MODULUL DE ELASTICITATE A BETONULUI ȘI MICROBETONULUI CU MICROSILICE SAU CENUȘĂ DE TERMOCENTRALĂ ȘI ADAOS DE FIBRE
THE MODULUS OF ELASTICITY OF CONCRETE AND MICROCONCRETE WITH MICROSILICA OR FLY ASH AND ADDITION OF FIBERS

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The main purpose of this study is to investigate the impact of microsilica and fly ash as cement replacements on the modulus of elasticity of concrete and microconcrete, as well as the effect of metal and polypropylene fibres in this context. Different concrete and microconcrete mixtures were designed with 5% and 10% microsilica or fly ash as cement replacements, with and without metal or polypropylene fibres. The modulus of elasticity was determined through compression tests, and the results were analyzed to evaluate the effects of the additives and fibres on the modulus of elasticity compared to traditional concrete.

According to the results obtained, it was found that microsilica and fly ash as cement replacements can improve the modulus of elasticity of microconcrete in most cases, while in the case of concrete, only a few exceptions with a higher modulus of elasticity were recorded. Comparing the values of the modulus of elasticity from the two data sets, it can be observed that the modulus of elasticity values of the fly ash/microsilica-based microconcrete are up to 27.03% higher than those of the fly ash/microsilica-based concrete. The general trend observed is that replacing a higher proportion of cement with microsilica and fly ash can lead to a decrease in the modulus of elasticity of concrete/microconcrete. Regarding fibers, they did not significantly influence the modulus of elasticity of microconcrete and concrete with fly ash or microsilica, except for metal fibers, which had a more pronounced effect in some cases. At the same time, it is important to note that the addition of polypropylene fibers had a negative effect in certain situations. With regard to strength class, the majority of concretes were classified as C12/15 strength class.

It is essential to highlight the benefits of replacing cement with fly ash or microsilica in terms of reducing costs and carbon dioxide emissions associated with cement production. Therefore, using these additives brings multiple environmental advantages and, at the same time, maintains or even improves the properties of concrete.

Scopul principal al acestui studiu este de a investiga impactul adaosurilor de microsilice și cenușă de termocentrală ca înlocuitori de ciment asupra modulului de elasticitate al betonului și microbetonului, precum și efectul fibrelor de metal și polipropilenă în acest context. Au fost proiectate diferite amestecuri de beton și microbeton, cu 5%, respectiv 10% microsilice sau cenușă de termocentrală ca înlocuitoare de ciment, cu și fără fibre metalice sau de polipropilenă. Modulul de elasticitate a fost determinat prin încercări de compresiune, iar rezultatele au fost analizate pentru a evalua efectele adaosurilor și fibrelor asupra modulului de elasticitate în comparație cu betonul tradițional. Conform rezultatelor obținute, s-a constatat că microsilicea și cenușă de termocentrală ca înlocuitoare de ciment pot îmbunătăți modulul de elasticitate al microbetonului în majoritatea cazurilor, în timp ce în cazul betonului s-au înregistrat doar câteva excepții cu un modul de elasticitate mai mare. Comparând valorile modulului de elasticitate din cele două seturi de date, se poate observa că valorile modulului de elasticitate ale microbetonului cu cenușă/silice sunt cu până la 27.03% mai mari decât cele ale betonului cu cenușă/silice. Tendința generală observată este că înlocuirea unei proporții mai mari de ciment cu microsilice și cenușă de termocentrală poate conduce la o scădere a modulului de elasticitate al betonului/microbetonului. În ceea ce privește fibrele, acestea nu au influențat semnificativ modulul de elasticitate al microbetonului și betonului cu cenușă sau silice, cu excepția fibrelor metalice care au avut un efect mai pronunțat în unele cazuri. În același timp, este important de menționat că adăugarea de fibre de polipropilenă a avut un efect negativ în anumite situații. În ceea ce privește clasa de rezistență, majoritatea betoanelor au fost încadrate în clasa de rezistență C12/15.

Este esențial să evidențiem beneficiile înlocuirii cimentului cu cenușă sau microsilice în ceea ce privește reducerea costurilor și emisiilor de dioxid de carbon asociate producției de ciment. Prin urmare, utilizarea acestor adaosuri aduce multiple avantaje de mediu și, în același timp, păstrează sau îmbunătățește proprietățile betonului

Keywords: *Concret, fly ash, microconcrete, microsilica, moduls of elasticity, fibers*

1.Introduction

This article will focus on an important aspect of modern constructions, the modulus of elasticity of concrete that uses microsilica or fly ash as a replacement for cement and with the addition of metal or polypropylene fibers. The modulus of elasticity is a measure of a material's stiffness and represents the ratio of stress to strain. The modulus of elasticity is an important property for concrete, referring to its ability to deform under load (1,2). It is influenced by several factors, including the water-cement ratio, the ratio of aggregate volume to total volume of concrete mix, the mineralogical nature of the aggregates, porosity, and casting temperature (3,4). Comparing the modulus of elasticity of concrete to other building materials such as steel highlights that concrete has a relatively lower value. Consequently, concrete exhibits less flexibility compared to other materials and is more susceptible

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to deformation when subjected to external forces. However, concrete has a high capacity to withstand large loads without breaking.

The modulus of elasticity of concrete is essential for designing and analyzing structures, ensuring their stability and safety in the long term. In recent years, there has been an increasing need for eco-friendly building materials that reduce the use of cement and minimize the impact on the environment. In this regard, researchers have developed theoretical models for using residual materials in the production of structural concrete, offering a sustainable and efficient alternative. Additionally, the development of new materials such as concrete with metal and polypropylene fibers and the use of microsilica and fly ash has contributed to improving the performance of concrete structures and reducing costs and environmental impact. All of these innovations are essential to ensure a healthier and safer environment for the future.

