

Effects of the Functional Compound on the Properties of Composite Tape Yarns

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Abstract

While the functional compound Polycom JB 7100 is often introduced into polyolefins as a modifier, processing aid and bonding agent, little is known about its influence upon the basic structure and mechanical properties of composite tape yarns. Polycom JB 7100 is a master bath of inorganic materials and polyolefins. To show the effects of different amounts (0 - 6 wt%) of this additive in polypropylene (PP)-based composite tape yarns, experiments were made without changes to other additive portions and at constant process parameters. The linear composition-property relations showing the effects of portions of the variable component on the changes in morphology, geometrical properties and tensile behaviour were obtained. Tape yarns, in which a portion of PP was replaced by the functional compound Polycom JB 7100, had tensile properties about 2 - 9% lower than the yarns without this additive, whereas the values of width, thickness and linear density after applications of the additive were about 3 - 4% greater if compared with those of the basic sample.

Key words: additives, geometrical properties, morphology, polyolefins, tape yarns, tensile properties.

ured using extrusion lines. The melts from polyolefins such as polypropylene (PP) or polyethylene (PE) are most often used for the manufacture of technical tape yarns. Isotactic PP is the commercially desired form for packing applications. However, leading trends are connected with the use of the new modifications, i.e. blends of polyolefins, copolymers of ethylene with propylene and other olefinic monomers [4, 5], as well as supplementary applications of different portions of various types of additives [6 - 10], namely stabilisers, whiteness maintenance materials, colorants, anti-static components, flame retardants, antimicrobial components, water-repellent compounds, anti-scratch materials, soiling resistance compounds, among others, as materials for the enhancement of mechanical behaviour and improvement of processability. The additives can be converted into solid forms, either master batch pellets or powders, that are easy to feed or mix. Among the advanced materials, nano scale additives such as nano-particles, nano-rods, nanotubes and nano-capsules are known [11 - 15].

For each application of the additive master batch, a wide range of modifiers, compounds and other special components can be used [16 - 20]. For instance, stabilisers as antioxidants hindered amine light stabilisers (HALS), and ultraviolet (UV) light absorbers are used directly or in combinations to prevent the degradation of materials for a long time [19]. For some types of materials, which are specially developed for short time of usage, special additives can be applied as agents

for the acceleration of degradation [20]. These additives play a beneficial role in terms of the product environmental sustainability. The various effects and synergistic impacts of special compounds on the different properties of polymeric materials were also indicated [18, 20 - 23].

It should be mentioned that calcium carbonate particles were investigated as an additive for PP based materials [24 - 28]. For instance, different influences on the toughening properties were studied in [24]. In this study, the modulus of materials increased, while the yield stress was lowered with additive content. This lowering of yield stress was connected to the debonding of particles from the PP matrix. In another study [27], nanosilica-coated calcium carbonate additives were used in composites. As a result, the flowability of the particles was improved if compared with those without the nano-particulate coating. Therefore a more uniform and extensive dispersion of the additives inside the materials was achieved compared with simply prepared (without coating) particles. Different samples of PP tape yarns with the use of an additive for whiteness maintenance as well as with a fixed portion of UV light stabiliser were also examined [28]. For present-day applications, more complex combinations of the new additives as well as the composition-property relations are necessary to be verified. Applications of processing compounds and their direct benefits on processes [21] such as lower dusting or better processability are known, but the issue of additional effects on other properties such as the structure and tensile parameters, re-

■ Introduction

Numerous studies have recently been conducted to add new functionalities to textile materials. Additives with polymeric and inorganic components, polymeric covers, microcapsules, active agents and various functional compounds are known as effective means in the development of advanced modifications of textile products [1 - 3].

Technical tape yarns can be made applying different technologies, but mostly they are produced from film manufac-

quires further investigation. Variation in the width and thickness as well as some changes in the tensile properties of tape yarns is a question of great importance for the quality and functionality of such products as woven sacks, bags and flexible intermediate bulk containers. It is worth noting that because of the coherence with corresponding portions of the additives, the above-mentioned properties of structure and tensile behaviours are also connected with changes in PP amounts.

Therefore, in actual fact the current paper is aimed at enlarging information about the effects of variable components on the specific characteristics of composite tape yarns. In this study, the morphology, geometrical and tensile properties of the yarns after adding different portions of the functional compound and corresponding reduction of PP portions were examined.

