EFFECT OF DISPERSIVE NON-METALLIC FIBRE REINFORCEMENT ON FINE-GRAINED CEMENT COMPOSITE PROPERTIES

RENÉ ČECHMÁNEK, VLADAN PRACHAŘ and JOSEF KNĚZEK

Research Institute of Building Materials, JSC, Hněvkovského 30/65, 61700 Brno, Czech Republic

ABSTRACT

Fibres and grained particles are generally determining structural elements of high quality cement composites with dispersed non-metallic fibre reinforcement. Uniform fibre distribution and fibre position in a final composite have important effect to expected utility characteristics. Evaluation of various parameters influence on fibre-cement composite properties with using of different granulometry with various kind, type and amount of fibres. Possibilities of fibre reinforcement combination. Efficiency of used components for workability and final physical-mechanical properties (flexural strength, impact strength, bulk density, water absorption). Mixing optimization for adequate dispersion and minimal wearing of fibre reinforcement. Evaluation of PVA fibre contribution to reinforcement of cement composites as an alternative to alkali resistant glass fibres.

KEYWORDS:

Cement composites; fine-grained particles; glass fibres; PVA fibres.

INTRODUCTION

Thin-walled cement composites reinforced with various types of fibres find today increasingly broader possibilities of improvement in all spheres of building industry: especially facing panels, U-shaped channels for high-voltage cables deposition up to various shaped architectural elements. Cement-based materials as well as many other silicates are characterized by very good properties in compression but their brittle manner of failure under tensile or impact load was a limiting factor for their applicability range from the very beginnings. Fibre reinforcement is a traditional and effective method how to improve the toughness and durability of silicates. Utilization of the fibre reinforcement in the cement composites benefits generally above all improvement of their operating characteristics in tension under both static and dynamic loading. The steel rod reinforcement became very popular during the whole last century and remains the most frequently used type of concrete reinforcement until now. However, in the second half of the 20th century, an application of uniformly dispersed short fibres strengthening the brittle cement and other silicate matrices appeared with an increasing frequency. In the current practice steel, glass, carbon and various polymeric fibres such as polyethylene, polypropylene, nylon, polyester, polyurethane, cellulose, etc., are commonly used in cement-based materials as well as in many other silicates.

Efforts for favourable properties at tensile stress of these composites are guided by effort to use of relatively high ratio of fibrous reinforcement. The known homogenization difficulties of productive fibrous mixtures with standard mixers more or less affect reached level of technical utility of applied fibres. More complicated situation occurs at efforts for effective parallel usage of more fibrous reinforcement types.

Practical need to guarantee certain standards of mechanical properties requires taking maximum care to dispersal uniformity of all structural components in final composite volume. The difficulties in homogenization of productive mixtures with fibrous component in actual technical practices tend to minimalization of used mixing time. Mentioned trends can have very undesirable effect on some usable properties of these composites, firstly in cases of thin-walled elements. Searching for technical possibilities of effective homogenization for fine-grained components of composites is needed. The homogenizing level should always be a proof component of general quality of final composite.

Proportionally to properties of used matrixes it is need to select reinforcing fibres. With respect to general formation of definite structural products and characterization of their physical and mechanical properties there is a certain problem to create a composite with 3D fibres reinforcement orientation.

OUR APPROACH TO THE PROBLEM

In the frame of our own development we deal with possibilities of effective utilization of another fibre types more than 10 years. In our research we would like to make a new type of cement composite with a hybrid fibre reinforcement with expected good durability and high impact resistance, high resistance to dynamic load and deformation, excellent post-cracked cohesion.

Generally used alkali resistant glass fibre types have time-limited capability to provide definite composite with long term favourable resistance to dynamic loading. Therefore there are present efforts for synergetic utilization of synthetic organic fibres. Creation of effective composites with hybrid fibre reinforcement hangs together with considerable problems with creation of compact structures.

A target of the research was a utilization of non-metallic fibres - inorganic as well as organic synthetic fibres. Precondition of fibres and matrix co-operation is a state of interface between fibre surface and matrix, when it is need to respect a level of long term chemical compatibility as the basis of utility and durability parameters.

