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CRACK PROPAGATION MODEL OF THE TEXTILE FABRIC REINFORCED POLYPROPYLENE COMPOSITES[1]

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Abstract

The crack propagation was studied on specimens of model composites containing a single layer of different textile fabrics. Both crimped woven (co-woven and/or hybrid clothes) and non-woven (swirl mat) structures were found among the reinforcing fabrics. The fracture toughness was calculated from the load-displacement curve of the compact tension (CT) specimen on $v = 2$ and $v = 500$ mm/min, $T = RT$ and $T = -50$ °C. The fracture surfaces were monitored by scanning electron microscope (SEM) and it serves as a basis to propose a crack propagation model of the composites.

Keywords: plastic composites, polypropylene, textile fabric reinforced, CT specimen, fracture toughness, scanning electron microscope, crack propagation model.

1. Introduction

The past decades have brought some significant changes in the choice of engineering materials. These include polymers and polymer composites.

The emergence of new types of plastic materials which possess several combinations of properties, e.g. thermal and mechanical, has made the material an attractive replacement for the metal parts. As a result, machines and equipment will be smaller, lighter and of course cheaper. However, to use the polymer as a structural material one needs to know the mechanical properties.

One of the best means of achieving a good structural material from polymer is to produce polymer composites. Some of these composites have been claimed to have mechanical properties close enough or better than metals. The most popular form of polymer composites are the short and long fiber reinforced plastics. Recently there is an increasing trend to

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use textile fabrics as reinforcements for both thermoplastic and thermoset resins. These applications are found mainly in the manufacturing of aircraft and automobiles. The advantages of fabric based composites compared to short and long fiber reinforced material are that former materials are more homogeneous, the mechanical properties of the matrix can be tailored more precisely by controlling the fiber orientation and the mode of weaving. The main task of the textile fabric in composite is to act as a load bearing medium, while the matrix will serve its two main functions, i.e. to transfer the load to the reinforcing fibers and protect the surface of fibers.

The most serious form of damage of plastic products is the fracture. Fracture not only ended the service life of the products but also can be dangerous to human life. Because of the crack initiation is preceded by the fracture it is very important to know the behaviour of products prior to the fracture and to know the circumstances of the crack propagation.

Thus in order to use polymers and their composites as engineering materials it is unavoidable to characterise them from the viewpoint of the fracture mechanics.

The aim of the present contribution is to examine the crack propagation in model composites containing a single layer of different two-dimensional reinforcing fabrics embedded in a ductile polypropylene (PP) block copolymer matrix.

2. Experimental

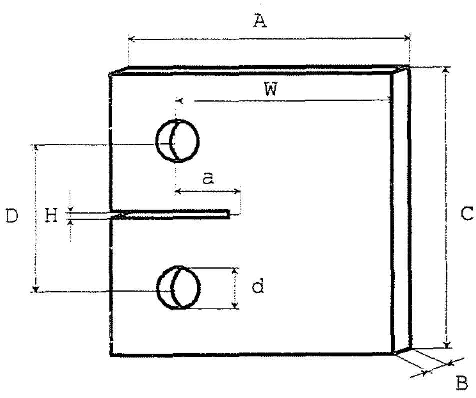
The PP block copolymer contained ca. 5 wt% polyethylene and 10 wt% surface coated chalk filler (Modylen 2-8134, produced by Tisza Chemical Works, Hungary). Its melt flow index (MFI) was 0.4 g/10 min measured at 230 °C and 2.16 kg load.

One layer of various crimped woven and non-woven fabrics produced by Textile Research Institute (Budapest, Hungary), was placed between two PP plates and pressed at 200 °C and 4 MPa into plaques of about 3.5 mm thickness. The properties of the various types of fabrics used in this study are shown in *Table 1*. It should be noted here that the fibre volume fraction (Vf) was very low, i.e. less than 4.4 vol% (cf. *Table 1*).

For the static fracture measurements, razor-blade notched compact tension (CT) specimens were used. The sum of the sawn and razor-blade introduced notch was treated as the initial notch (a, cf. *Fig. 1*). The dimensions and notching of the CT specimens used are depicted schematically in *Fig. 1*.