■ Experimental

Materials used in the experiment

The different variants of PP based composite tape yarn samples with application of the additives shown in **Table 1** were produced, i.e. variable amounts of the functional compound Polycom JB 7100 (Omega Plasto Compounds Co., India) up to 6.00 wt% and constant portions of additives Granic 422 (Granico Co., Spain) and UV 01017 PP (Constab Co., Germany) were used. The ranges of portions were selected in accordance with experience of preliminary experimentation. The five variable amounts of Polycom JB 7100 in wt% were applied for samples MA-A, MA-B, MA-C, MA-D and MA-E. Therefore, as the portion of the additive Polycom JB 7100 increases, the portion of PP component decreases accordingly from 93.25 wt% to 87.25 wt%.

Mosten TB 003 granules of PP homopolymer were obtained from Unipetrol Co. (Czech Republic). The melt flow index (MFI) [29, 30] value was 3.1 g/10 minutes. The yield stress value was 34 MPa, and strain at break was more than 50%.

Additive Polycom JB 7100 is known as a modifier, processing aid and bonding agent [31]. In this additive, the portion of inorganic materials was 75.50 wt%, and that of the polyolefins was 24.50 wt%. The additive has an MFI [29, 30] value of 3.8 g/10 minutes and density of 1.60 g/cm³.

The additive Granic 422, i.e. portion of 5.00 wt% was applied to give whiteness to the tape yarns. A master batch with a high content of treated and ultrafine calcium carbonate particles was used. The calcium carbonate content was 80.00 wt% and that of linear low-density polyethylene (LLDPE) 20.00 wt%. In this research, LLDPE was a copolymer of ethylene and 1-octene. The MFI value of Granic 422 was 1.2 g/10 minutes [29, 30]. And the density of the additive was 1.80 g/cm³.

A UV light stabiliser (1.75 wt%), type UV 01017 PP [32] was added as a protector of photochemical oxidation. For all samples, a UV light stabiliser with 20.00 wt% of monomeric HALS in PP was applied. The density of the master batch was 0.92 g/cm³.

Method of tape yarn production

Samples of PP based composite tape yarns were manufactured from a film using a single-screw extruder - E10 (Barmag Saurer Co., Germany). Before moulding, the materials were mixed in a dry form. In the extruder, the processes of moulding, extrusion, thermoacting, cutting and drawing were applied. The length per diameter ratio (L/D) of the extruder screw was 30:1 and $D = 90$ mm. For monitoring the thickness of the film during the manufacture process, Betac-control systems [33] were used.

To show the effects of the functional compound for all samples at identical manufacturing conditions, the process parameters given below were selected as constant values.

The temperatures at different extruder zones were 212 - 235 °C. The temperature in die zone was 235 °C. The film was solidified by water in a cooling unit at 35 °C. The samples were heated in a heating oven at 173 °C. After that they were fixed onto an annealing stand at 120 °C.

The melt pump speed value of the extruder was specially applied at a fixed level of 44.0 min⁻¹, and adjusted so that the tape yarns finally drawn and relaxed had nominal values suitable for the manufacture of woven packing materials. Therefore changes in the metering of the melt during the manufacture of different variants of tape yarn samples were conditioned

Table 1. Codes of tape yarns and amounts of additives.

Sample code	Portions, wt%		
	Polycom JB 7100	Granico 422	UV 01017 PP
MA-A	0.00	5.00	1.75
MA-B	1.50		
MA-C	3.00		
MA-D	4.50		
MA-E	6.00		

only by the portion of the variable component.

A conventional distance between the slit dye of the extruding device and the cooling unit of 50 mm was used. The total draw ratio of all samples of fully drawn tape yarns was 6.380.

Testing methodology

An FEI Quanta™ 200 FEG model (FEI Co., The Netherlands) scanning electron microscope (SEM) was used to examine the surfaces of the tape yarns and additives. SEM micrographs with magnifications of 1000× were applied to show a general picture of the material surfaces, and larger magnifications, i.e. 5000× were selected to observe the particles of the additives. Energy-dispersive X-ray (EDX) spectroscopy was used as a tool of elemental analysis of solid particles. For instance, to show agglomerations of the calcium (Ca) element in the modified yarn, EDX micrographs (500×) were made.

