Table 2D Scaled contributions (relative variance contributions) [%]

Variable ID	F1	F2	F3
Var1 (Length)	0.1	74.8***	0.0
Var2 (Diameter)	9.3	22.9***	0.0
Var3 (Aspect ratio)	37.5***	0.3	0.3
Var4 (FIER)	37.9***	0.4	0.1
Var5 (Hook geometry)	2.7	0.5	41.9
Var6 (Tensile strength)	12.0	0.1	0.7
Var7 (Ductility)	0.4	1.0	57.0***

The detailed contribution of all variables to the main PCA factors is presented in Table 2B (most important according to contribution of the variables criterion were marked as bold and labelled with asterisk). To inspect more strictly the PCA factors in terms of the relevant variables the squared cosines of the variables and scaled contributions (relative variance contributions) were calculated and presented in Tables 2C and 2D, respectively. For variables 4 and 5 (F1 column) the squared cosines are greater than 0.5. According to such criterion (David & Jacobs 2014), the real correlation may exist and these variables strongly contribute for PCA factor F1 (appropriate numbers are marked as bold and labelled as double asterisks within Table 2C).

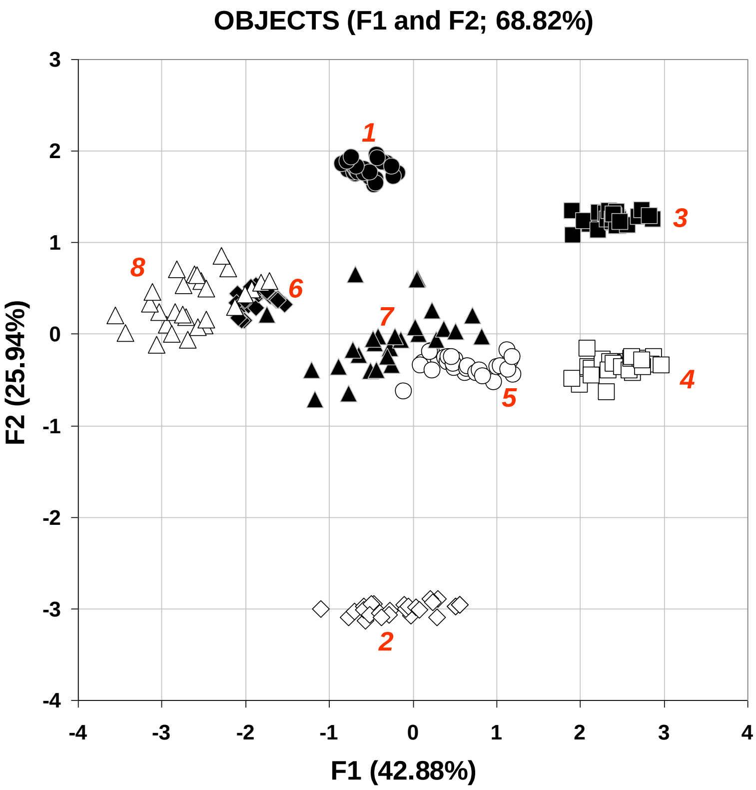

Fig. 7 Principal component plot showing objects clustering (all individual steel fibres) in two dimensional space (F1 and F2 factors scores) - numbers from 1 to 8 are related to particular types of engineered steel fibres (see Table 1)