Table 1
Properties of the textile fabrics used

Pattern Type	Surface Weight $[g/m^2]$	Warp Type Tex	Weft Type Tex	Warp–Weft [roving/10cm]	W_f [vol.%]
1.			Matrix		
2. Plain-weave 1/1	320	Glass 300	PP 750	40 – 25	1.14
3. Twill 2/1	295	Glass 300	Glass 600	40 – 30	2.34
4. Swirl mat	450	Glass (oriented)	Glass		4.37
5. Twill 2/1	225	Glass 300 Carbon 400	PP 300 Glass 400	40 – 16 (GF: 20 – 8)	1.52 (GF: 0.68)
6. Twill 2/1	340	Glass 300 Carbon 400	Glass 600 Carbon 800	40 – 30 (GF: 20 – 15)	2.33 (GF: 0.68)
7. Twill 2/1	220	Carbon 400	PP 750	40 – 8	1.63
8. Twill 2/1	280	Carbon 400	Carbon 400	40 – 30	1.12



CT specimen [mm]
A=35 (≈1.2·W)
a=10+1 (razor)
B= 3
C=35 (≈1.2·W)
D=16
d=6.5
H= 1
W=29

Fig. 1. Geometry sizes of CT specimens

The CT specimens were cut from the plaques in two directions with respect to warp and weft behaviour in fabrics and anisotropic effects in matrix. This can be seen in *Fig. 2.*

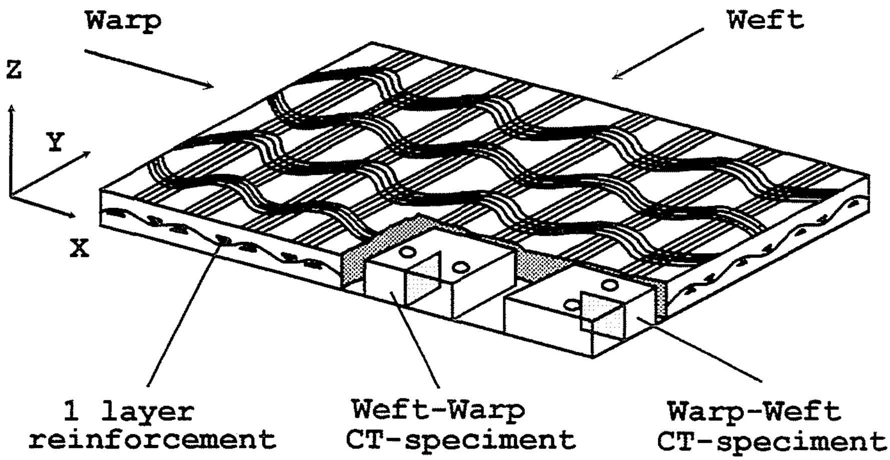


Fig. 2. Cutting direction for the CT specimens from the plaques

Static fracture of the CT specimens was performed on a Zwick 1445 and Zwick 1485-type tensile loading machine equipped with a thermostatic chamber. Loading occurred at two crosshead speeds, $v = 2$ mm/min and $v = 500$ mm/min and at two different temperatures, $T = 22$ °C (RT) and $T = -50$ °C. The sub ambient temperature used is based on the T_g value of the matrix which was initially established from dynamic mechanical measurement using DMA model Explorer 150 N in three-point bending mode. The thermomechanic curve can be seen in *Fig. 3* [1].

3. Results and Discussion

3.1. Fracture Toughness

In determining the fracture toughness values 5-5 CT specimens were tested. The critical stress intensity factor or fracture toughness (K_q) was determined according to the ASTM E 399 standard [2]. The geometry sizes, i.e. a, W and B of all specimens were measured for the calculations of K_q. The best and the worst K_q results were neglected and the average of the remaining three specimens were considered. Their results are shown in the next diagrams.