Authors Ade Lisantono and Pratama conducted a study to evaluate the effect of using microsilica in high-strength concrete on its modulus of elasticity. The study included using microsilica in proportions of 0%, 5%, 10%, 15%, and 20%. It was found that the modulus of elasticity increased up to 15%, but decreased to almost the same as the reference concrete at 20%. Additionally, high-strength concrete mixed with 10% and 15% microsilica achieved the best modulus of elasticity properties (5). A similar study was conducted by Lustosa and Magalhães, who analyzed the effect of adding fly ash to concrete on its compressive strength and modulus of elasticity. Their study showed that adding fly ash led to an increase in the modulus of elasticity of concrete. They observed a decrease in the modulus of elasticity of concrete with increasing fly ash replacement rate. However, an increase in compressive strength was recorded with increasing fly ash replacement rate up to 20% (6). Other studies have demonstrated that replacing cement with fly ash or silica can be a viable solution, yielding positive results for this parameter (7,8,9,10,11,12,13,14).

According to test results, the use of fibers in concrete can lead to an increase of up to 23% in the static modulus of elasticity compared to traditional concrete (15). In general, metallic fibers increase the mechanical properties of concrete, including the modulus of elasticity (16, 17, 18). By using nanodentistry techniques and X-ray tests, it has been found that steel fibers are more effective in improving the modulus of elasticity of concrete compared to synthetic fibers. Overall, this finding suggests that the use of steel fibers may be a viable option for improving the performance of concrete (19).

The study conducted by Köksal and his colleagues showed that the effect of polypropylene fibers (PF) on the durability of concrete is much smaller than that of steel fibers (SF). Although adding PF to concrete can improve cracking and deformation resistance, this effect is limited compared to adding SF, which can significantly improve the mechanical and durability properties of concrete. Therefore, the use of steel fibers is considered more efficient in improving the performance of reinforced concrete, including the modulus of elasticity (20). The study conducted by Ahmed and Daoud highlighted a reduction in the modulus of elasticity of fiber-reinforced concrete with polypropylene fibers (21). Fiber-reinforced concrete with polypropylene fibers has lower workability than ordinary concrete due to the fact that polypropylene fibers can interfere with the concrete compaction process. This can lead to greater non-uniformity of concrete, which can affect its mechanical properties. With regard to the modulus of elasticity of concrete, the addition of polypropylene fibers can lead to a decrease in its value. Polypropylene fibers have a lower stiffness than that of concrete, which can lead to a reduction in the modulus of elasticity of concrete (22, 23).

The modulus of elasticity is an important property for fiber-reinforced concrete with microsilica and fly ash. It plays a crucial role in determining the load capacity of concrete structures and ensuring their long-term stability. Therefore, researching and developing the modulus of elasticity of this type of concrete is of great importance to the construction industry.

2.Experimental Program

In this study, the behavior of the modulus of elasticity of concrete and microconcrete with partial cement replacements and additions of metal and polypropylene fibers will be analyzed through laboratory testing. The aim of the study is to evaluate the modulus of elasticity of concrete/microconcrete with these materials and to compare its performance with conventional concrete. These investigations will provide a better understanding of the behavior of the modulus of elasticity of these concretes, which can help in developing superior performing concretes under diverse loading conditions.

Partial cement replacements and additions of metal and polypropylene fibers are materials that have been used in modern concretes to reduce negative environmental impacts, improve concrete properties, and increase its durability. In this study, the modulus of elasticity of concrete and microconcrete with these materials will be evaluated, which can help in optimizing their use in construction and infrastructure. The results obtained from this study can be used to develop more durable and efficient concretes, which can have a positive impact on the environment and the construction industry.

Table 1

Recipe for the control concrete/ *Rețeta betonului martor*

Material	Quantity (kg/m^3)
Sand 0-4 mm	858.50
Gravel 4-8 mm	408.00
Gravel 8-16 mm	595.00
Ciment CEM I 42.5 R	382.50
Water (l/m^3)	208.60
Plasticizer*	4.59

Table 2

Recipe for the control microconcrete /Rețeta microbetonului martor

Material	Quantity (kg/m^3)
Sand 0-4 mm	1070.00
Gravel 4-8 mm	655.00
Ciment CEM I 42.5 R	430.00
Water (l/m^3)	236.50
Plasticizer*	5.15

*Note: The plasticizer is added in proportion to the weight of the cement: 1.2% of the cement quantity.

2.1.Materials

In this experimental study, various types of materials were used to produce concrete and microconcrete, including fly ash and microsilica as partial cement replacements, metallic fibers and polypropylene fibers as additives in the concrete compositions, and an admixture for improving the workability of the concrete. Several concrete and microconcrete variants were developed using these materials, and their properties were analyzed. In the study, 12 concrete compositions and 12 microconcrete compositions were made using different combinations. The control sample, called BM for concrete and MBM for microconcrete, served as a reference for comparison with the other concrete/micro-concrete variants. Concrete and microconcrete recipes were developed that included cement replacements such as fly ash and microsilica in proportions of 5% and 10%, as well as metallic or polypropylene fibers.

For the BM concrete (concrete with aggregate sizes of 0-4 mm, 4-8 mm, and 8-16 mm), the recipe includes the components in Table 1.

The recipe for the MBM microconcrete (concrete with aggregates of sizes 0-4 mm and 4-8 mm) includes the components in Table 2.

Several concrete recipes were developed, starting from the reference concrete recipe, BM, such as BC5/BS5, BC10/BS10, BCF5/BSF5, BCF10/BSF10, BCP5/BSP5, BCP10/BSP10, which contain fly ash or microsilica as partial cement replacements at percentages of 5% or 10%, and metallic fibers (F) or polypropylene fibers (P) in different quantities. A quantity of 150 kg/m^3 was used for the metal fibers and 9.16 kg/m^3 for the polypropylene fibers. Similarly, for the micro-concrete with particle sizes of 0-8 mm, the same variants were developed starting from MBM (reference sample), MBC5/MBS5, MBC10/MBS10, MBCF5/MBSF5, MBCF10/MBSF10, MBCP5/MBSP5, and MBCP10/MBSP10. All these recipes were analyzed and tested to verify their properties.

