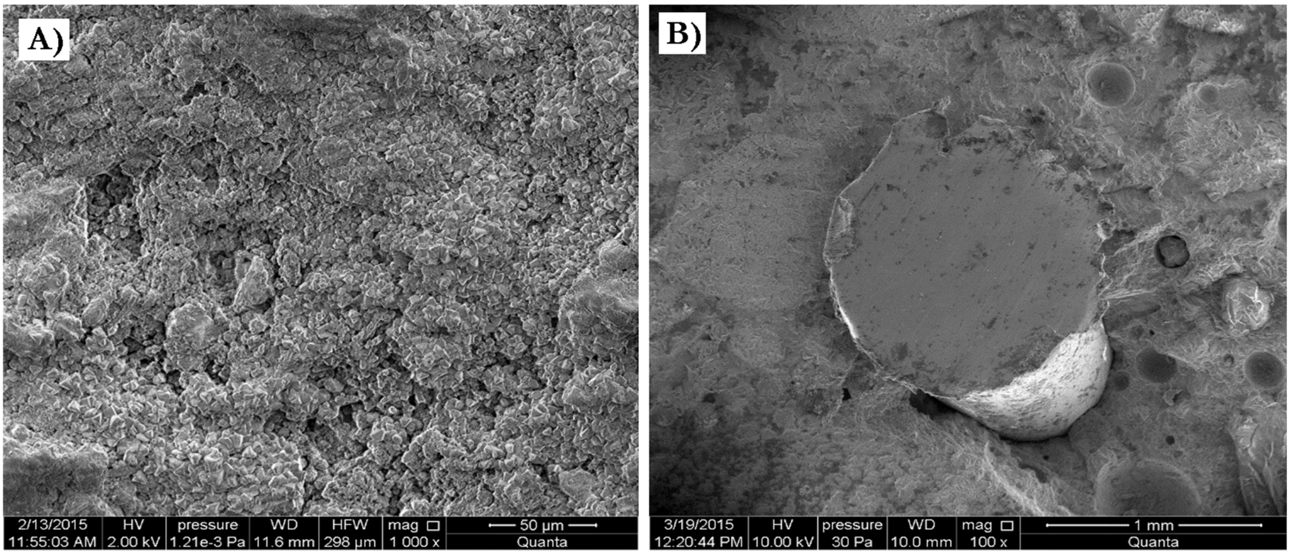

Fig. 5 *Photos of the microstructure of concrete a) without steel fibers b) with steel fiber content [39]*

2.3 Compressive strength and Young's modulus in concrete

The compressive strength of concrete is its basic mechanical property. The compression test is carried out in order to determine the stresses at which failure occurs and to determine the work of deformations. The strength of concrete depends on [40-41]:

- grain size, quantity and quality of aggregate,
- quantity and quality of cement,
- water content,
- concrete mix production technology,
- concrete maturation conditions,
- age of concrete,
- environmental humidity.

The phenomenon of increasing the strength of concrete with time is presented in Fig. 6.

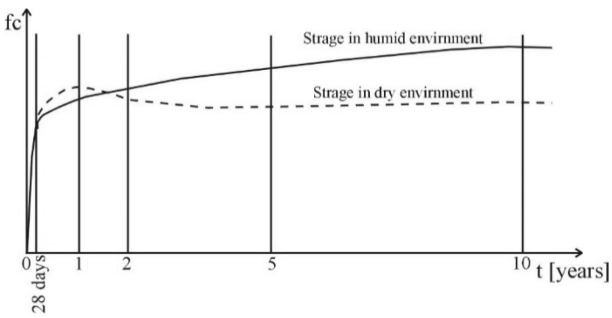

Fig. 6 *The phenomenon of increasing the strength of concrete with time (unloaded concrete) [42]*

The samples are tested 28 days after they were made.

The modulus of elasticity determines the stiffness of the structure. Its value is used, among others, in the calculation of deflections and cracks in the serviceability limit state, in the analysis of structure stability, critical force, second-order effects, as well as in the modal analysis (including determination of the frequency and the form of natural vibrations). Young's modulus is a characteristic quantity for a given substance and is equal to the stress at which the length of the body is doubled. In general, doubling the length of the body fails because usually the body ruptures before this happens. Young's modulus is one of the basic spring constants characterizing the material. It is a proportionality factor that determines the physical relationship between normal stresses and strains in the form σ = ε * E. Young's modulus is defined as the ratio of the normal stress under uniaxial stress to the corresponding strain [43-44].

Young's modulus (E) - in other words, the modulus of linear deformation or the modulus (coefficient) of longitudinal elasticity is a quantity that determines the elasticity of a material. It expresses characteristic for a given material (Fig. 7), the dependence of the relative linear deformation of the material on the stress that occurs in it in the range of elastic deformation [45].