The values of width and thickness of the tape yarns were examined using a special installation. To monitor the tape yarn width, a zoom microscope - SM 2800 Achro 0,5x (Nikon Co., Japan) with digital camera - Nikon Coolpix 4500 (Nikon Co., Japan) was applied. Software METRIC 7.0 was used to measure the width values. The thicknesses of tape yarns were determined using a thickness gauge (Hans Schmidt & Co., Germany). To compute the linear densities of the tape yarns, samples of fixed length (10 m) were weighed on an EW 150-3M electronic balance (Kern & Sohn Co., Germany).

The tensile properties of tape yarns were determined on a tensile tester - H5KT, Tinius Olsen Ltd. (United Kingdom), according to the requirements of [34]. The tests were performed using a Tinius Olsen DBBMTOL-250N load cell. During the tests, the slippage of specimens

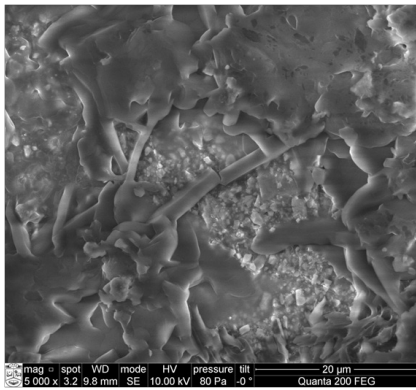


Figure 1. SEM image of additive Polycom JB 7100.

was checked. To avoid slippage, the special grips for the tape yarns were used. For specimens, a pretension of 0.5 cN/tex was applied. The specimen length was set at 500 mm, and the rate of specimen extension was 100% per minute. The breaking forces and elongations at break were obtained from the stress and strain graphs at the breaking point. Values of work of break were determined as an equivalent to the area under the force extension curve [35]. The breaking tenacity and specific work of break were computed on the basis of the breaking force, work of break and linear density of the yarns. The initial modulus in cN/tex

of each specimen was measured using the initial part of the force extension curve, in which proportionality between the stress and strain may be observed.

The conventional atmospheres for testing were as specified in [36]. Twenty repetitions were reported for each test, and each data point reported in this paper is an average value.

The effects of additives on the properties of tape yarns as well as statistical values of measurements were determined by applying a Microsoft Excel Data Analysis Tool Pak. A confidence level of 0.95 was used. Values of determination coefficients (R^2) were computed, and then empirical equations showing relations between variable portions of the additive and properties of tape yarns were proposed. For this purpose, the least squares method was applied. Finally the empirical equations were used to compute the maximum changes in properties in the whole range of variable portions of the additive. Student's test value t was used for comparison of maximum and minimum experimental values in ranges of variation. In this case, the value t computed was compared with the value t_{α} , where α is the confidence level.

Results and discussion

Morphology of additives

As mentioned previously, the melt of polyolefins and the inorganic particles of calcium carbonate are used as components of additive Polycom JB 7100. **Figure 1** shows that these particles have the morphology of parallelepipeds. The minimum dimension of the particles ranged from 0.3 to 0.6 μm . The maximum dimension of the particles was 1.2 - 1.8 μm . Thus the size of the particles was less if compared with the requirement for particles, which are used as toughening (less than 5 μm) [24]. The surfaces of the particles are mostly smooth, whereas the edges are sharp. The anisotropy of particles may be an important factor for the tensile behaviour of tape yarns, because with anisotropic particles the stress concentration that develops can be significantly large near the ends or edges of the particles. As shown in **Figure 1**, the particles have a tendency to form agglomerations, which are surrounded by the melt of polyolefins.

Changes in the morphology of tape yarns

Typical SEM micrographs of tape yarns produced without additive Polycom JB 7100 (sample MA-A) and with 6.00 wt% of additive Polycom JB 7100 (sample MA-E) are shown in **Figures 2.a, 2.b**, respectively. The surface features of the tape yarns, like their smoothness, the arrangements of pits and agglomerations of the additives are also different. It was found that the number of protrusions of particles increases with a rise in the amounts of the variable additive and decrease in the PP component. The greatest agglomerations of particles of inorganic materials were observed on the surfaces of sample MA-E. Meanwhile the surface of sample MA-A has the smallest indications of additives Granic 422 and UV 01017 PP. The specimens of all samples contain many small pits, which are the remnants of collapsed air bubbles. Some pits, especially for samples with great portions of additives, are filled by their elastomeric components.

Local signs of the presence of Ca as an element were especially observed using EDX analysis. **Figure 3** shows EDX micrographs where signs of Ca are presented as bright patterns on a dark background, confirming that the agglomerations of Ca are greater for sample MA-E if compared with those of sample MA-A.