Legend for Notations:

*BC5/BS5 - concrete with 5% fly ash/microsilica as a cement substitute;

*BC10/BS10 - concrete with 10% fly ash/microsilica as a cement substitute;

*BCF5/BSF5 - concrete with 5% fly ash/microsilica as a cement substitute and 150 kg/m^3 of metal fibers;

*BCF10/BSF10 - concrete with 10% fly ash/microsilica as a cement substitute and 150 kg/m^3 of metal fibers;

*BCP5/BSP5 - concrete with 5% fly ash/microsilica as a cement substitute and 9.16 kg/m^3 of polypropylene fibers;

*BCP10/BSP10 - concrete with 10% fly ash//microsilica as a cement substitute and 9.16 kg/m^3 of polypropylene fibers;

*MBC5/MBS5 - microconcrete with 5% fly ash/microsilica as a cement substitute;

*MBC10/MBS10 - microconcrete with 10% fly ash/microsilica as a cement substitute;

Table 3

Compressive Strength of Concrete with 0-16 mm aggregates
………………………………………………

No.	Mix Design	Compressive Strength (N/mm2)
1	BM	31.43
2	BC5	42.39
3	BC10	38.81
4	BS5	40.83
5	BS10	37.66
6	BCF5	43.52
7	BCF10	36.67
8	BSF5	44.98
9	BSF10	43.16
10	BCP5	28.79
11	BCP10	30.38
12	BSP5	28.44
13	BSP10	27.30

Table 4

Compressive Strength of Microconcrete / ……………………………………

No.	Mix Design	Compressive Strength (N/mm2)
1	MBM	36.07
2	MBC5	46.35
3	MBC10	43.12
4	MBS5	42.97
5	MBS10	39.52
6	MBCF5	47.02
7	MBCF10	41.56
8	MBSF5	43.12
9	MBSF10	38.65
10	MBCP5	32.01
11	MBCP10	32.45
12	MBSP5	29.86
13	MBSP10	31.38

*MBCF5/MBSF5 - microconcrete with 5% fly ash/microsilica as a cement substitute and 150 kg/m^3 of metal fibers;

*MBCF10/MBSF10 - microconcrete with 10% fly ash/microsilica as a cement substitute and 150 kg/m^3 of metal fibers;

*MBCP5/MBSP5 - microconcrete with 5% fly ash/microsilica as a cement substitute and 9.16 kg/m^3 of polypropylene fibers;

*MBCP10/MBSP10 - microconcrete with 10% fly ash//microsilica as a cement substitute and 9.16 kg/m^3 of polypropylene fibers;

2.2.The experimental program

The compressive strength of the concrete samples was tested using a 300 tf hydraulic press in accordance with standard EN 12390-3:2019.

The values of the compressive strengths of the studied concretes are presented in tabular form, in Table 3 and Table 4.

According to Table 3.1, "Strength and deformation characteristics of concrete," from the standard SR EN 1992-1-1:2004, and based on the obtained values for compressive strength from Table 3 and 4, the concrete exhibits a modulus of elasticity between 31-34 GPa.

The process of determining the elasticity modulus was carried out using cylindrical specimens with dimensions of 100x200 mm. To obtain the most accurate results, the concrete mixing process was done using a concrete mixer which ensured a uniform distribution of the materials. Prior to pouring, the molds were prepared by greasing them with a special substance, ensuring they were completely filled without any air pockets. After pouring, the concrete in the specimens was compacted using a vibrating table, eliminating any voids or air pockets - see Figure 2.

Fig. 1 - Testing the specimens for compressive strength
Testarea epruvetelor la rezistenta la compresiune

Fig. 2 - Making the test specimens / *Realizarea epruvetelor*

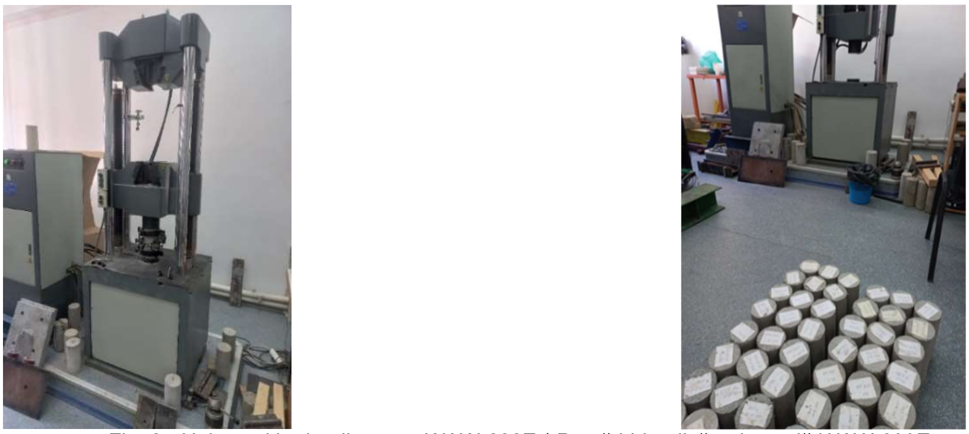

Fig. 3 - Universal hydraulic press WAW-600E / *Presă hidraulică universală WAW-600E*

The specimens were allowed to set in the molds for at least 24 hours, ensuring that they formed chemical bonds and increased their strength in a controlled temperature and humidity environment. Subsequently, the specimens were removed from the molds and kept under optimal temperature conditions until the time of testing. All these steps were necessary to obtain precise and consistent results in determining the modulus of elasticity of concrete. In addition, they were carried out with great care to avoid any possibility of errors and to obtain relevant data for further research.

In the presented research, the determination of the compressive modulus of elasticity of concrete was carried out according to the European standard EN 12390-13/2013. This standard was chosen to ensure the appropriate testing and evaluation methods of the mechanical properties of concrete, including the modulus of elasticity, thus ensuring precise and consistent results. The testing was carried out using specialized equipment, including a WAW-600E universal hydraulic press, as shown in Figure 3, and a specific displacement measuring device, Humboldt H2917-D, as shown in Figure 4. The hydraulic pressure was used to apply a constant and controlled force on the concrete specimens, so that the deformation could be measured and the modulus of elasticity subsequently calculated. The Humboldt H2917-D

Fig. 4 - The Humboldt H2917-D compressometer
Compresometrul Humboldt H2917-D

displacement measuring device was used to measure the deformation of the concrete during testing, ensuring the necessary data for the determination of the modulus of elasticity.