Since the strain is a unitless quantity, Young's modulus is expressed in stress units N / m2 = 1Pa.

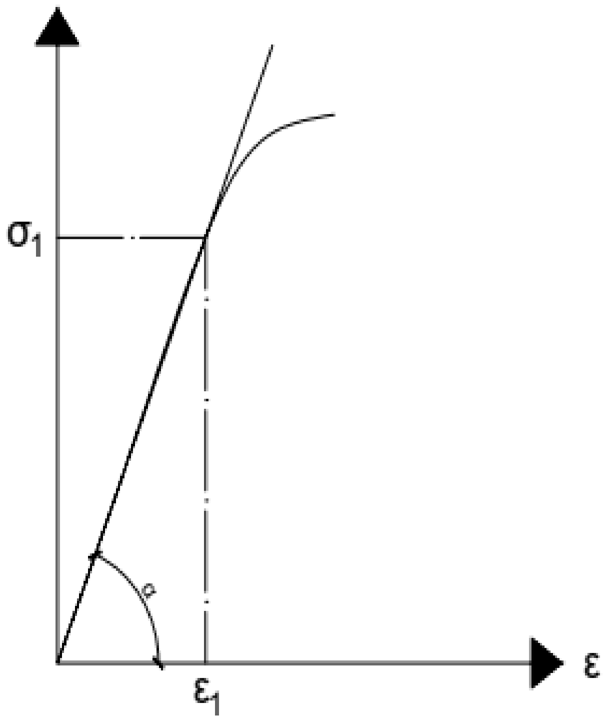

Fig. 7 *Graphic interpretation of the Young's modulus [46]*

In this case, the elasticity coefficient E is equal to:

$$E = \frac{\sigma_1}{\varepsilon_1} = tg\alpha \tag{1}$$

Where:
σ …Stress,
Ɛ …Deformation.

3 Methodology

Compressive strength is the basic parameter of concrete responsible for the load-bearing capacity and durability of the structure made of it. Its measurement is part of material tests of the hardened concrete and is carried out on a testing machine (hydraulic press). In this case it was Zwick / Roell SP-Z6000 testing machine with software. Compressive strength test is not difficult or complicated. All is needed is the right equipment in the form of a testing machine with software. A testing machine is a specialized device that is used to test the strength of materials such as concrete or steel. Tested samples of materials are subjected to stress, which leads to their deformation, using a specific force for a specified time. Strength machines are classified according to the method of carrying out the test, therefore there are strength machines for static tests and strength machines for dynamic tests.

Measurement procedures (standard) for the measurement of Young's modulus in concrete maybe are not only complicated and time-consuming, but often involve the rejection of test samples, which, given their limited number, may make it impossible to determine the Young's modulus. According to the standard, the Young's modulus can be determined using two methods - A or B. Method A enables the determination of both the initial modulus of elasticity of concrete (Ec, 0) and the incisal modulus (Ec, s) - three preload cycles are initially performed and only then the real ones are performed. Method B allows to determine only the stabilized modulus of elasticity of concrete (Ec, s) after three load cycles.

Nine concrete samples in the form of cylinders 150x300mm were analyzed. The samples were divided into three groups:

- group 1 - 3 samples without steel fibers,
- group 2 - 3 samples containing 0.25% of steel fibers,
- group 3 - 3 samples containing 0.50% of steel fibers.

The samples were made according to the recipe contained in Tab. 2.

Tab. 2 *Recipe for making test samples [a) recipe; b) mixture]*

BS-0.25 – Concrete according to the base recipe + steel fibers			
0.25% steel fibers			0.50% fibers
	Rec-ipe	Mix-ture	The same recipe + steel fibres 0.50% / 1m³ mb instead of 0.25%
	kg/m³	0.21	
Cement 42.5 N MSR NA	384	80.640	
Sand	680	142.80	
Basalt 2-8	600	126.00	
Basalt 8-16	650	136.500	
Water	166	34.860	
plasticizer 0.5%/kg of cement	1.92	0.403	
aerator 0.2%/kg of cement	0.768	0.161	
Steel fibers 0.25% / 1m³ concrete mixture	19.65	4.127	$39.3^{a)}/8.253^{b)}$

The research presented in the paper were carried out in the laboratory according to the schedule presented in Fig. 8.