Simplicity of a production of fine-grained cement composites with a dispersive fibrous reinforcement by means of a wet mixing enables to use this technology in a technical practice. Due to specific requirements to utility characteristics of these composites it is necessary to aim for matrix components as well as hybrid fibre reinforcement. Requirements to stochastic spatial distribution of one fibre type with constant length and slenderness ratio are limited by the maximal volume fraction of these fibres in the final composite. If particles dimensions of a cement matrix are not smaller than fibre length, their dimensions will be significant by the final composition formation.

It is also advisable to aim for an appropriate fixing of fibres in the matrix to achieve maximal flexural strength of particular fibres in the final composite. In the case of exceeding of the optimal fibre fraction in the final composite a high increase of porosity with subsequent decrease of bulk density, tensile and flexural strength could happen. Improvement should be achieved by means of a higher content of fine particles for better fibre-matrix interaction.

Fibres with high flexural rigidity have better potential for the cement composites, on the other hand a homogenization of the wet fibrous mixture is more difficult. In the case of use of brittle fibres, it is necessary to mix the fibres as gentle as possible. Fibres with low flexural rigidity enable easier homogenization, however utilization of their tensile characteristics is uneasy due to their position in a final structure. In particular cases these fibres contribute to creation of oval fibre clusters, which are connected each other with particular fibres very poorly.

More complicated situation occurs, when we use two or more types of the dispersive non-metallic fibres with relatively low flexural rigidity. Prospective efficiency of the non-metallic dispersive hybrid fibre utilization relates to availability of potentially suitable fibres with the appropriate geometry.

Recent experiments with the wet fibre mixture homogenization indicate a way to a combination of fibres with equal length and flexural rigidity, or a combination of fibres with significantly different geometrical characteristics – in this case it is necessary to evaluate a fixing of all types of the fibre reinforcement in the matrix.

Combination of the fibres with equal geometry and flexural rigidity in the wet conditions is without technological problems. Proportions of the used fibres are chosen according to their significance and contribution to the final utility characteristics of the cement composite. As an example could be a fine-grained cement composite with equal volume fraction of ARG fibres (tex 45) and PVA fibres (dF = 100 µm), length of both fibres is 12 mm, total volume of all fibres is 2,5 %. With this combination it is possible to make an economic variant with impact strength cca 50% higher than in case of only alkali resistant glass fibres.

THEORETICAL MODEL

Very little attention was paid to the structure of fibre composites with hybrid reinforcement. Only theoretical studies aimed to the modelling of idealized fibre structure with just one fibre type and geometry or to the modelling of particle structures without considering the fibre were done. Particular information was published about selected mechanical properties of silicate matrixes reinforced by glass, carbon, polypropylene, cellulose and other fibres or by their combination.

Our research was primarily set on a base of the theoretical model of contact disperse fibre structure showed in the Figure 1. The proposed model of the cement composite structure with the non-metallic hybrid dispersive fibres enables a basic orientation for the design of geometrical proportions of the reinforcing fibres with qualitative different properties and the matrix components. For the realization it is necessary to use a plasticizer with sufficient efficiency. Uniformity of the components distribution in the mixture is ensured by order of their adding to the mixture and optimal time of their homogenization.

A qualitative criterion of the final cement composite is not only an achieved stage of parameters but also an achieved stage of utility characteristic variability. Technical problem of the realization of the cement composite with the hybrid dispersive fibre reinforcement could be availability of the defined fibres with suitable slenderness and effective cohesion in the final cement composite.