During the testing of concrete specimens, they were loaded in stages at a constant rate of 0.4 N/mm^2/s. This process was necessary to ensure a gradual and controlled loading of the specimens, which allowed for precise measurement of the deformations.

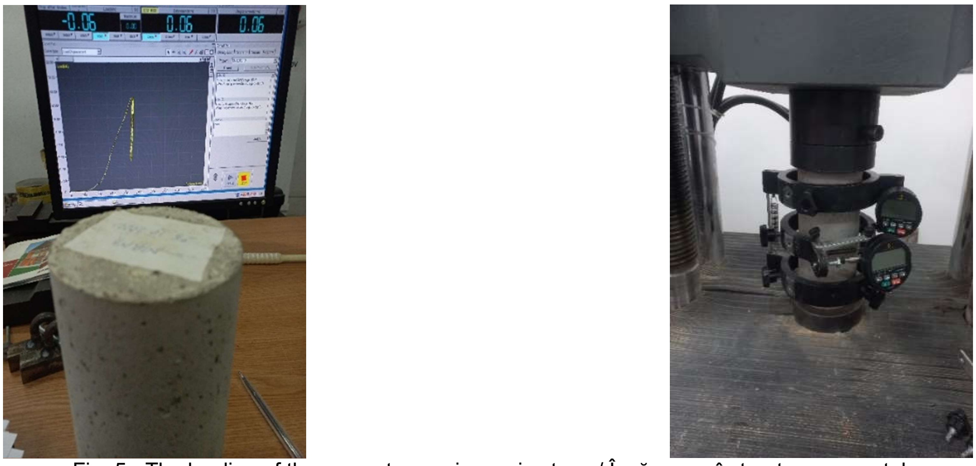

Fig. 5 - The loading of the concrete specimens in steps / Încărcarea în trepte a epruvetelor

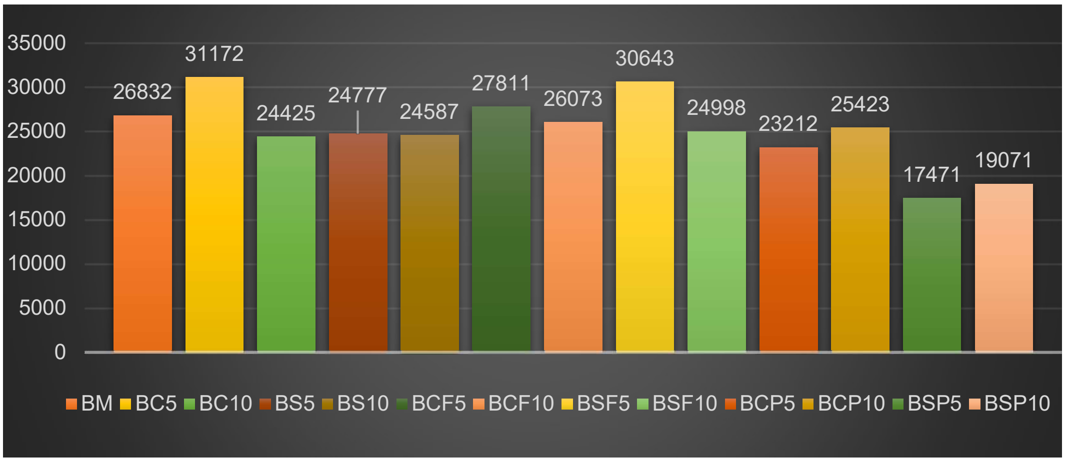

Fig. 6 - Elastic modulus of concrete, E [MPa] / *Modulul de elasticitate a betoanelor, E [MPa]*

During the testing, measurements of the deformations of the specimens were taken using the Humboldt H2917-D compressometer. These measurements were essential for obtaining precise data regarding the behavior of the concrete specimens under load, which allowed for the calculation of the modulus of elasticity.

To ensure precise and consistent results, the loading-unloading cycle of the concrete specimens was repeated three times during the testing. During these cycles, a gradual and controlled loading of the specimens was ensured, so that precise readings could be taken on the measuring devices. To ensure maximum accuracy of the measurements, the difference between the two readings should not exceed 5%. In this regard, the measurements of the measuring device were taken both at the maximum-unloading and maximum-loading steps. Thus, by repeating the loading-unloading cycles and ensuring precise and consistent readings on the measuring devices, a precise evaluation of the mechanical properties of the concrete used in the research was obtained. The modulus of elasticity (E) was determined using formula 1:

$$E = \frac{\Delta\sigma\ (\text{stress difference})}{\Delta\varepsilon\ (\text{compression strain difference})} \qquad (1)$$

3. Results and their interpretation

3.1. The modulus of elasticity, E [MPa], of concrete with aggregates of 0-16 mm size range

According to Figure 6, it can be observed that the BSP5 concrete, which contains 5% microsilica and polypropylene fibers in a proportion of 4.58 kg/m^3, has the lowest modulus of elasticity. On the other hand, the BC5 concrete, which contains 5% fly ash, has the highest modulus of elasticity, with an increase of 16.17% compared to the control concrete (BM). Most of the concretes have a lower modulus of elasticity than BM, with the exception of the BC5, BCF5, and BSF5 concretes. Regarding concretes with fly ash or microsilica as partial cement replacements, the BC5 concrete shows an increase of approximately 16%, while the BC10 concrete has a reduction of approximately 9% compared to BM. The BS5 and BS10 concretes have a decrease of approximately 8% in modulus of elasticity compared to BM. However, these variations are generally minor and do not significantly affect the performance of concrete with partial cement replacements. Therefore, in this case, fly ash/microsilica as partial cement replacements do not have a significant influence on the modulus of elasticity.