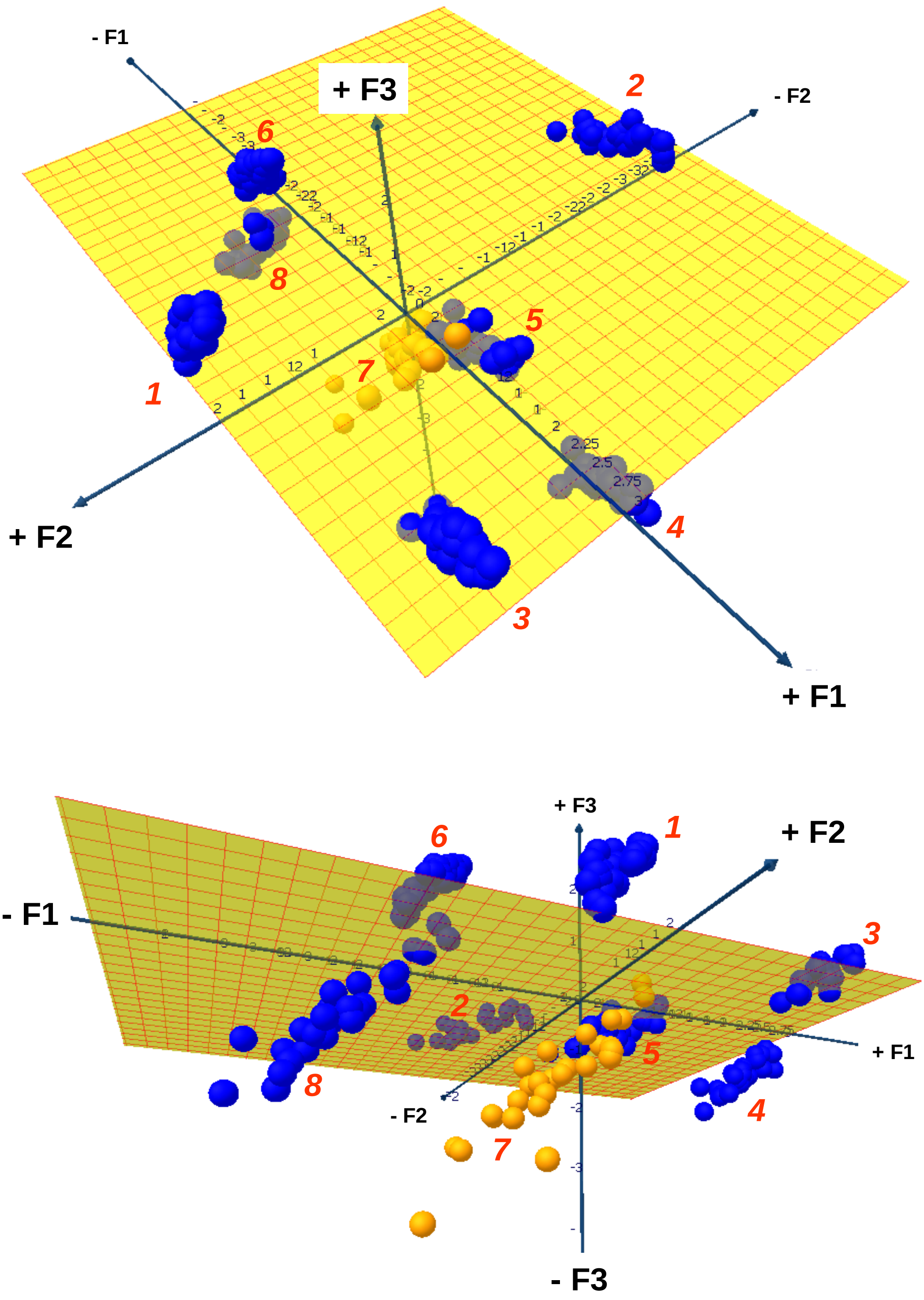

Fig. 8. Principal component plot showing relationships between objects investigated (all individual steel fibres) in three dimensional space (F1, F2 and F3 factors scores). Numbers from 1 to 8 are related to particular types of engineered steel fibres (Table 1)

Considering scaled contributions values (Table 2D) related to the first PCA factor, the variables 3 and 4 are responsible for 75.4% of information included in F1 (sum of data bolded and labelled as triple asterisks within F1 column). In case of PCA factor F2 the squared cosines and scaled contributions data confirm the analysis based on the factor loadings (Table 2A) and contribution of the variables (Table 2B) criteria. Basically, the fibres length (variable 1) and diameters (variable 2) are strongly contributing to F2. Nevertheless, considering data included in Tables 2C and 2D the ductility (variable 7) should be considered as the main variable contributing to PCA factor F3.

The principal component plot showing objects (individual fibres) clustering is presented in Fig. 7. According to data presented in the principal component plot, information that persists in studied mechanical and spatial parameters is sufficient for accurate fibres classification using the multivariate approach. As it may be observed, this technique allows precise classification of individual fibres taking into account two dimensional space, involving factors F1 and F2. Complete clusters separation (including fibre types 6, 8 and particularly 5 and 7) can be performed considering three factors simultaneously, due to their location in three dimensional factor scores space (Fig. 8). Observed on these PCA graphs individual steel fibres clustering and significant separation between clusters related to particular types of the fibres, strongly supports the hypothesis that parameters selected in this study contain key and almost complete information that may reveal the important differences between steel fibre types. Nevertheless, the calculations should be repeated using additional parameters such as pull-out strength etc. There is also a need to find new parameters describing, more precisely, properties of steel fibre that may improve accurate classification of such objects using multivariate computations. PCA factors, proposed in this study, may occur very valuable for modelling fibre reinforced concrete and identification of its properties (Sucharda et al. 2015).

4. CONCLUSIONS

Presented research has revealed that direct comparison of engineered steel fibres used as reinforcement for concrete *via* univariate approach may be strongly limited. It became clear that properties of tested fibre populations were significantly differentiated. Due to the nature of parameters commonly used for their steel fibre characterization, resulting quantitative data may be treated as multivariate data set. The applied in this research multivariate approach enables easy comparison of the parameters (variables) and to classify individual fibres for given type of engineered steel fibre. Utilized PCA calculations indicated that length/diameter ratio and FIER parameters may carry equal information in case of the fibres that are characterized by similar cross-section shape. The calculations should be repeated using additional parameters such as pull-out strength etc. The achieved results proved that there is a need of finding new parameters describing, more precisely, properties of steel fibre. New parameters may improve accurate classification of steel fibre such objects using multivariate computations.

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