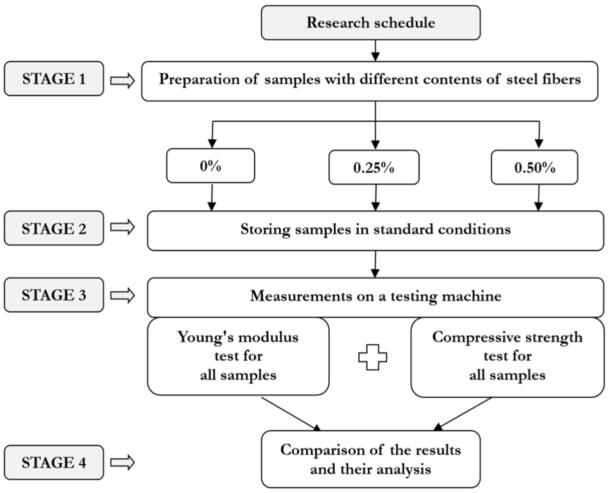

Fig. 8 *Research schedule*

Fig. 9 *a) Sample no. 1 subjected to the Young's modulus test b) Extensometers used to measure Young's modulus*

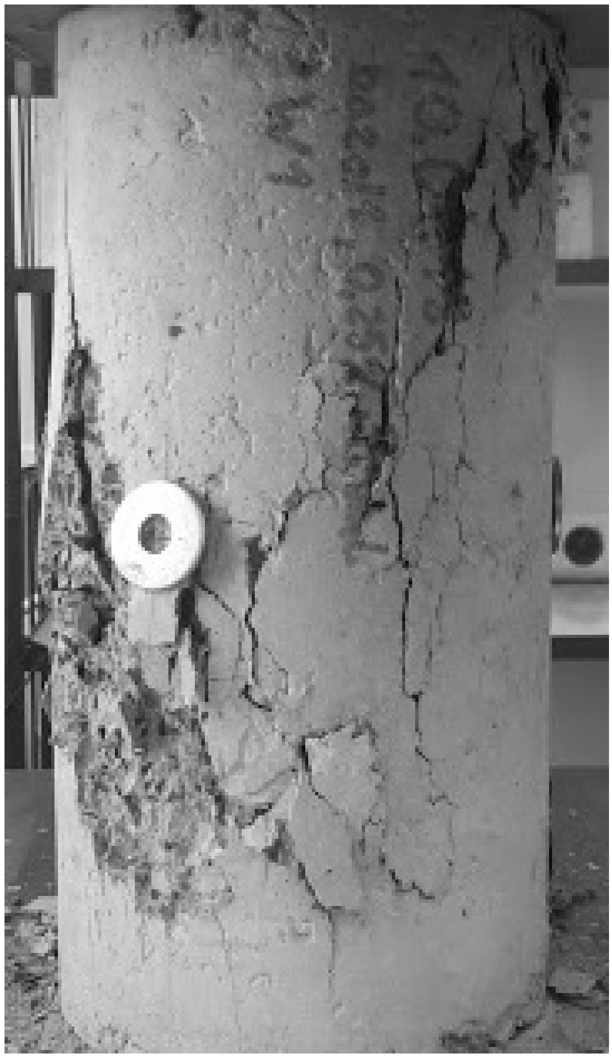

Fig. 10 *An example of a sample destroyed in the compressive strength test*

The samples were seasoned according to the standard PN-EN 12390-2. As mentioned before, compressive strength tests were carried out using a Zwick / Roell SP-Z6000 testing machine with software. The machine consists of a hydraulic power unit, a load frame, and measurement and control electronics. The breaking force is measured with a liquid pressure sensor and recorded electronically. The maximum test force that can be achieved in the compressive direction is 6,000 kN. During the test, the load increased continuously without sudden force jumps at a speed of 0.5 MPa/s. The destructive force for each of the samples was saved automatically in the testXpert software controlling the machine.

The deformations were measured using an extensometer with a measuring base length of 120mm, at 3 equal intervals around the cylinder surface (Fig. 9, 10). The roller with the extensometer mounted was positioned axially in the strength press and loaded with the initial force. The deformation values were automatically measured and recorded by a computer connected to the strength press, which allowed to obtain a ready result of the elastic modulus value.

4 Results and discussion

Properties of concrete and fibro-concrete as well as individual relationships between these properties have been the subject of interest of many researchers for years. These properties depend not only on the composition of the concrete mix, the storage conditions of the samples, the temperature of the addition of fibers and their types, but also many other factors. The results of the analysis that a higher content of steel fibers (0.50%) are less beneficial than a fibro-concrete with 0.25% is important for science. It would be worth checking the tested properties with a different content of steel fibers in the range of 0.25-0.50%. It is known from the literature that the fibro-concrete is widely used in construction. However, there is still a lot of space for researchers to study other types of fibers, their different lengths, shapes and thicknesses, and of course their contents.

During the research it was analyzed how selected mechanical properties of concrete change - compressive strength and Young's modulus. Three groups of samples were tested:

- 1. samples without steel fibers,
- 2. containing 0.25% of steel fibers,
- 3. containing 0.50% of steel fibers.

