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THE EFFECT OF FIBRE ORIENTATION ON FRACTURE PROPERTIES OF GLASS FIBRE-EPOXY COMPOSITE

UTICAJ ORIJENTACIJE VLAKNA NA KARAKTERISTIKE LOMA KOMPOZITA TIPA STAKLENA VLAKNA-EPOKSI SMOLA

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- composite
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- epoxy resins
- fibre orientation
- impact testing
- stress intensity factor

Ključne reči
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- epoksi smola
- orijentacija vlakna
- ispitivanje udarom
- faktor intenziteta napona

Abstract

The effect of glass fibre orientation in an epoxy matrix composite on impact load and fracture toughness is experimentally analysed by testing Charpy V notched specimens, and notched CT specimens. Specimens are produced from samples with glass fibre orientation $[\pm 45°]_{4s}$, and $[0°/90°]_{4s}$. Specimens with V notch have been tested on instrumented Charpy machine, enabling to separate energies for crack initiation and crack propagation. The stress intensity factor K_c is selected as the fracture toughness parameter.

Izvod

Ispitivanjem Šarpi epruveta sa V zarezom u radu je eksperimentalno analiziran uticaj orijentacije staklenih vlakana u matrici epoksi smole kompozita na udarno opterećenje i žilavost loma. Epruvete su izrađene iz uzoraka orijentacije staklenih vlakana $[\pm 45°]_{4s}$ i $[0°/90°]_{4s}$. Epruvete sa V zarezom su ispitivane na Šarpi klatnu, čime je omogućeno razdvajanje energija za inicijaciju i rast prsline. Faktor intenziteta napona K_c je izabran kao parametar žilavosti loma.

INTRODUCTION

In order to meet very strong requirements for airplane design application, composite materials with epoxy resin matrix and glass fibres acting as stiffener are developed and considered as materials of the third generation, /1/. Combining two or more different constituents, in the physical sense, new strength and toughness properties can be obtained in the composite material. Constituents preserve their initial properties and the composite is intended to preserve their best individual properties and also achieve properties not typical for individual constituents. Selecting convenient constituents and their ratio in a composite structure, the required strength and toughness properties, corrosion resistance, heat resistance, conductivity or vibration damping can be achieved with minimum material consummation, /2/.

The characterisation of mechanical properties of composite materials is a difficult task. First of all, the question arose on how to define their tensile and toughness properties, and how to apply standard test methods developed for homogeneous materials. This is particularly the case with local properties, such are impact toughness and fracture mechanics parameters. These are valuable design characteristics, but it is not possible to evaluate them using the same approach as for homogeneous materials, /3/. The analysis of results obtained in the performed experimental investigation can help to a better understanding of local and singular properties of complex structures, such as the tested composite.

MATERIALS AND EXPERIMENTS

The tested material in this experiment is a glass fibre-epoxy resin composite, produced from glass fabric by a standard polymerization procedure in the autoclave, /4/. Each panel consists of 32 laminae, 8 mm thickness in total. Three sets of samples had been prepared, depending on the arrangement of fibre direction and laminae in the composite:
– I set - arrangement sample A - $[\pm 45°]_{4s}$,
– II set - arrangement sample B - $[0°/90°]_{4s}$

Impact testing is performed with Charpy V specimens, 8 mm thick, on the instrumented machine SCHENCK TREBEL 150 J, at room temperature, according to the ASTM E23-86 standard procedure. The stress intensity factor K_c at the notch tip is determined by following the procedure defined in ASTM E399. Testing is performed at room temperature on the electrical-mechanical testing machine SCHENCK TREBEL RM 100. Crack opening displacement (COD) is monitored by clip-gauge DD1, with an accuracy of ±0.001 mm. In order to achieve a continuous crack opening rate, the testing is COD controlled.

Impact test results

Typical relationships, force vs. time, obtained by instrumented impact testing, are presented in Fig. 1 for the Charpy V specimen A1, and in Fig. 2 for specimen B1. The obtained results of impact testing, the total impact energy and its components of crack initiation and crack propagation, with deflection values, are summarised in Table 1.