The addition of metallic fibers to concrete with 5% or 10% microsilica as a cement replacement leads to an increase in the modulus of elasticity, with an increase of approximately 24% for BSF5 compared to BS5 and approximately 2% for BSF10 compared to BS10. In the case of concrete with 10% fly ash as a cement replacement, the addition of metallic fibers leads to an increase of approximately 7% in the modulus of elasticity for BCF10 compared to BC10. On the other hand, the addition of metallic fibers leads to a decrease in the modulus of elasticity in the case of concrete with 5% fly ash as a cement replacement, with a reduction of approximately 10% (BCF5) compared to BC5.

The addition of polypropylene fibers to concrete with 10% fly ash as a cement replacement leads to an increase in the modulus of elasticity by approximately 4% for BCP10 compared to BC10. The addition of polypropylene fibers leads to a decrease in the modulus of elasticity in the case of concrete with 5% fly ash/microsilica or 10% microsilica as cement replacements, obtaining lower values of approximately 26% (BCP5) compared to BC5, approximately 30% (BSP5) compared to BS5, and approximately 23% (BSP10) compared to BS10.

Overall, research suggests that the addition of metal fibers and cement replacements such as fly ash or microsilica in concrete can increase the modulus of elasticity. These findings are in line with previous studies conducted by other researchers (17, 24, 25).

Comparing concrete samples BC5 and BSF5, which contain the same proportion of cement replacement (5% fly ash/microsilica) but differ in the presence or absence of metal fibers, it can be observed that both samples exhibit the highest values of the modulus of elasticity. Specifically, BC5 has a value of 31171.67 MPa, while BSF5 has a value of 30643.28 MPa.

Furthermore, it can be observed that, in general, concretes with fly ash as a cement replacement have higher values of the modulus of elasticity than those with microsilica as a cement replacement. However, there are a few exceptions, such as the cases of BCF5 and BC10, where a decrease in the values of the modulus of elasticity is recorded by 9.24% and 0.66%, respectively.

Interestingly, concretes containing 10% fly ash or microsilica as cement substitutes and the addition of polypropylene fibers obtain higher results of the elastic modulus, with an increase of 9.53% for BCP10 compared to BCP5 and 8.39% for BSP10 compared to BSP5. Other compositions obtain higher results for a quantity of 5% fly ash or microsilica as cement substitutes, with values ranging from 0.77% to 27.62%, compared to those with 10% fly ash/microsilica. In general, concretes containing metal fibers or cement substitutes such as fly ash or microsilica exhibit higher values of the elastic modulus than concretes without fibers. In contrast, concretes with polypropylene fibers exhibit lower values of the elastic modulus compared to those without fibers or with metal fibers, as they have a lower rigidity. Additionally, adding a large quantity of polypropylene fibers can lead to the formation of fiber clusters in the concrete, which can reduce its density and strength, and thus can influence its structural behavior and overall performance. Research has indicated that the impact of adding fibers to concrete on the elastic modulus is limited, especially in the case of polypropylene fibers, which can even decrease the elastic modulus (23,26,27).

According to Table 3.1 Strength and deformation characteristics of concrete, from the SR EN 1992-1-1:2004 standard, and based on the values obtained for the modulus of elasticity, it appears that the majority of the concretes align with the typical strength class C12/15, with the following exceptions:

-BCP5, BSP5, BSP10 are classified as strength class C8/10

-BSF5 is classified as strength class C20/25

-BC5 is classified as strength class C25/30.

The experimental results for the modulus of elasticity of concrete indicate that its stiffness is lower than what would be expected based on the initially assigned modulus of elasticity.

3.2 *Elastic modulus, E [MPa], of microconcrete with 0-8 mm aggregates*

Figure 7 illustrates the differences in modulus of elasticity between different types of microconcrete. It was observed that the microconcrete with the lowest modulus of elasticity is MBSP5, which contains 5% microsilica replaced with cement and added polypropylene fibers. On the other hand, the microconcrete with the highest modulus of elasticity is MBC10, which contains 10% fly ash replaced with cement. MBC10 recorded a 30% increase in modulus of elasticity compared to MBM, while MBSP5 recorded a decrease of 20.57%.

Most of the microconcrete recipes showed a higher modulus of elasticity than that of MBM, except for MBSF10 with 4% lower, MBCP10 with 12%, MBSP5 with 21%, and MBSP10 with 14%.

It was observed that, in general, the more cement is replaced, the lower the modulus of elasticity, except for microconcrete with 10% fly ash (MBC10) and 10% microsilica and polypropylene fibers (MBCP10), which recorded an increase in modulus of elasticity compared to the 5% replacement variants.

The addition of metallic fibers led to an increase in the modulus of elasticity when the cement matrix was replaced with 5% fly ash (MBCF5) by approximately 11% compared to MBC5 and by approximately 3% in the case of MBSF5 compared to MBS5. However, metallic fibers led to a decrease in the modulus of elasticity

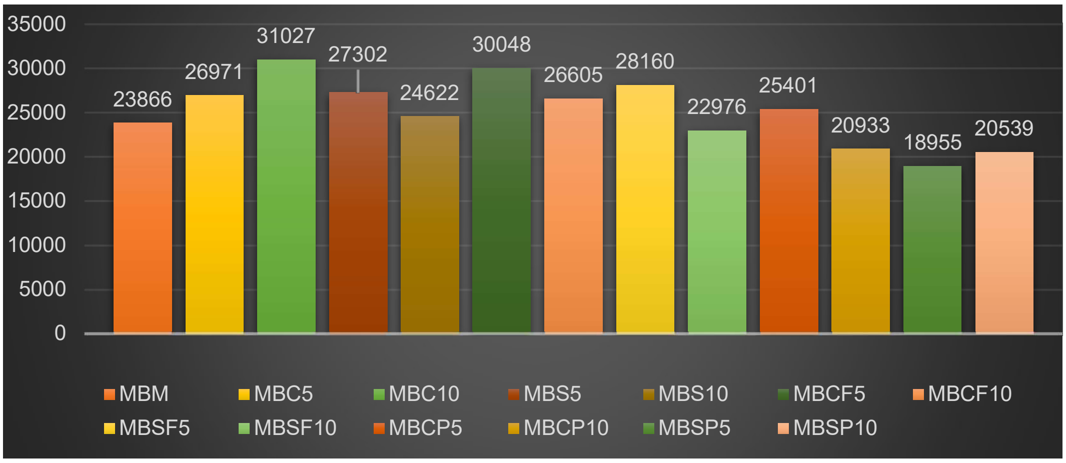

Fig. 7 - The modulus of elasticity of microconcretes, E [MPa] / *Modulul de elasticitate a microbetoanelor, E [MPa]*

in the case of 10% fly ash or microsilica replacement, with a decrease of approximately 14% in the case of MBCF10 compared to MBC10 and approximately 7% in the case of MBSF10 compared to MBS10.