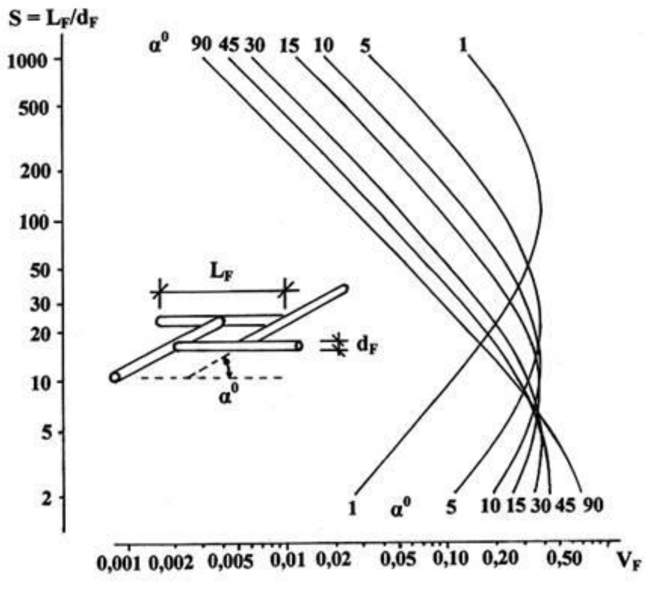

Figure 1 – The model of contact disperse fibre structure

PRACTICAL PART OF RESEARCH

In the frame of actual technological exams we operated with constant cement matrix composition: Portland cement CEM I 52,5, fine-grained sand (D_{max} = 1 mm), microsilica, plasticizer, defoaming agent and alkali resistant glass fibres with tex 48 mm, length 12 mm, addition cca 2,5 vol.%. This laboratory work would be finished with a design of cement composite with new utility characteristics. According to achieved level of properties we want to offer new types of balcony panels, variable formwork panels, light-weight structures of pedestrian catwalks, shelters along cycling tracks etc.

There were designed two mixtures differing in filler composition. Contrary to the standard mixture (S) in the fine-grained mixture (F) a part of silica sand was substituted by fine silica filler, in order to percentage share of filler volume in total volume be equal. Due to this substitution a workability of fresh mixture tended to be worse, thus higher dosage of superplasticizer was needed.

Table 1 – Mixture components

Mixture S	
Component	(%)
Cement	47,4
Silica sand	35,7
Silica fume	2,4
Superplasticizer (% of cement)	1,6
Water	14,5
water-cement ratio 0,31	

Mixture F	
Component	(%)
Cement	47,4
Silica sand	23,7
Fine silica filler	11,9
Silica fume	2,4
Superplasticizer (% of cement)	1,9
Water	14,5
water-cement ratio 0,31	

For reinforcing of the above defined mixtures were used:

Glass fibre: - 12 mm - in amount 2 %

PVA (polyvinyl alcohol) fibre: - 6 mm - in amount 1 %
- 12 mm - in amount 2 %
- 6 mm - in amount 0,5 % + 12 mm - in amount 1,5 %

Glass fibre (12 mm - in amount 1,5 %) + PVA fibre (6 mm - in amount 0,5 %)

Carbon fibre: - 10 mm - in amount 1 %

Aramid fibre: - 6 mm - in amount 1 %
- 1,5 mm - in amount 1 %
- 6 mm - in amount 0,5 % + 1,5 mm - in amount 0,5 %

Carbon fibre (10 mm - in amount 0,5 %) + Aramid fibre (6 mm - in amount 0,5 %)

(amount in % of dry components weight)

Notice:

kind of fibre = material of fibre (glass, PVA, carbon, aramid)

type of fibre = dimensional proportions of fibre (length, diameter, slenderness)

EVALUATION OF MIXING PROCESS

Within proposition of optimal mixing process it was important to take into account all the factors with significant effect on final characteristics of the composites. Typical problem in fibre-cement composite production is difficult achievement of acceptable dispersion of fibre reinforcement in matrix without erosion and wearing of fibres within homogenization in a mixing drum.

Lots of mixing processes differing in order and duration of individual mixing stages were examined with following results: When fibres are added to the mixtures in the last stage of mixing after batch water addition, they are minimally damaged but insufficiently dispersed in the mixture volume. When fibres are added to the mixture in the first stage of mixing together with dry components, some wearing can occur, but we can achieve better dispersion of the fibres and better final characteristics of the composite.

While in the case of glass fibres it is recommended to mix them in the last stage of the mixing process for only 1 minute (W1), in the case of other fibre kinds two most optimal processes were evaluated:

W4 - dry mixture homogenization for 2 minutes
- wet mixture homogenization for 2 minutes
- fibre homogenization for 4 minutes

D3/W4 - dry mixture + fibre homogenization for 3 minutes
- wet mixture homogenization for 4 minutes

Total mixing time in both cases was equal, but mixing time of fibres is different and more favourable to the reinforcing fibres by the process marked as W4.