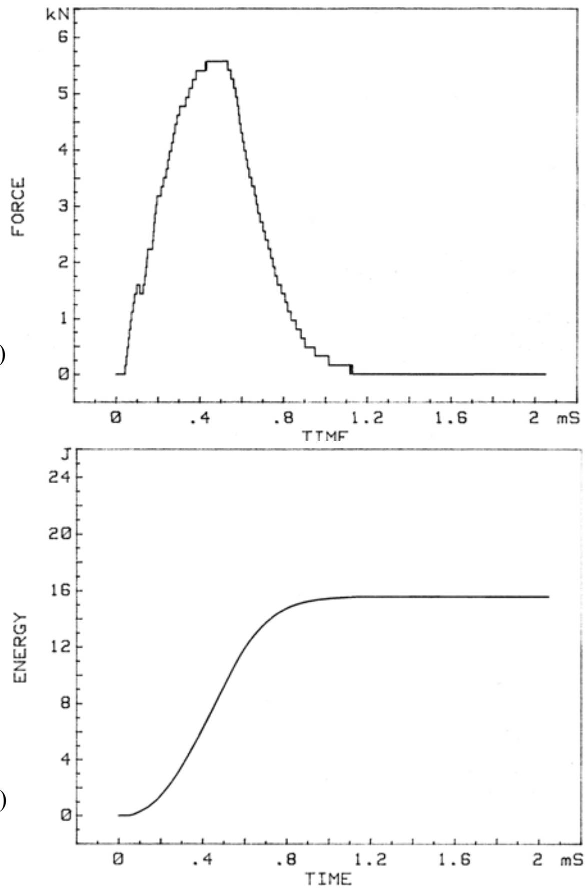
(a)
(b)


Figure 1. Force–time (a) and energy–time (b) plots for specimen A1.
Slika 1. Dij. opterećenje–vreme (a) i energija–vreme (b) za epruv. A1

(a)
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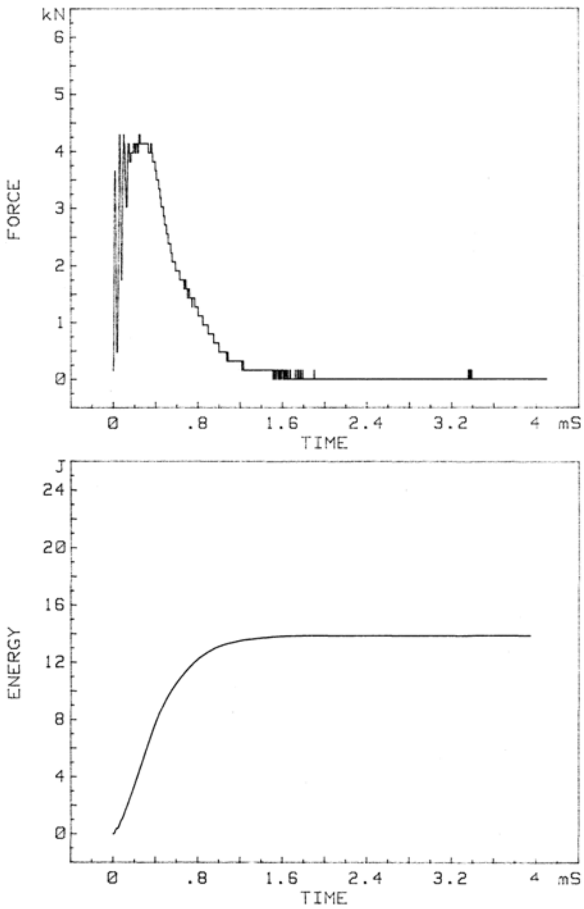

Figure 2. Force–time (a) and energy–time (b) plots for specimen B1.
Slika 2. Dij. opt.–vreme (a) i energija–vreme (b) za epruvetu B1

Table 1. Impact test results: total impact energy, crack initiation and propagation components, and deflection values.
Tabela 1. Rezultati ispitivanja udarom: ukupna energija udara, komponente inicijacije i rasta prsline, i odstupanja

Sample	Spec.	Total impact energy, E_t (J)	Crack initiation energy, E_{in} (J)	Crack propagation energy, E_{pr} (J)	Deflection D_f (mm)
A	1	16.9	8.4	8.5	6.6
	2	17.6	8.7	8.9	6.2
	3	19.3	9.3	10.0	6.9
B	1	17.3	8.1	9.2	7.1
	2	18.5	8.6	9.9	7.5
	3	19.3	9.0	10.3	7.3