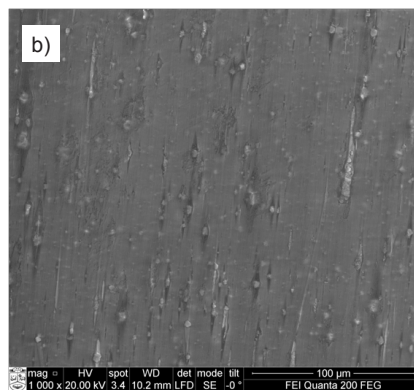
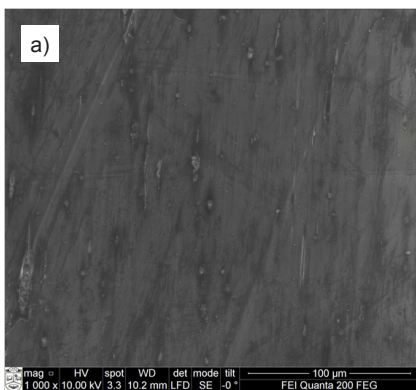


Figure 2. SEM images of tape yarn surfaces: a – MA-A, b – MA-E; scale 100 μm .

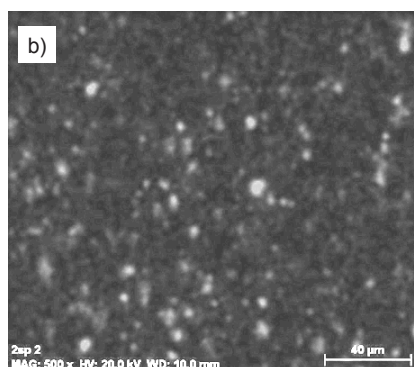
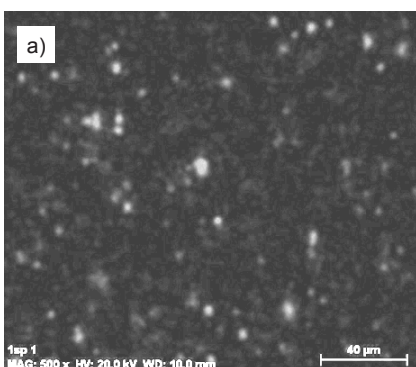


Figure 3. EDX images of Ca element in tape yarns: a – MA-A, b – MA-E; scale 40 μm .

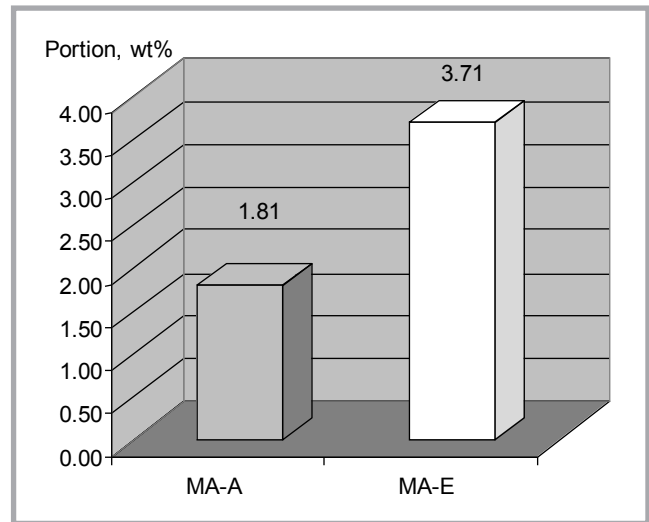
The experimental quantities of Ca portions are shown in **Figure 4**, where the EDX test values are in agreement with the above-mentioned qualitative changes.

Changes in the geometrical properties of tape yarns

The geometrical parameters, namely the width and thickness, of tape yarns after applications of variable amounts of the additive Polycom JB 7100/PP component were examined, the results of which are shown as linear relations in **Figure 5**. Experimental values of the width and thickness were 2564.7 - 2641.0 μm and 50.0 - 51.4 μm , respectively. Very similar tendencies for values of the width and thickness were observed, i.e. when the portion of one additive increases and the amount of the PP component decreases, the width and thickness of tape yarn has a tendency to increase by 3.0% and 2.8%, respectively. The great values of R^2 , i.e. 0.8789 and 0.9614, show a strong correlation between the portion of the additive and the above-mentioned geometrical parameters. Thus for all Student's tests $t > t_{99}$ the significant differences between maximum and minimum experimental values are obtained. The tendencies of the relations may be explained by the several reasons given below.