Table 2 – The mixing process

Mixing time (minutes)					
Mixing process	**W1**	**W2**	**W4**	**Mixing process**	**D3/W4**
Dry components	2	2	2	Dry components with fibres	3
Batch water with plasticizer	3	2	2	Batch water with plasticizer	4
Fibres	1	2	4		

RESULTS

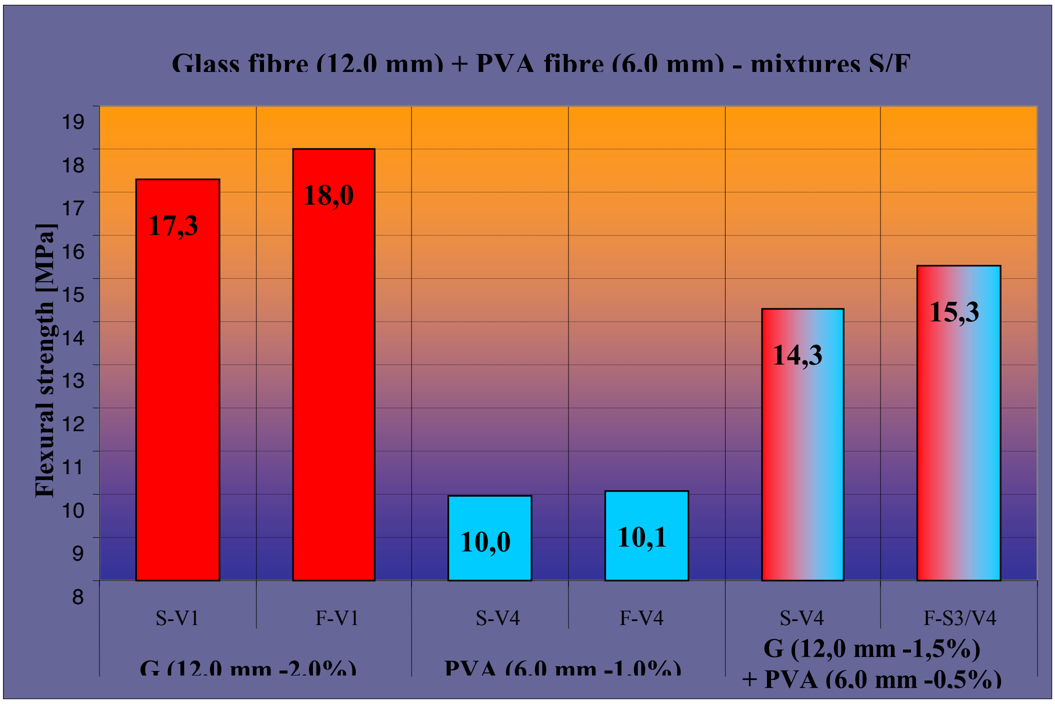

Figure 2 – The comparison of highest flexural strength (Glass / PVA fibre)