Figs. 4–7 illustrate the counted K_q values at the different directions (warp-weft), speeds and temperatures. The numbers under the shaded triangles are the same as it was indicated in the first column of *Table 1.*

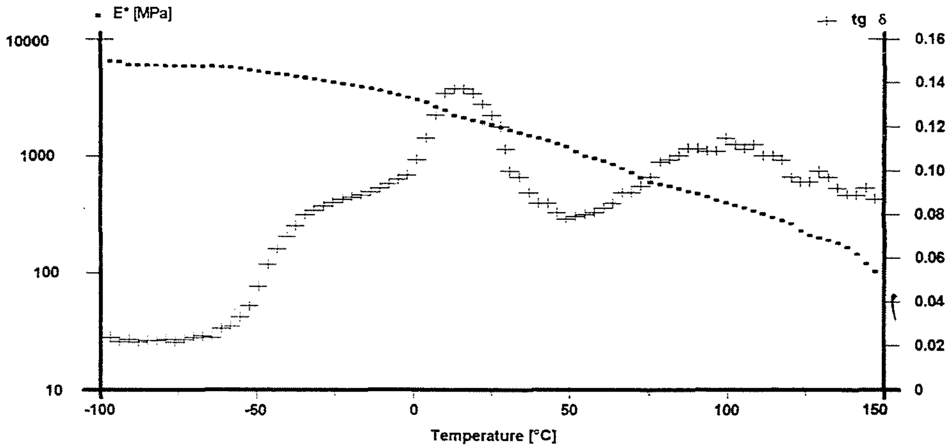


Fig. 3. DMA examination of MODYLEN matrix

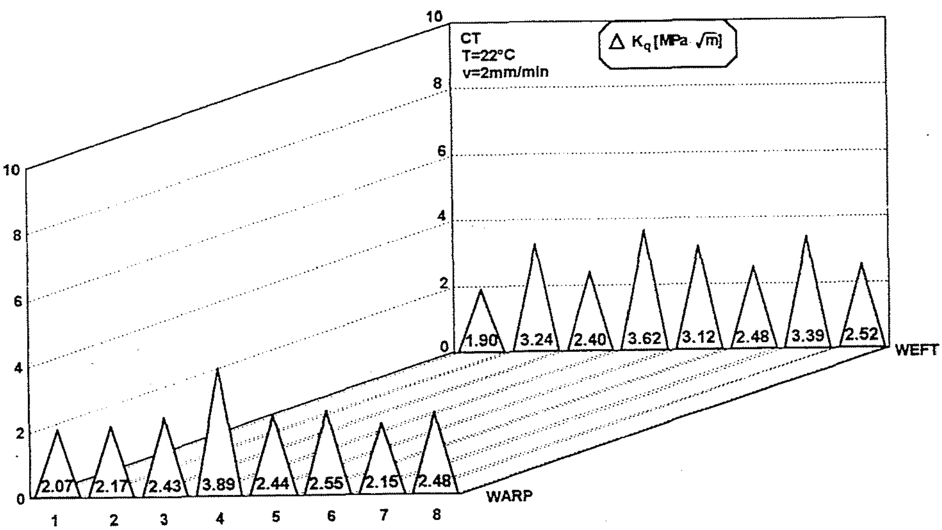


Fig. 4. The effect of warp and weft directions on the K_q values at $T = 22$ °C and $v = 2$ mm/min

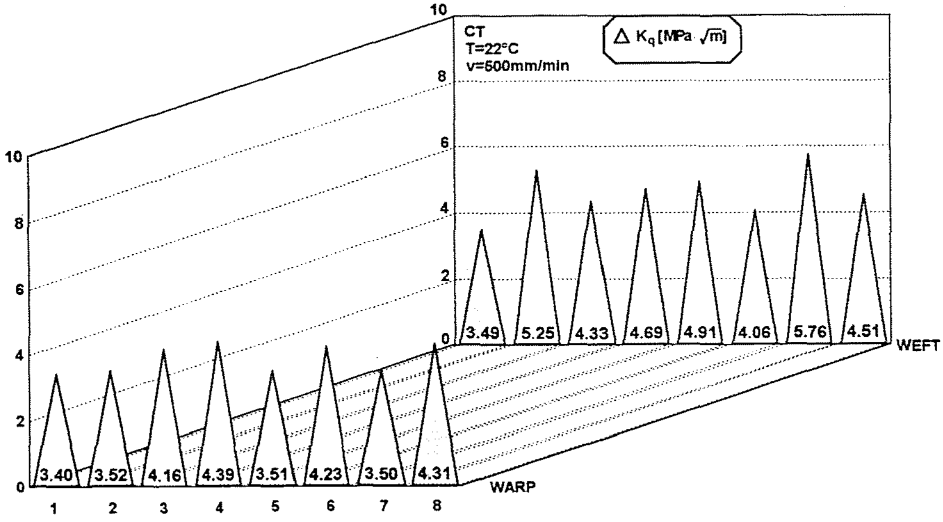


Fig. 5. The effect of warp and weft directions on the K_q values at $T = 22$ °C and $v = 500$ mm/min