Thanks to these data it is possible to evaluate crack behaviour of samples in which some notch or crack-like defects already exist. In addition, the capacity of the material to be strained, e.g. the deflection in the bend test, is an interesting characteristic for material behaviour under loading. All force–time diagrams for the impact testing specimens exhibited many pop-ins that occurred depending on composite arrangement. After reaching a maximal force, the load dropped in stair-step-like pop-ins. The highest maximal force is found for specimen A (5.5 kN) and the lowest for specimen B (4.3 kN). Anyhow, during the impact process the specimens had totally fractured into small segments with typical significant delamination.

Compact tension specimen test results

Typical diagrams of load (P) vs. crack opening displacement (COD) obtained by modified CT specimens in static loading are presented in Fig. 3 for CT specimen A1, and in Fig. 4 for CT specimen B1. The obtained results for the stress intensity factor are summarised in Table 2.

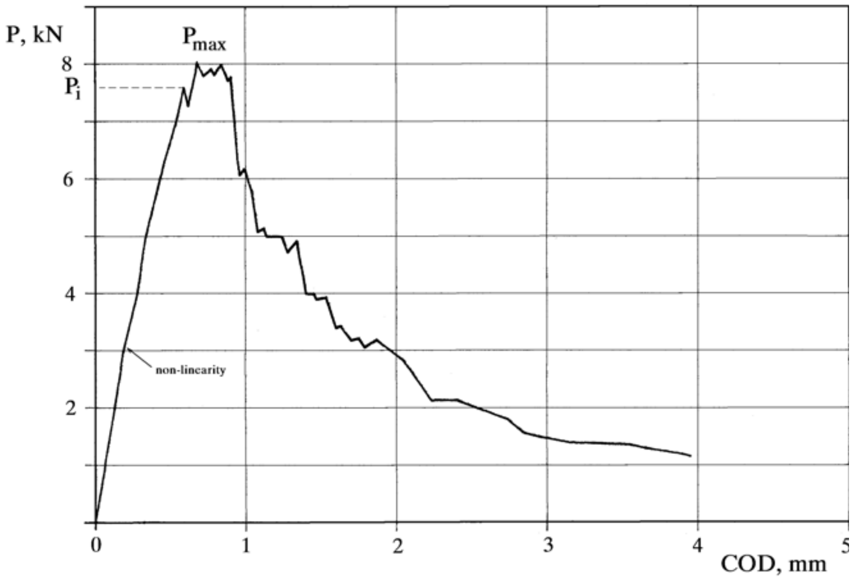

Figure 3. Load vs. COD plot for CT specimen A1.
Slika 3. Dijagram opterećenje–COD za CT epruvetu A1

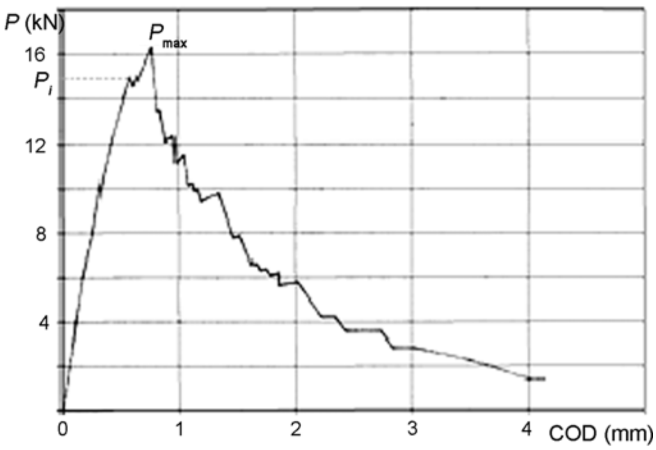

Figure 4. Load vs. COD plot for CT specimen B1.
Slika 4. Dijagram opterećenje–COD za CT epruvetu B1

Table 2. Stress intensity factor of glass fibre–epoxy composite.
Tabela 2. Faktor intenziteta napona za kompozit stakleno vlakno-epoksi smola