In the case of polypropylene fibers, they led to a decrease in the modulus of elasticity when the cement matrix was replaced with 5% or 10% fly ash, with values lower by approximately 6% (MBCP5) compared to MBC5 and approximately 33% (MBCP10) compared to MBC10. In the case of 5% or 10% microsilica replacement, the lower values were approximately 31% (MBSP5) compared to MBS5 and approximately 17% (MBSP10) compared to MBS10.

From the data analysis in Figure 7, it can be concluded that the use of fly ash/microsilica in proportions of 5% or 10% improves the stiffness of microconcrete, but the addition of fibers does not seem to significantly influence this property.

Comparing microconcretes with fly ash and those with microsilica, it can be observed that MBC5 has a slightly lower modulus of elasticity by only 1.21% compared to MBS5, but MBC10 has a modulus of elasticity 26.01% higher than MBS10.

In general, the values of the modulus of elasticity for microconcretes with fly ash as a cement replacement, with or without fiber addition, are higher, ranging between 1.92-34%, than those of microconcretes with microsilica as a cement replacement. However, it is important to note that there is an exception to this trend in the case of MBC5 microconcrete, where a decrease of only 1.23% in the modulus of elasticity was recorded.

According to Table 3.1 Strength and Deformation Characteristics of Concrete from the SR EN 1992-1-1:2004 standard and the values obtained for the modulus of elasticity, it appears that the majority of the microconcretes align with the typical strength class C12/15, with the following microconcretes being exceptions:

-MBM, MBSF10, MBCP10, MBSP5, MBSP10, which fall into the strength class C8/10

-MBCF5 - strength class C20/25

-MBC10 - strength class C25/30.

The experimental values of the modulus of elasticity indicate that microconcretes have lower values than those predicted based on compressive strength. This suggests that microconcrete may have reduced stiffness compared to what would be expected normally based on the initially assigned modulus of elasticity. It is important to consider these differences in evaluating the structural performance of microconcrete because the modulus of elasticity plays a crucial role in determining its deformations and behavior under loads.

3.3. Comparison between the modulus of elasticity, E [kg/m³], of concrete and microconcret

It can be observed that microconcretes with fly ash or microsilica additives generally exhibit higher values of modulus of elasticity compared to concretes with the same additives, with differences ranging from 0.14% to 27.03%, but there are exceptions, such as microconcrete MBC5, where a decrease of 13.48% is recorded. When fibers are added, the trend is similar, with higher values of modulus of elasticity for most microconcretes, with differences ranging from 2.04% to 9.43% compared to the modulus of elasticity of concretes. However, there are exceptions, such as microconcretes MBSF5, MBSF10, and MBCP10, where a decrease in modulus of elasticity of 8.10%, 8.08%, and 17.66%, respectively, is observed. Additionally, it can be noted that the percentage of fly ash or microsilica in both types of concrete influences the modulus of elasticity, and an increase in these percentages can lead to a reduction in the modulus of elasticity. Moreover, it can be observed that concretes and microconcretes that use microsilica as a cement substitute have a more consistent and predictable behavior than those that use fly ash as a cement substitute. This difference is explained by the fact that microsilica has a more constant and uniform chemical composition and physical properties than fly ash, which can vary significantly depending on its source and composition.