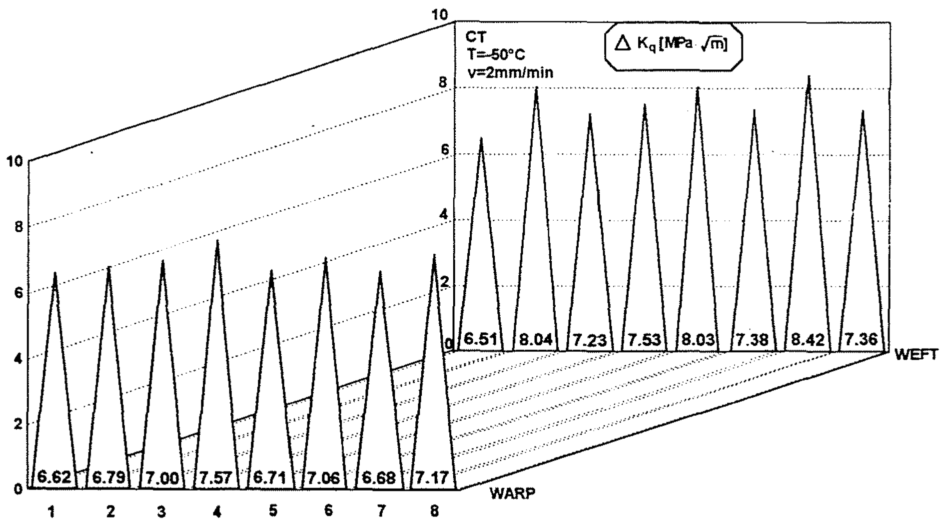


Fig. 6. The effect of warp and weft directions on the K_q values at $T = -50$ °C and $v = 2$ mm/min

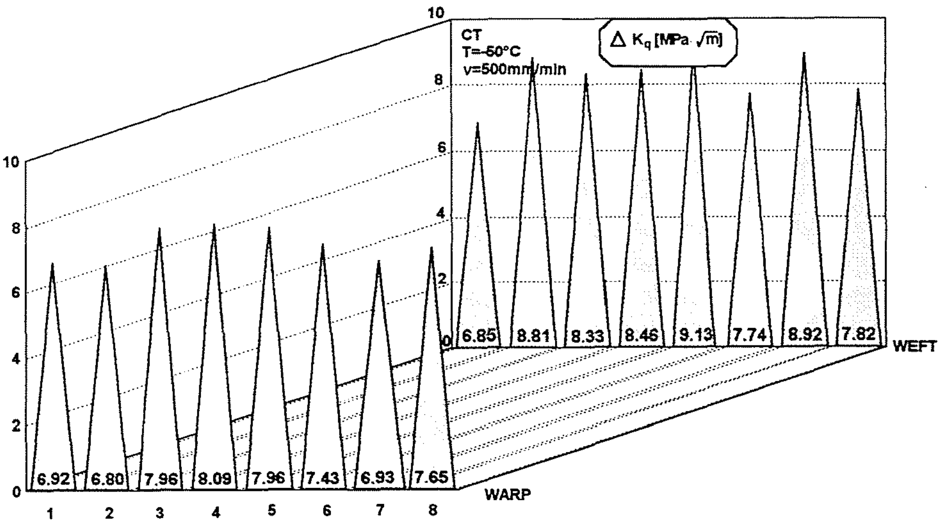


Fig. 7. The effect of warp and weft directions on the K_q values at $T = -50$ °C and $v = 500$ mm/min