Steel fibers of the BauMix 60/1 type with the following parameters were used: fiber length lw = 60 mm, fiber diameter ∅ 1.0 mm. Straight fibers with hooked ends are used. The average values of the compressive strength and Young's modulus for the tested samples are presented in Tab. 3.

Tab. 3 *The results for the compressive strength test for the tested samples*

Mechanical properties	Arithmetic mean / coefficient of variation V [%]	Samples without steel fibers 1	Samples containing 0.25% of steel fibers 2	Samples containing 0.50% of steel fibers 3
Compressive strength CS [MPa]	Average value [MPa]	46.19	54.07	52.74
	Coefficient of variation [%]	0.8	0.27	5.34
Young's module MY [Gpa]	Average value [GPa]	37.2	44.71	37.63
	Coefficient of variation [%]	1.2	1.44	3.2

The average results of the compressive strength measurement for samples without steel fibers, with 0.25% steel fibers and 0.50% steel fibers are presented in Fig. 11.

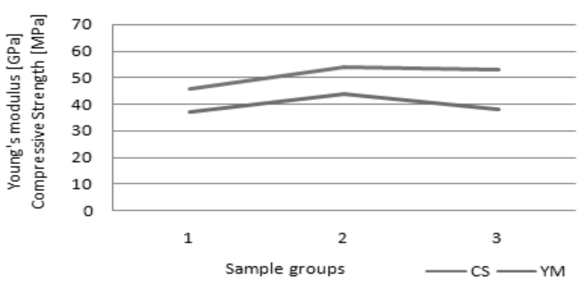

Fig. 11 *Compressive strength [MPa] and Young's modulus [GPa] values for three types of samples*

The analysis of the chart shows that the samples containing 0.25% of steel fibers have the highest compressive strength. The average compressive strength for this group (2) increased by about 17% compared to the samples without steel fibers. In the samples containing 50% of steel fibers, the average compressive strength was higher than that of the samples from the group 1, but slightly lower than the ones for the group 2. Also Young's modulus is the highest for samples from group 2 (content of 0.25% of steel fibers). Moreover, the examination of Young's modulus showed that it is comparable for samples without steel fibers and for samples with 0.50% steel fibers.

The level of variation for the compressive strength (for n = 3) of the group 1 was 0.8%, the group 2 was

0.27% and 5.34% for the group 3. For the value of Young's modulus, the highest level of variability also concerned the group 3 (3.2%). The much higher level of variation for the group 3 probably results from the more difficult workability of the mixture with a greater number of steel fibers.

5 Conclusions

Concrete production is a complex process influenced by many factors. The final properties of concrete depend on the composition of the mixture as well as the influence of the environment. The pursuit of optimal properties of this material is therefore associated with the appropriate selection of ingredients and the conditions of the external environment.

In the paper, the authors focused on ingredients that are directly influenced by the manufacturer. The use of fibers in concrete has for years been the subject of research aimed at improving its mechanical properties. The samples were seasoned in accordance with the standard PN-EN 12390-2. An analysis of the influence of steel fiber content on the compressive strength and Young's modulus in concrete was carried out. For this purpose, three groups of samples were analyzed: 1 – concrete without steel fibers, 2 – the fiber-reinforced concrete containing 0.25% steel fibers, and 3 - the fiber-reinforced concrete containing 0.50% steel fibers.

As the conducted analysis has shown, the greater number of steel fibers is not directly proportional to the increase in its compressive strength or the value of Young's modulus. The analysis of the conducted tests showed that both the compressive strength and the Young's modulus for concrete are of the highest values for samples containing 0.25% of steel fibers. The lower compressive strength with a higher fiber content (0.50%) is associated with difficulties in accurately distributing the mixture. In this situation, more water is often added, which unfortunately reduces endurance. The more difficult workability of concrete with a higher fiber content is also associated with greater variability for individual samples.

It is not known what values of Young's modulus and compressive strength would be obtained with steel fibers in the amount between 0.25% and 0.50%. It would also be worth checking what amount of steel fibers is enough to obtain properties such as 0.25% (maybe 0.15%, or maybe 0.20%). There is a lot of research on the effect of fibers on the properties of concrete, but the multitude of types of fibers, both the material they are made of and the shape, means that the topic is still relevant and checked. The topic will not be exhausted quickly, as there are many properties that depend on the fibers, and such studies require a lot of time (preparation and maturation of samples) and trials (Young's modulus is demanding / complicated in the study). In the future, the authors plan to make more samples with different contents.

The use of steel fibers of a different length and shape would allow to optimize the amount and type of this fiber concrete component in order to obtain the best properties which can be checked and confirmed in the future research.

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