Strength parameters of unidirectional and quasi-unidirectional composite

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***Abstract* — In this work, the identification of selected elastic constants and strength parameters of unidirectional moulded composite with continuous fibres was performed. Furthermore, the analysis of so-called quasi-unidirectional composite was performed. The composite has special 3D structure, which is achieved by wrapping continuous fibre bundles with transverse fibres with the aim to increase mainly the transverse compressive strength while keeping the volume fraction of continuous fibres.**

***Index Terms* — Composite, identification, experiment, transverse compressive strength, quasi-unidirectional.**

I. Introduction

COMPOSITE materials have very good mechanical properties (e.g. stiffness, strength) but only in fibre direction (longitudinal) [1, 7]. These properties cannot be fully used in all cases because of much lower strength in the direction perpendicular to the fibres (transverse) [3]. This problem occurs for example in case of wrapped pin joint (WPJ) of composite-metal (see Fig. 1) where transverse compressive failure results in lower longitudinal tensile strength [4, 5]. Other examples, where the values of the respective strengths were identified by the combination of experiment and finite element analysis, can be found in [6, 8].

Therefore, special 3D structures of moulded composite with continuous fibres are investigated, where the increase of the transverse compressive strength is expected. The 3D structure is achieved by wrapping continuous fibre bundles with transverse fibres. The 3D structure can have different configurations (see Fig. 5) in dependence on the fibre bundle laying into the form [2]. This type of composite is designated as quasi-unidirectional composite in this work.

The mechanical properties of the quasi-unidirectional composite are compared with unidirectional composite using compressive and interlaminar tests. The selected mechanical parameters of the unidirectional composite which were possible to investigate using simple tensile and compressive tests were also identified in this work. These parameters will be used for example in numerical models of the WPJ.

The investigated composites consist of PITCH carbon fibres designated as Dialed K63712 (tex 1972 g/km) and the matrix was epoxy anhydride resin designated as Vantico LY564/917/960-1. The mechanical properties of the fibres and the matrix are shown in Table 1 and Table 2, respectively. The experimental samples were made by CompoTech company [2].

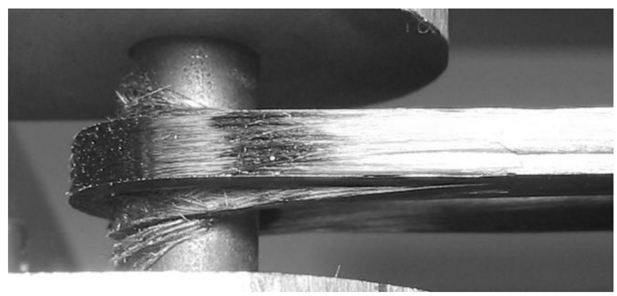

Fig. 1 Compressive matrix failure before tensile fibre failure in case of wrapped pin joint of composite-metal.

Table 1 Mechanical properties of Dialed K63712 fibre.

Fibre strength in tension X^{T}_{f}	2600 MPa
Fibre density ρ_f	2000 kg.m^{-3}
Fibre longitudinal modulus $E_{f\mathrm{L}}$	640 GPa
Fibre transverse modulus $E_{f\mathrm{T}}$	5 GPa
Fibre shear modulus G_f	20 GPa
Fibre Poisson's ration ν_f	0.35

Table 2 Mechanical properties of resin LY564/917/960-1.

Test	Property	Values [MPa]
Tensile test according to ISO 527	Ultimate strength	75 – 91
	Young's modulus	3100 – 3200
Bending test according to ISO 78	Ultimate strength	140 – 150
	Young's modulus	3000 – 3100
Interlaminar strength according to ASTM D 2344	Shear strength	54 – 58

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II. Unidirectional Composite

Experiments were performed with Zwick/Roell Z050 machine. The shapes and marking of experimental samples are obvious from Fig. 3. The displacements were measured by an extensometer of initial length l_0 (see Table 3) in case of tensile tests. An extensometer for bending test was used in the case of compressive tests and it was attached to the upper jaw of the testing machine. Therefore, the measured compressive strain includes certain error corresponding to deformations of the machine parts located under lower machine grip.