The comparing of the effect of the warp and weft direction has led to the following conclusions (the numbers following are the same as in first column of *Table 1*):

1. As expected the values of K_q for the matrix are about the same in both directions. This can be attributed to the homogeneous nature of the matrix material.
2. The value of K_q in the weft direction and at room temperature has increased by 50–60%, and under the glass temperature by 20% compared to matrix. On warp direction the K_q values were similar to that of the matrix because the PP rovings were molded in the PP matrix. Thus it can be considered as unidirectional reinforcement.
3. The little difference in the K_q values between the two directions may be due to the different density close and count of fibers.
4. The observed small difference on twill is caused by fiber orientation.
5. The biggest increase in the K_q value is in the weft direction, and this value corresponds to the unidirectional glass reinforcement.
6. The values of K_q were almost the same in both directions.
7. Similar behaviours can be observed as it is shown by number 2.
8. The values of K_q were almost equal in both directions because of the same density close and count of fibers.

It can be concluded that significant reinforcement can be achieved if we use fiber rovings which also contain matrix material as this will improve the wettability of the roving with the matrix. This conclusion is based on the observation indicated by number 2 and 3 for the glass fiber and number 7 and 8 for the carbon fiber. It can be observed that the value of K_q on second and seventh clothes in warp direction was similar to matrix value because of the molded PP rovings. Furthermore it has been proven that the K_q values for the glass and carbon reinforcements are almost the same [3, 4].

The column diagrams have shown that while the values of K_q are quite dependent on tensile speed at room temperature, the influence of tensile speed under T_g are not as significant.

Finally it needs to be mentioned that in the present study only one layer reinforced systems were used because of the easiness to establish the contribution of the matrix and reinforcement. Practically it is more beneficial to use more layers as this will increase the fracture toughness values more significantly than that obtained in the present work.