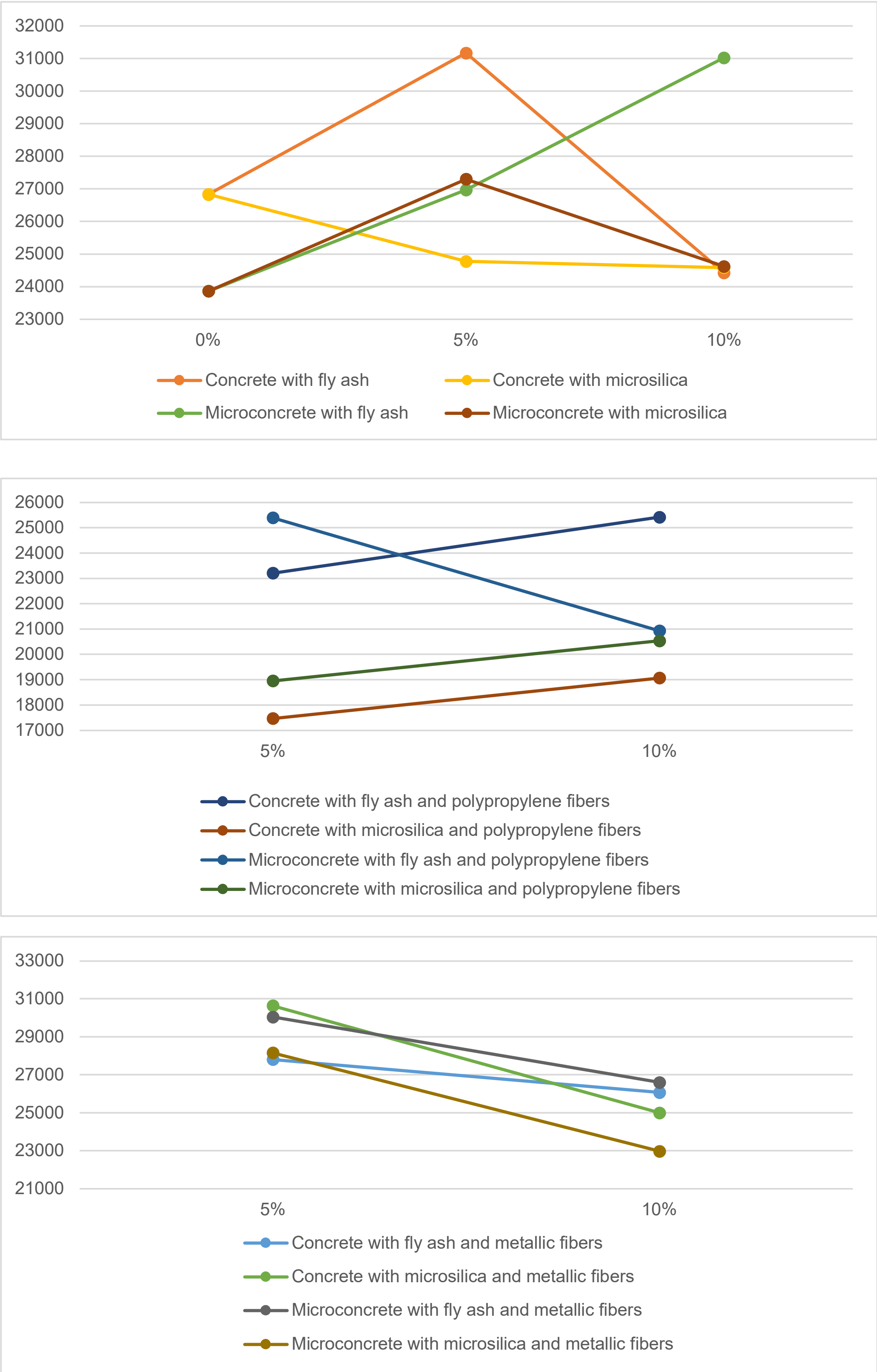

Fig. 8 The modulus of elasticity of microconcretes and concretes, E [MPa] / *Modulul de elasticitate a microbetoanelor și betoanelor, E [MPa]*

4.Conclusion

After conducting research on concrete and microconcrete mixtures, it was observed that most compositions exhibit a modification of the modulus of elasticity compared to control samples. The modulus of elasticity is a measure of the material's rigidity, representing the ratio of applied stress to resulting deformation. Thus, a decrease in the modulus of elasticity indicates greater deformability of the material under external force.

In the case of concrete mixtures, a decrease of up to 35% in the modulus of elasticity was observed compared to the control concrete. However, there are exceptions, such as concrete with the addition of 5% fly ash/microsilica and metallic fibers and concrete with 5% ash, which showed an increase of approximately 16% in the modulus of elasticity compared to the control concrete.

Regarding microconcrete, most compositions showed an increase in the modulus of elasticity of up to 30% compared to the control microconcrete. However, there are also exceptions, such as microconcretes with the addition of polypropylene fibers, which led to a reduction in the modulus of elasticity of up to 21%.

Adding fibers to concrete and microconcrete compositions does not have a significant impact on the modulus of elasticity, as the recorded growth or decline values are between 2-17%, which is not considered a significant difference in civil engineering practice. However, there are exceptions when metallic fibers are used in concrete with 5% microsilica, which can lead to a significant increase in the modulus of elasticity, up to 24%. On the other hand, using polypropylene fibers in concrete and microconcrete compositions can lead to a significant reduction in the modulus of elasticity, with values ranging from 23-33%. Although these variations can be important in certain applications, it is important to consider other properties of concrete and microconcrete when deciding to add fibers. In general, adding fibers can improve properties such as tensile and crack resistance, which can be beneficial in certain applications. It is important to consider the specific needs of each project and to perform appropriate testing to determine the best option for adding fibers to concrete and microconcrete compositions. Considering the variations observed in the effect of adding fibers to concrete and microconcrete compositions on the modulus of elasticity, more experiments are needed in this direction to obtain more precise results and to better understand how certain types of fibers and proportions affect the properties of concrete and microconcrete.

In conclusion, adding fly ash or microsilica to the composition of concrete and microconcrete, as well as adding fibers, can be a good option to increase the modulus of elasticity and to maintain the parameters of compositions, as well as to reduce CO_2 emissions and have a positive impact on the environment. However, it is important to conduct intensive studies and experiments to determine the optimal replacement percentages and fiber quantities for each composition in order to achieve the best results in terms of properties and performance of concrete and microconcrete. In addition, it is important to consider other aspects, such as the availability of raw materials, costs, and technical feasibility of these options, in order to make an informed choice. Therefore, civil engineers and researchers should continue to study and develop new and innovative options for improving concrete and microconcrete compositions so that we can have more durable, safe, and sustainable structures in the future.

References

[1]. Dhir R.K., Ghataora G.S., Lynn C.J., (2017), Sustainable Construction Materials: Concrete-Related Applications. *Sewage Sludge Ash*, **2017** 111-158. https://doi.org/10.1016/B978-0-08-100987-1.00005-6.

[2]. Chunsheng Z., Kefei L., Fu M., (2014), Numerical and statistical analysis of elastic modulus of concrete as a three-phase heterogeneous composite. *Computers and Structures*. **139**, 33-42. https://doi.org/10.1016/j.compstruc.2014.04.007.

[3]. Helene P.R.L., Monteiro P.J.M., Kang S.H., (1993), Designing concrete mixtures for strength, elastic modulus and fracture energy. *Materials and Structures*. **26**, 162, 443-452. ISSN: 1359-5997. https://www.phd.eng.br/wp-content/uploads/2014/06/ar12.pdf.

[4]. Narayanan S., (2021), Elastic Modulus of Concrete. *Journal of the Indian Concrete Institute*. **34**. https://www.researchgate.net/publication/352863356_Elastic_Modulus _of_ Concrete.

[5]. Ade Lisantono, Pratama Y.P.B., (2020), Effect of silica fume on the compressive strength and modulus elasticity of self-compacting high strength concrete. *IOP Conference Series: Earth and Environmental Science*. **426**, 012057. https://doi.org/10.1088/1755-1315/426/1/012057.