The averaged maximal forces reached are shown in Table 3 with corresponding strengths. The longitudinal tensile strength of the composite was not investigated because the transverse compressive failure occurs (crushing in the grips) before the longitudinal tensile failure in case of T-L samples.

The transverse compressive strength in T’ direction (see Fig. 3) was investigated using two types of samples marked as C-T’1 and C-T’2. These samples had the same sizes of the compressive surfaces 5.05×30.1 mm, but the fibres were shorter in case of C-T’1 samples. Higher strength (33 %) was found in case of C-T’1 samples compared to C-T’2 samples.

The elastic longitudinal modulus E_L = 330 GPa was identified from the tensile test in the fibre direction (T-L) and the elastic transverse modulus E_T = 4.37 GPa was identified from the tensile test in the perpendicular direction to the fibres (T-T).

Typical failures of the samples with corresponding stress-strain curves are obvious from Fig. 4.

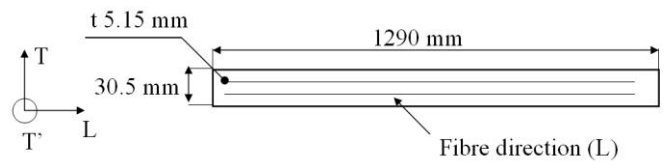

Fig. 2 Semi-finished product for manufacture of samples.

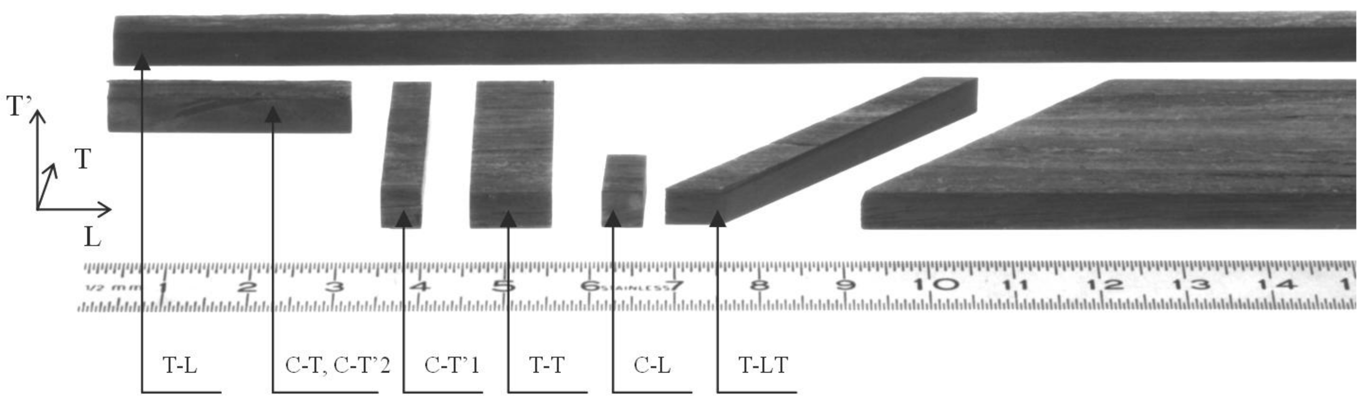

Fig. 3 Shapes and marking of experimental samples: First letter denotes the sample for tensile test (T) or compressive test (C), designation after dash corresponds to loading directions (L, T, T’, LT), and numbers 1 and 2 distinguish different fibre lengths.

Table 3 Parameters of experimental samples.