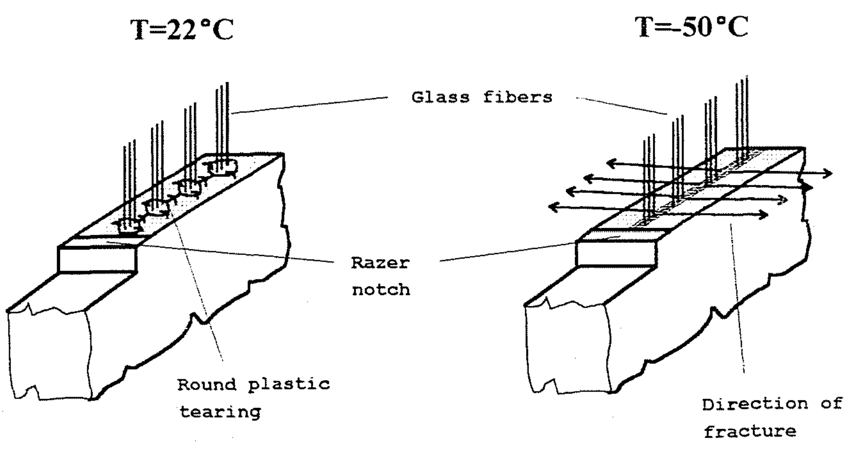


Fig. 8. Models of the crack propagation

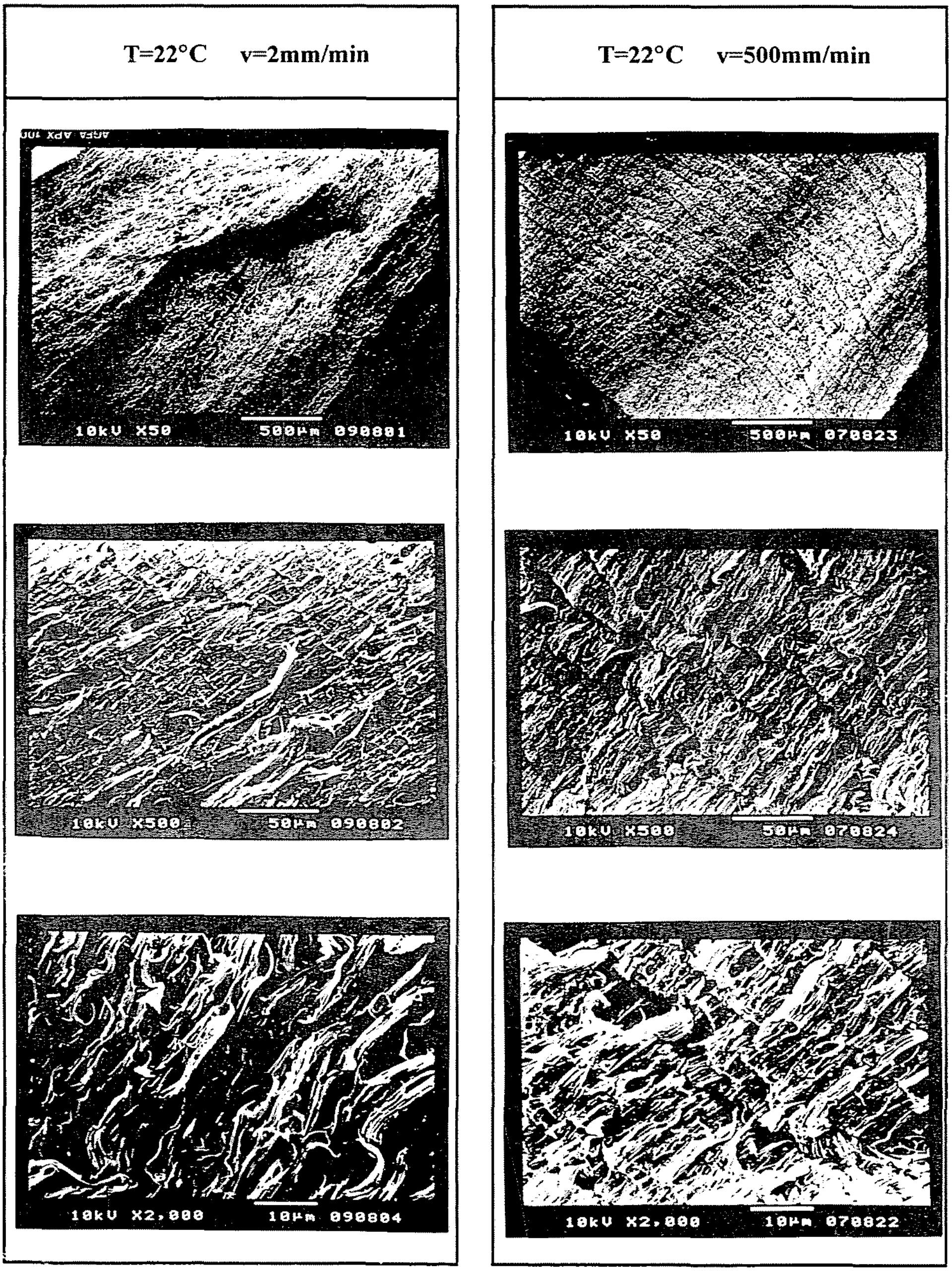


Fig. 9. Examination of the matrix fracture surface by SEM [$T = 22\ ^\circ$C]