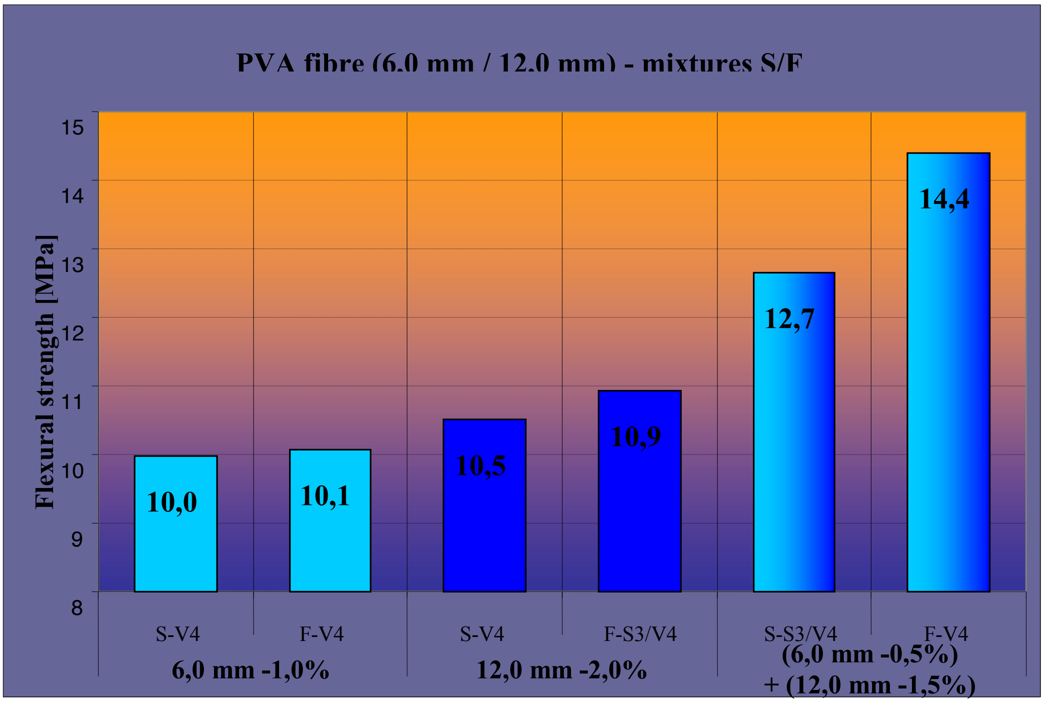

Figure 3 – The comparison of highest flexural strength (PVA fibre)

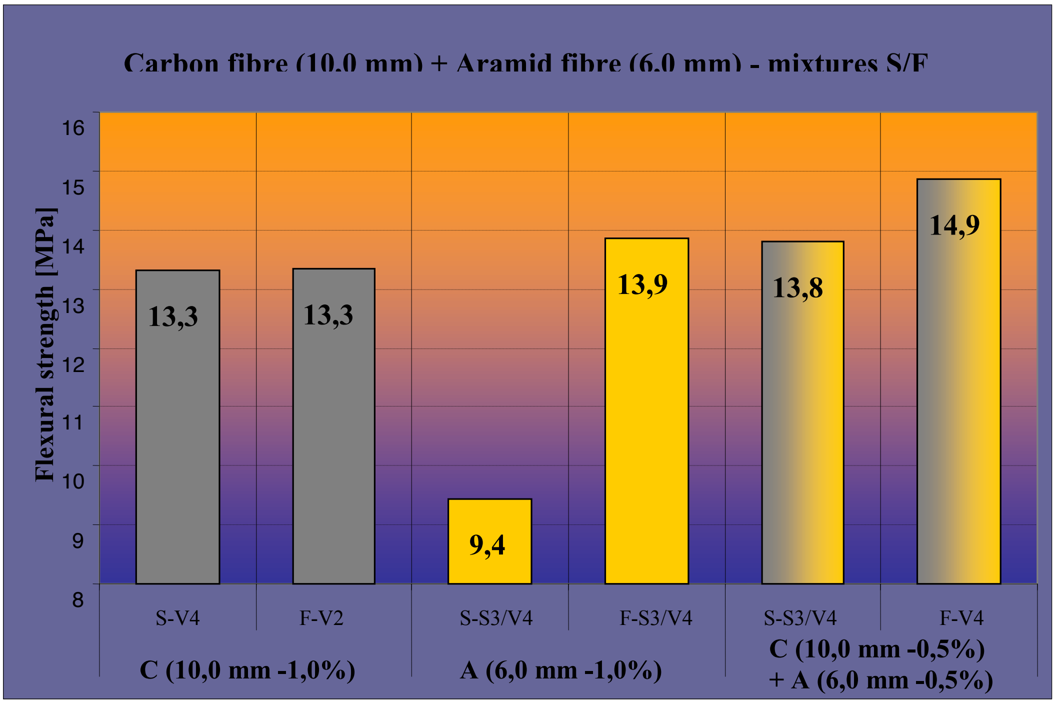

Figure 4 – The comparison of highest flexural strength (Carbon / Aramid fibre)