[6]. Lustosa P.R., Magalhães M.S., (2019), Influence of fly ash on the compressive strength and young's modulus of concrete. *Academic Journal of Civil Engineering*. **37**(2), 107-111. https://doi.org/10.26168/icbbm2019.15.

[7]. Hashmi A.F., Shariq M., Baqi A., (2021), An investigation into age-dependent strength, elastic modulus and deflection of low calcium fly ash concrete for sustainable construction. *Construction and Building Materials*. **283**, 122772. https://doi.org/10.1016/j.conbuildmat.2021.122772.

[8]. Durán-Herrera A., Juárez C.A., Valdez P., Bentz D.P., (2011), Evaluation of sustainable high-volume fly ash concretes. *Cement and Concrete Composites*, **33**(1), 39-45. https://doi.org/10.1016/j.cemconcomp.2010.09.020.

[9]. Dragaš J., Ignjatović I., Tošić N., Marinković S., (2016), Mechanical and time-dependent properties of high-volume fly ash concrete for structural use. *Magazine of Concrete Research*. **68**(12), 632-645. https://doi.org/10.1680/jmacr.15.00384.

[10]. Smarzewski P., (2019), Influence of silica fume on mechanical and fracture properties of high performance concrete. Procedia Structural Integrity. 17, 5-12. doi: 10.1016/j.prostr.2019.08.002.

[11]. Sarıdemir M., (2013), Effect of silica fume and ground pumice on compressive strength and modulus of elasticity of high strength concrete. *Construction and Building Materials*. 49, 407-413. doi: 10.1016/j.conbuildmat.2013.08.091.

[12]. Ngo V.T., Bui T.T., Nguyen T.C.N., Nguyen T.T.N., Lam T.Q.K., (2021), Effect of nano-silica content on compressive strength and modulus of elasticity of high-performance concrete. *Proceedings of the 3rd International Conference on Sustainability in Civil Engineering*. **2020**, 153-159. doi: 10.1007/978-981-16-0053-1_19.

[13]. Schiavon J.Z., Borges P.M., Silva S.R., Andrade J.J.O., (2021), Analysis of mechanical and microstructural properties of high performance concretes containing nanosilica and silica fume. *Matéria*. **26**(04). https://doi.org/10.1590/S1517-707620210004.1304.

[14]. Smarzewski P., (2023), Mechanical and Microstructural Studies of High Performance Concrete with Condensed Silica Fume. *Applied Sciences*. **13**(4), 2510. https://doi.org/10.3390/app13042510.

[15]. Kumar V., Sinha A.K., Prasad M.M., (2005), Static modulus of elasticity of steel fiber reinforced concrete. *Cement Combinations for Durable Concre*te, 527-536. https://doi.org/10.1680/ccfdc.34013.0058.

[16]. Sulphia Beevi U, Josep A., Nazeer M., (2020), Effect of hybrid fibers on the mechanical properties of high performance concrete. *IOP Conference Series: Earth and Environmental Science*, **491**, 012035. doi: 10.1088/1755-1315/491/1/012035.

[17]. Gul M., Bashir A., Naqash J.A., (2014), Effect of Steel Fiber on Modulus of Elasticity of Concrete. *International Journal of Engineering and Advanced Technology (IJEAT)*, **3**(4), 304-309. ISSN: 2249-8958.

[18]. Masoud M.A, (2015). Compressive strengths and modulus of elasticity of steel fiber reinforced concrete under different temperature conditions. Thesis, Muhammadiyah University Surakarta.

[19]. Yu R., Liu K., Yin T., Tang L., Ding M., Shui Z., (2022), Comparative study on the effect of steel and polyoxymethylene fibers on the characteristics of Ultra-High Performance Concrete (UHPC). *Cement and Concrete Composites*. **127**, 104418. https://doi.org/10.1016/j.cemconcomp.2022.104418.

[20]. Köksal F., Gencel O., Unal B., Durgun M.Y., (2012), Durability properties of concrete reinforced with steel-polypropylene hybrid fibers. *Science and Engineering of Composite Materials*, **19**(1), 19-27. doi: 10.1515/SECM.2011.0064.

[21]. Hajali Ahmed T.A., Daoud O.M.A., (2016), Influence of Polypropylene Fibres on Concrete Properties. *IOSR Journal of Mechanical and Civil Engineering*. **13**(5), 9-20. doi: 10.9790/1684-1305060920.

[22]. Ahmed A., Mahmoud A.A., Elkatatny S., (2023), The effect of polypropylene fiber on the curing time of class G oil well cement and its mechanical, petrophysical, and elastic properties. *Journal of Petroleum Exploration and Production Technology*. **13**, 1181-1196. https://doi.org/10.1007/s13202-022-01339-9.

[23]. Rajak M., Rai B., (2019), Effect of micro polypropylene fibre on the performance of fly ash-based geopolymer concrete. *Journal of Applied Engineering Sciences*. **9**(22), 97-108. doi: 10.2478/jaes-2019-0013.

[24]. Shaikh F.U.A., Hosan A., (2016), Mechanical properties of steel fibre reinforced geopolymer concretes at elevated temperatures. Construction and Building Materials. **114**, 15-28, https://doi.org/10.1016/j.conbuildmat.2016.03.158.

[25]. Zhang P., Wang J., Li Q., Wan J., Ling Y., (2021), Mechanical and fracture properties of steel fiber-reinforced geopolymer concrete. *Science and Engineering of Composite Materials*. **28**, 299-313. https://doi.org/10.1515/secm-2021-0030.

[26]. Bosnjak J., Sharma A., Grauf K., (2019), Mechanical Properties of Concrete with Steel and Polypropylene Fibres at Elevated Temperatures. Fibers. **7**(2), 9. https://doi.org/10.3390/fib7020009.

[27]. Hosseinzadeh M., Dehestani M., Samadvand H., (2023), A comprehensive quantitative bottom-up analysis of fiber-reinforced recycled-aggregate concrete behaviour. Scientific Reports. **13**, 4502, doi: 10.1038/s41598-023-04136-0.

[28]. Romanian Association for Standardization, (2021), SR EN 12390-1:2021 Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds.

[29]. European Standard EN 12390-13, (2014), Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression.

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