Sample	Thickness t [mm]	Width b [mm]	Measured length l_0 [mm]	Fibre orientation[1] Θ [°]	Loading velocity v [mm/min]	Maximum force F_{max} [N]	Strength $F_{max}/(tb)$ σ_{max} [MPa]
T-L	5.15	5.00	60.00	0	1.00	16500[2]	640[2]
T-T	5.15	10.05	20.00	90	0.05	260	5
T-TL	5.15	5.00	20.00	45	0.05	417	16
C-L	5.15	10.00	5.10	0	0.50	10032	195
C-T	5.15	30.00	5.05	90	0.50	6285	41
C-T’1	5.05	30.10	5.15	90	0.50	9347	61
C-T’2	5.05	30.10	5.15	90	0.50	6929	46

[1] According to loading axis. [2] Tensile fibre failure did not occur – the value corresponds to compressive matrix failure in jaws.

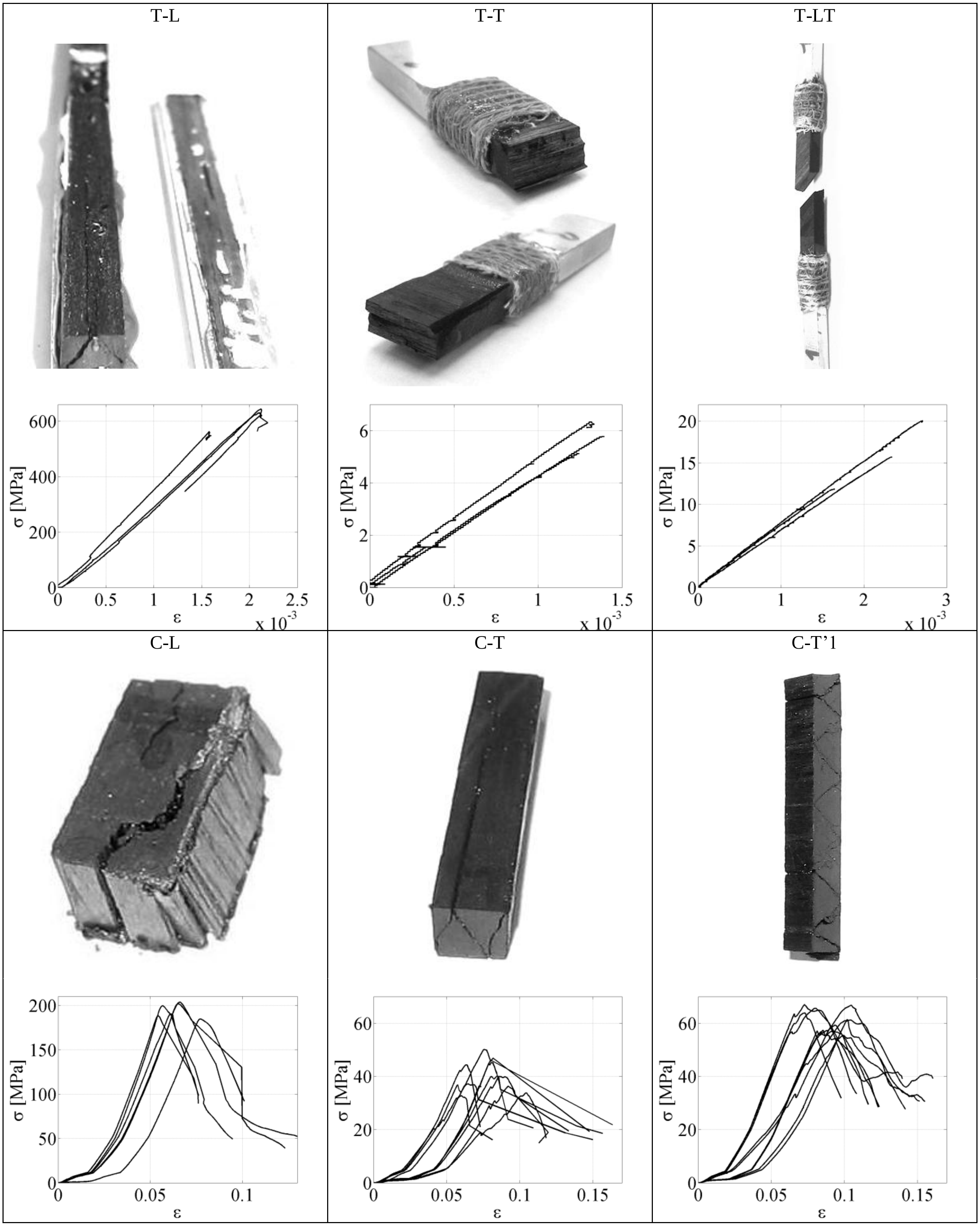

Fig. 4 Typical failure of tested samples and corresponding σ–ε curves.