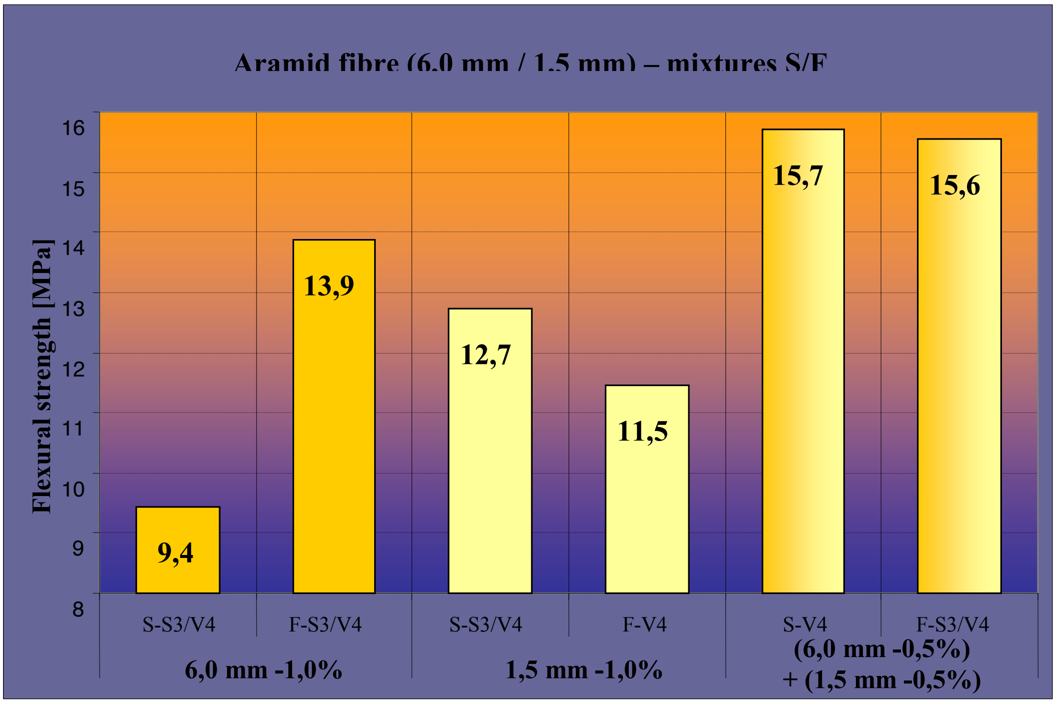

Figure 5 – The comparison of highest flexural strength (Aramid fibre)

Table 3 – The comparison of highest flexural strength

Fibre	Length and amount of fibres	Mixture	Mixing process	Flexural strength MPa
Glass fibre	12 mm (2,0 %)	F	W1	18,0
Polyvinyl alcohol fibre	12 mm (2,0 %)	F	D3/W4	10,9
Glass fibre + Polyvinyl alcohol fibre	G 12 mm (1,5 %) + PVA 6 mm (0,5 %)	F	D3/W4	15,3
Polyvinyl alcohol fibre (combination)	6 mm (0,5 %) + 12 mm (1,5 %)	F	W4	14,4
Carbon fibre	10 mm (1,0 %)	F	W2	13,3
Aramid fibre	6 mm (1,0 %)	F	D3/W4	13,9
Carbon fibre + Aramid fibre	C 10 mm (0,5 %) + A 6 mm (0,5 %)	F	W4	14,9
Aramid fibre (combination)	6 mm (0,5 %) + 1,5 mm (0,5 %)	S	W4	15,7

In the second part of our research several types of PVA (polyvinyl alcohol) fibres were used for cement matrix (both S and F) reinforcement:

Table 4 – Tested PVA fibres

Fibre type	amount [%] *
PVA I 6 mm	1,0
PVA II 12 mm	2,0
PVA I 6 mm + PVA II 12 mm	0,5 + 1,5
PVA III 6 mm	1,5
PVA IV 12 mm	1,5
	2,0
PVA V 8 mm	1,5
PVA VI 8 mm	1,5
PVA VII 8 mm	1,5

* (in % from dry mixture components)