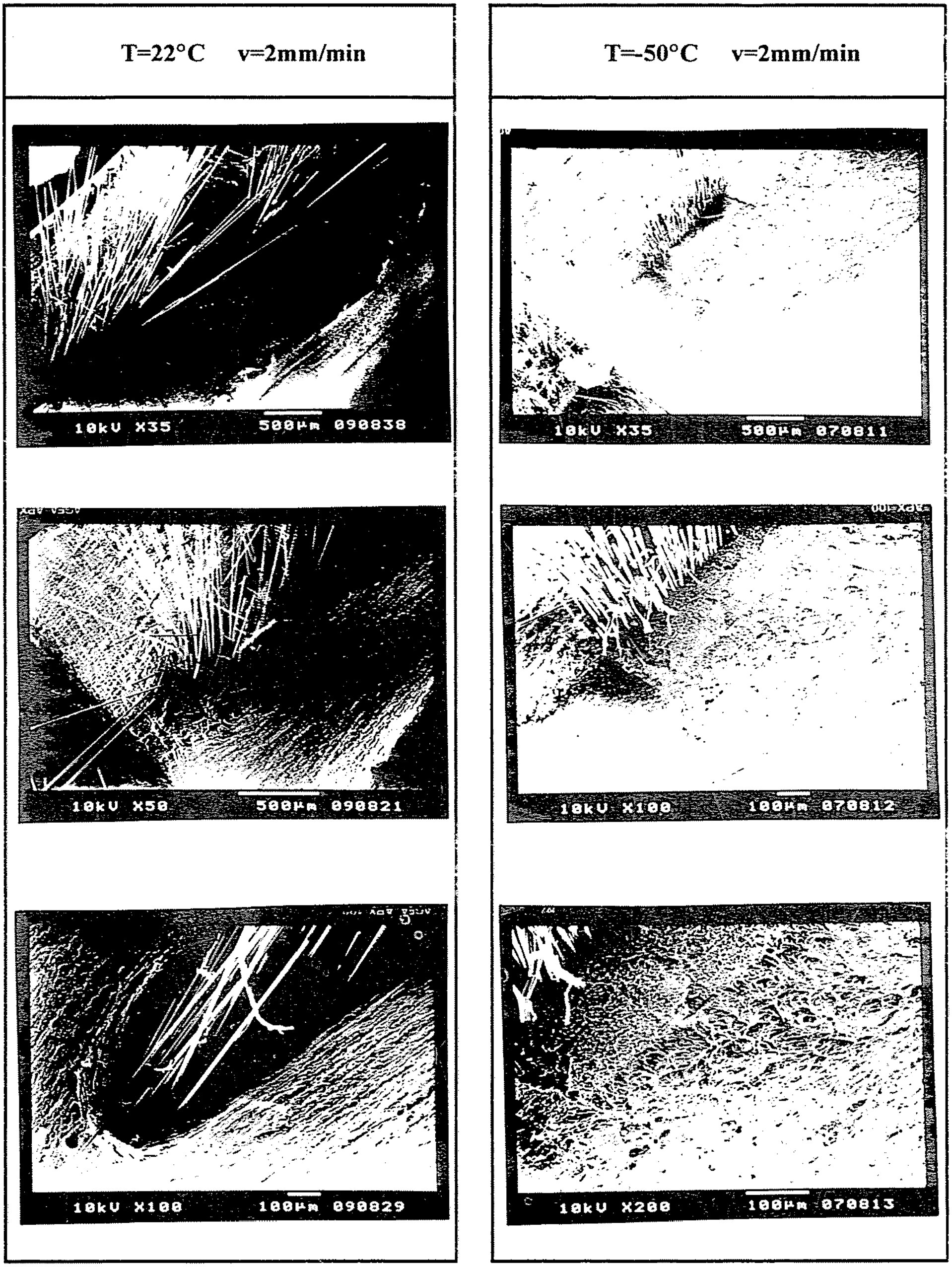


Fig. 10. Examination of the fracture surface of specimen 2 in weft direction by SEM

3.2. Fracture Surface Monitored by Scanning Electron Microscope (SEM)

The aim of this examination is to compare the fracture surfaces of various specimens tested at different speed and temperature. Scanning electron microscope model JSM-5400 was used.

First, the surfaces of the matrix tested at room temperature but at different speeds were examined. The micrograph is shown in *Fig. 9.* At both speeds some plastic deformations in the form of matrix tearing and stretched 'whips' can be observed.