Laminae arrangement	Specimen	Stress intensity factor, K_c (MPa·m$^{0.5}$)
$[\pm45°]_{4s}$	A-1	31.6
	A-2	32.1
	A-3	29.7
$[0°/90°]_{4s}$	B-1	36.8
	B-2	37.5
	B-3	36.4

For the CT specimen produced of sample A, ($[\pm45°]_{16s}$) the load vs. COD curve (Fig. 3) is initially linear, with some declination at 40–45% of the maximal load. The first load drop occurred at force P_i, considered as critical, and is attributed to delamination. The crack propagates by matrix cracking along the –45° directions and by fibre fracture along the +45° direction after the maximal force $P_{\max}$ is reached, with the global fracture path of a saw tooth appearance, /5/. The form of diagram for CT specimen of sample B (Fig. 4) is similar to the previous one; and only the maximal force is followed by an instant load drop. In this case, the dominant effect on overall fracture is due to fibre fracturing. As expected, the highest maximal load is experienced with the specimens of sample B.

DISCUSSION

Typical final fracture of Charpy specimen, produced of sample B (lay-up $[0°/90°]_{4s}$), found in one of the fractured segments after impact testing, is shown in Fig. 5. The load direction is perpendicular to 0° directed fibres. The failure around the notch tip is comprised of matrix cracking along the fibre direction and with a simultaneous occurrence of delamination, in addition to the most significant fracture of perpendicular fibres. Fibre fracture had developed continuously, since the strength of fibres had prevented instantaneous total fracture that reflects on the shape of the diagram.

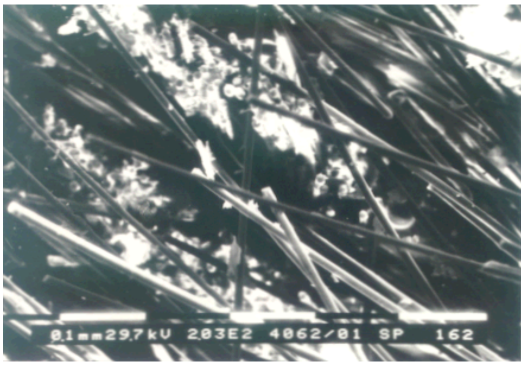

Figure 5. Typical fracture in one fractured segment of Charpy specimen sample B.
Slika 5. Tipičan lom kod jednog segmenta Šarpi epruvete uzorka B.

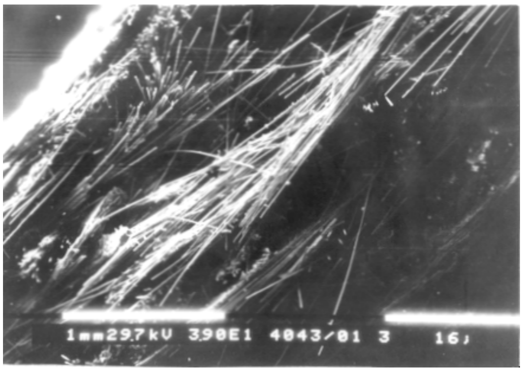

Figure 6. Typical fracture of CT specimen of sample B with lay-up $[0°/90°]_{4s}$.
Slika 6. Tipičan lom CT epruvete uzorka B sa orijentacijom $[0°/90°]_{4s}$

The force vs. COD diagram for specimen B does not exhibit a plateau of pop-ins at maximal force, but a sudden drop takes place. The contribution of matrix fracture and delamination is negligible in the crack growth resistance compared to fibre fracture resistance. A typical CT specimen B fracture is shown in Fig. 6. The fracture of these specimens is seen as fibre failure, followed by matrix cracking and delamination, /6/.

CONCLUSION

The direction of glass fibres in the epoxy matrix composite affects the toughness of the composite, as found in the impact- and fracture mechanics tests. The maximal toughness, expressed by impact energy with Charpy type specimens and by critical stress intensity factor on modified CT specimens, is obtained by sample B ($[0°/90°]_{4s}$), and minimal values are obtained by sample A ($[\pm 45°]_{4s}$). When designing components with epoxy matrix and glass fibres acting as the stiffener, one has to take into account that they can fracture by impact loading, as experienced in this investigation.

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