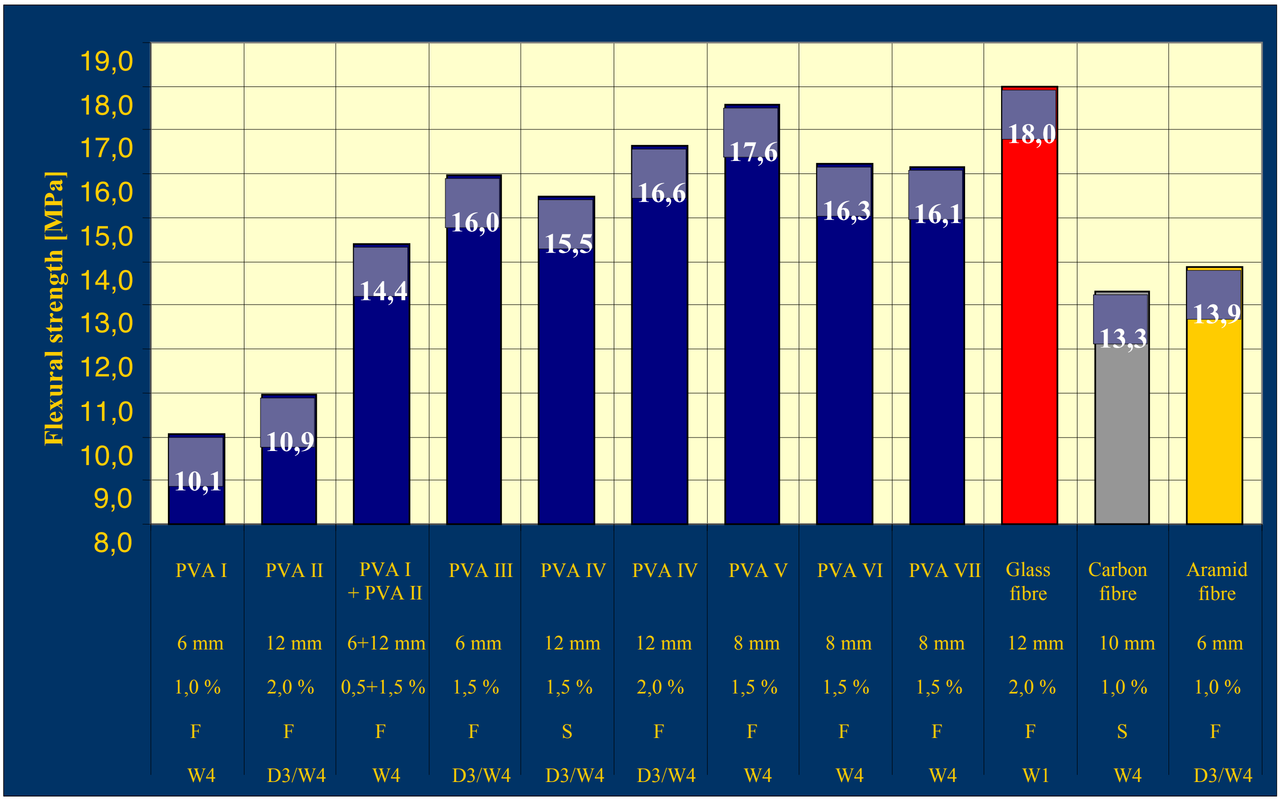

Figure 6 – The comparison of highest flexural strength of selected fibre types

CONCLUSIONS

The mixture F is more effective for flexural strength of the test samples. The reason is that in this mixture is a part of content of silica sand (about 1/3) substituted with fine silica filler in comparison to the standard mixture. Regarding to all results we can conclude following certain relation: The higher coarse particle content in matrix and the longer mixing time of fibres with coarse particles – the higher fibre wearing and the lower strength level.

The properties of both mixtures reinforced with combination of two kinds or types of fibres are evident better in comparison to one kind or type of fibre reinforcing. The test results of combined fibre reinforcement in cement composite proved a benefit to flexural strength, especially in the case of two type combination of the same fibre kind (PVA fibre 6 mm/12 mm; Aramid fibre 1,5 mm/6 mm).

Considering all tested characteristics (flexural strength, impact strength, bulk density, water absorption) there were evaluated the best samples with PVA fibre type marked PVA IV with length 12 mm in amount 2,0 % in matrix with higher content of fine fillers (F). The mixing process (W4 or D3/W4) isn't a dominant factor in this case. In both variants flexural and impact strength above standards as well as appropriate levels of bulk density and water absorption were achieved, thus this fibre type could be recommended for further research, especially in combination with other suitable fibres.

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