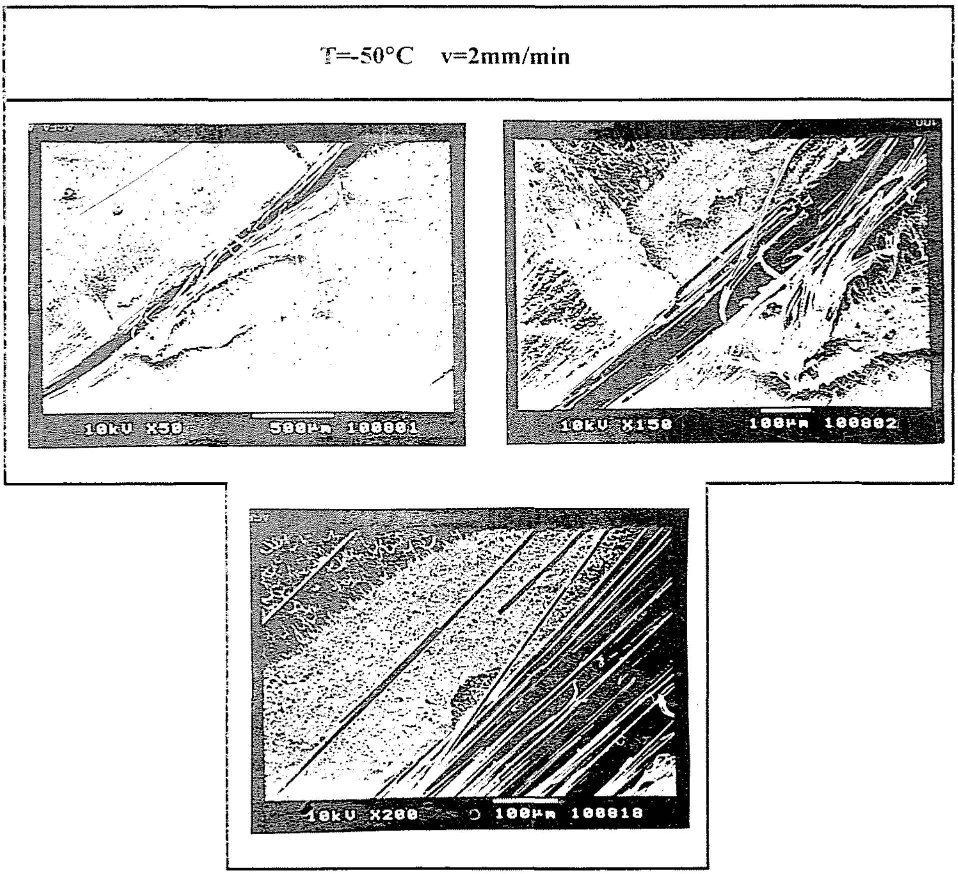


Fig. 11. Examination of the fracture surface of specimen 2 in warp direction by SEM

While there is a big difference in the appearance of the fracture surfaces for the specimens tested at room temperature but at different speeds, such differences are not apparent for those tested under T_g at different speeds (for room temperature, at $v = 2$ mm/min it was enough time for the specimen to stretch).

For the reinforced materials the differences in the surfaces appearance are more significant in *Fig. 10.* At room temperature the crack propagates around the rovings, and the matrix tears in a ductile manner. At −50 °C the cracks propagates go out from middle of the specimen, and the matrix cracks in ductile manner, too. It can be seen that at −50 °C the rovings are functioning only in a small process zone and thereafter they fail in a ductile manner, too. The crack propagation models are shown in *Fig 8.*

The third micrograph (*Fig. 11*) shows the fracture surface of the warp specimen 2, where the glass rovings are aligned parallel to the notch direction. Here also the ductile fracture appears in the form of 'craterlike' to start in the middle of the specimen.

In the third picture of *Fig. 11* it can be seen that the tear direction is perpendicular to the rovings (↖-indicates the direction of parabolas on the left upper corner of the picture).

4. Conclusions

This study was performed to investigate the crack propagation of different textile fabric reinforced model composites with polypropylene block copolymer matrix. The study led to the following conclusions:

a) The stress transfer and distribution capability of the reinforcing two-dimensional crimped textile fabrics depends on both their assembly and loading. Use of hybrized (containing PP rovings) or loose textile fabrics or non-wovens (such as swirl mats) may be beneficial due to a better impregnation by the matrix in hot pressing, so they can transfer a bigger load [5].

b) The appearance of the fracture surfaces is independent of the types of reinforcement (glass or carbon), but strongly influenced by the testing temperature and moderately by the testing speed. At room temperature the crack propagates initially round the reinforcing roving and than propagates straight until it gets to the next roving and the process continues until the specimen fails. Under the glass temperature the crack propagates out from the middle of material. The testing speeds have been observed to influence the types of failures. While the low speed (2 mm/min) has resulted in ductile tearing, at higher speed (500 mm/min) ductile fracture is observed to be more predominant [6, 7].

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