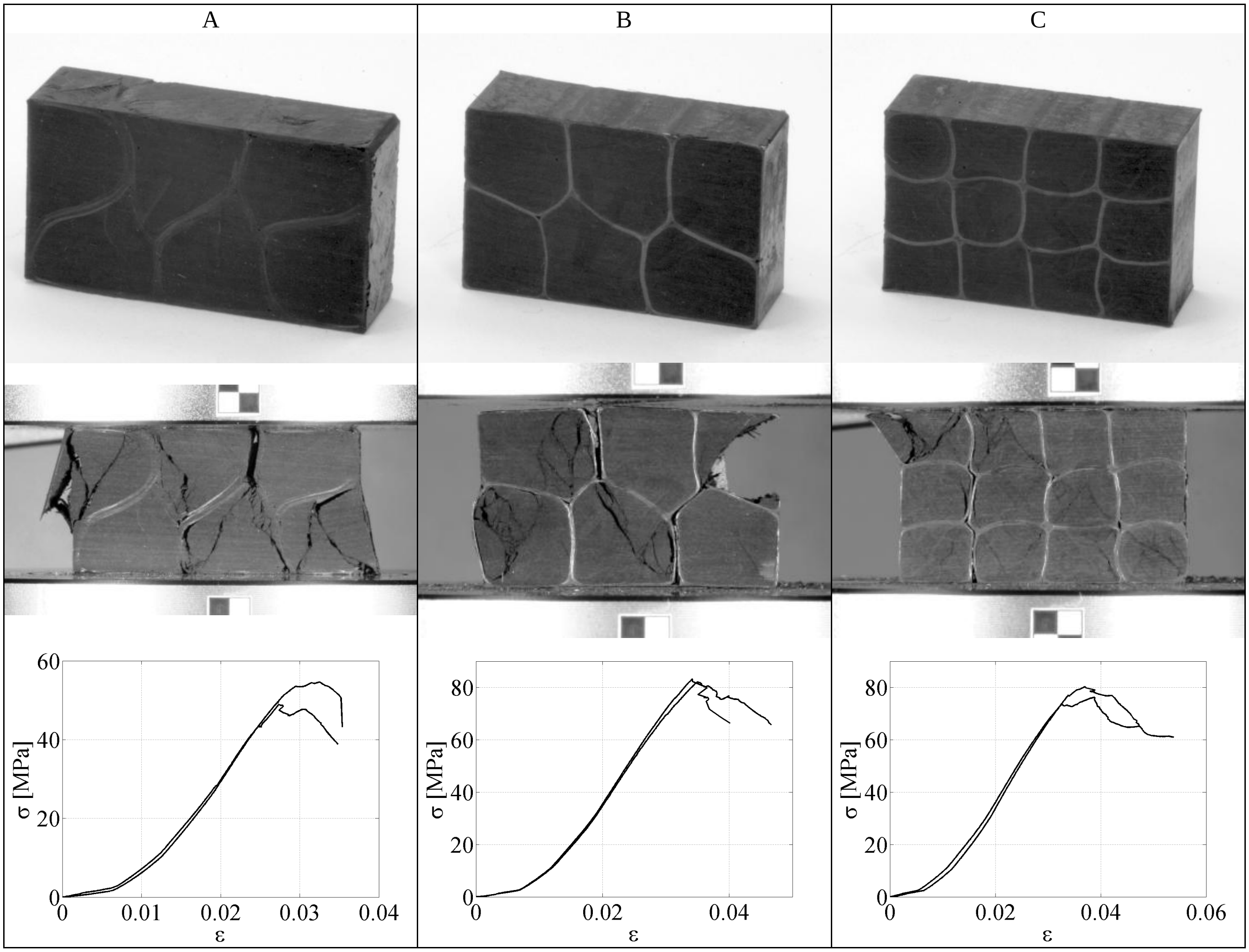

Fig. 5 Samples before and after failure and σ–ε curves of samples A, B and C.

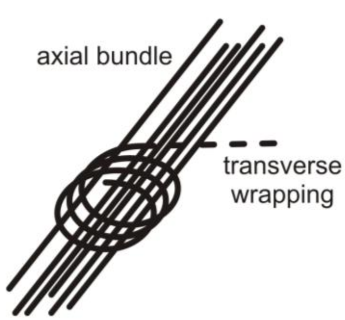

Fig. 6 Sketch of one 3D structure cell manufacturing.

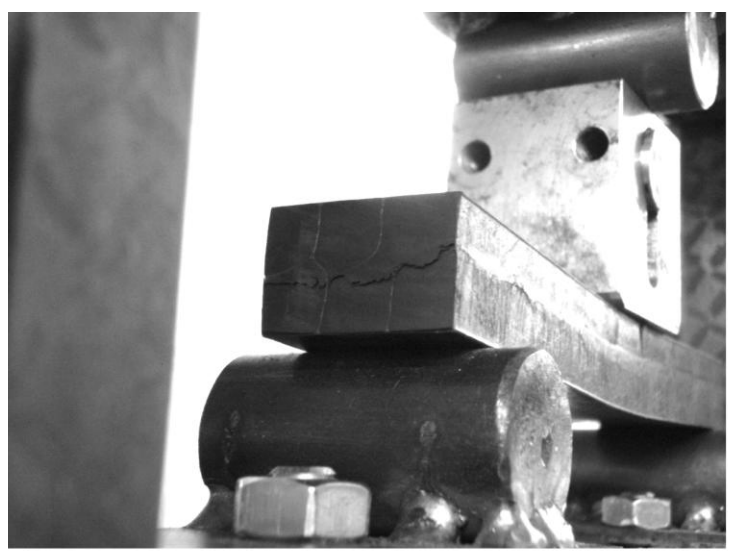

Fig. 7 Interlaminar test according to ASTM D2344/D2344M-00.

III. Quasi-Unidirectional Composite

In this part, three composite profiles manufactures by moulding fibre bundles wrapped with layer of transverse (tangential) fibres were investigated (see Fig. 6 for the wrapping technique description). The profiles differed in the numbers of bundles, their shapes and the dimensions: type A 36×20×10 mm, type B 31×20×10 mm and type C 31×20×10 mm. With respect to the resulting structure and the volume ratios of constituents, these profiles can be considered as quasi-unidirectional [9].

The tested specimens of all three types of profiles A, B and C are displayed in Fig. 5. Below are examples of typical failure patterns obtained by compressive test and the corresponding compressive stress–strain diagrams. The goal was to show the influence of the wrapping by transverse fibres on the compressive strength in comparison with purely unidirectional composite (designated as type D, 30×20×11 mm) with the same volume ratio of longitudinal fibres. The resulting strengths are compared in Fig. 9. The most significant improvement in compressive strength was reached for the type B structure.

Besides the compressive strength, the compressive stiffness was measured too. Young's moduli were measured in standard compressive test except modulus E_x which was measured in tensile test too. Shear moduli were measured in three-point bending (3PB). The results can be seen in Table 4. Notation of indices used in the table is obvious from Fig. 8.

The measured value of tensile stiffness was higher than that of the compressive one. This could be caused by inclination of fibres in bundles into the loading direction. Another remark can be made about the different stiffness values E_y and E_z. This fact results from unsymmetrical samples in directions y and z. There are different numbers of bundles in each direction; 3 in y direction and 4 in z direction.

Moreover, the compressive strengths were measured in directions y and z, and the relative difference was approximately the same as that of the corresponding moduli ratio E_y/E_z in Table 4.

Table 4 Elasticity constants of quasi-unidirectional samples.

E_x [GPa]	tensile test	301.8
	compressive test	243.8
E_y [GPa]	compressive test	10.8
E_z [GPa]	compressive test	13.2
G_{yz} [GPa]	-	-
G_{zx} [GPa]	3PB	2.0
G_{yx} [GPa]	3PB	2.6
ν_{zx}	compressive test	0.007
ν_{yx}	compressive test	0.025
ν_{xz}	-	-

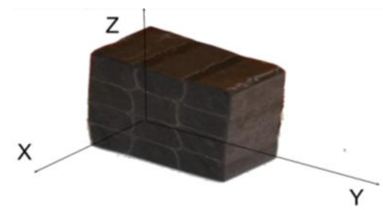

Fig. 8 Specimen co-ordinate system.

Furthermore, the interlaminar strength of the 3D structures was studied and compared with unidirectional composite (see Fig. 7). The tests were performed according to ASTM D2344/D2344M-00 (three-point bending) by CompoTech on specimens having the same cross-sections as the above mentioned compression specimens A, B, C and D while the length was 200 mm and the span of the supports was 170 mm. From the results shown again in Fig. 9 it shows that the wrapping can significantly improve also the interlaminar strength when compared to purely unidirectional composite, especially in case of the B and C profiles.

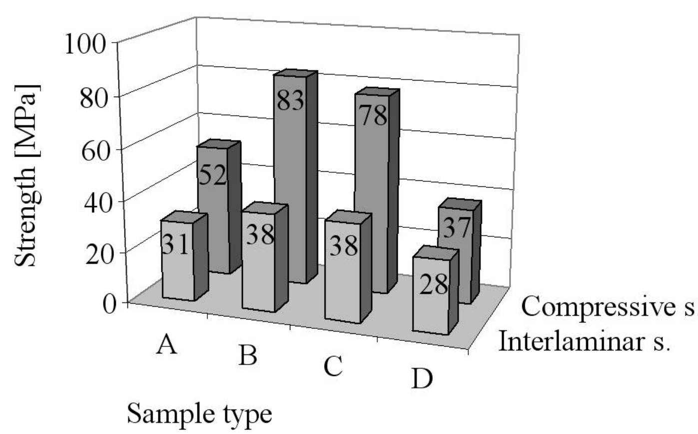

Fig. 9 Comparison of compressive and interlaminar strengths.

IV. Conclusions

Series of tensile and compressive tests of unidirectional composite were performed. Herewith, selected elastic and strength parameters of the material were identified. It was found out that specimens with short fibres have lower compressive strength than specimens with longer fibres. This phenomenon remains unexplained, however, it might be caused by the misalignment of the fibres. This will be analysed in future work.

Furthermore, the compressive strength and also other elastic constants of three types of so-called quasi-unidirectional composites were investigated. The quasi-longitudinal composite has a special 3D structure composed by longitudinal fibre bundles wrapped by layer of transverse fibres. It was shown, that the wrapping has significant positive influence on both the compressive and interlaminar strengths compared to the purely unidirectional composite. It is evident that for given cross-section or geometry there exists certain optimal shape of the 3D structure. Therefore, the performance of specific functional component could be significantly improved for example by means of numerical models with mathematical optimization methods. This will be the subject of the following study.

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