First the micro-pores, which are the result of the dissipation of thermal energy, when polymer, i.e. PP component melts, can be filled by the elastomeric component of the additive. The intensity of the filling can be more effective when the amount of the additive has the highest values. Therefore after tape yarn drawing, the possibilities of a width and thick-

Figure 4. Experimental values of EDX test for Ca element portions in tape yarns.



ness decrease are greater for samples with open micro-pores if compared with those for more filled structures.

Secondly the tape yarns with great portions of additives have a rather smooth surface, as can be seen from typical SEM micrographs, and hence the possibility of accidental slippage between such tape yarns and the rolls of the extruder during the drawing process of samples can occur. Therefore the actual draw ratio of the drawn tape yarn can be less compared with the value mentioned earlier in our work. However, this phenomenon is likely limited due to rather similar variations in the width and thickness values in the whole range of variable portions. For the width and thickness of tape yarns, the values of variation coefficients fluctuated very slightly, i.e. 0.4 - 0.7% and 1.0 - 1.6%, respectively.

Thirdly the effect of different MFI values on the macro-structure of tape yarns can play an important role. On the one hand, the MFI value of additive Polycom JB 7100 is greater if compared with that of the PP component, and therefore the mass, i.e. the quantity in grams of the blended substance of polyolefins and additives during extrusion, can be greater for samples with a great amount of the additive. On the other hand, with the application of additive Granic 422, which has a lower MFI value if compared with that of the PP component, the opposite effect can be obtained. However, in the current study, as was mentioned earlier, a constant portion of this additive was used.

Fourthly the additives have inorganic materials. Therefore the recoverable elastic deformations developed during the manufacture of samples containing the greatest amounts of additives can be

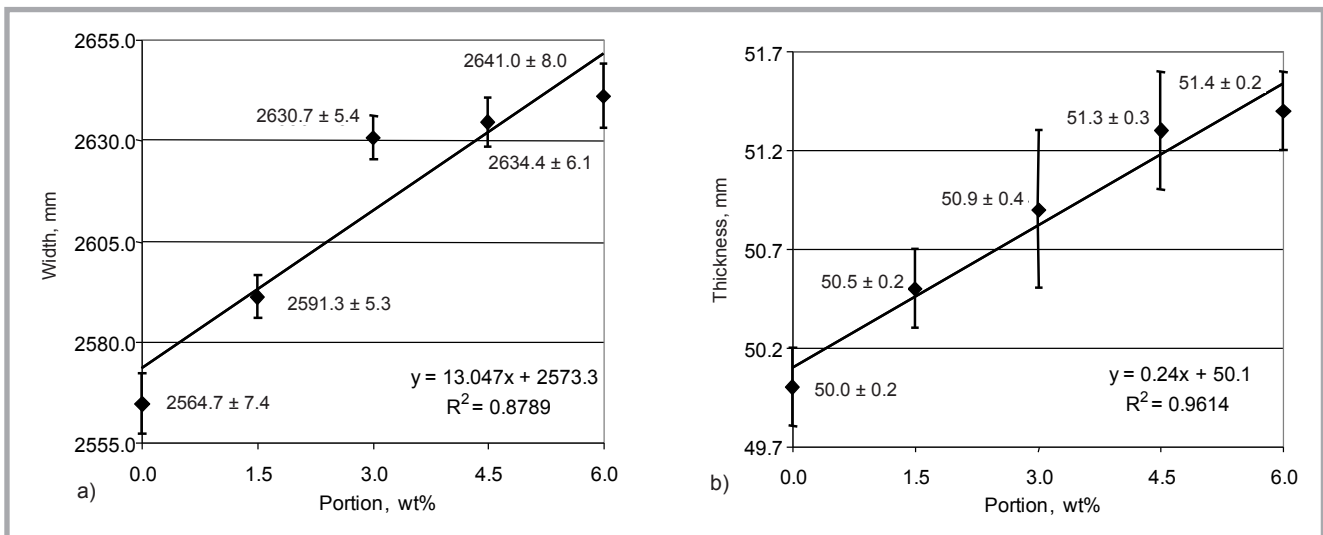


Figure 5. Effect of additive Polycom JB 7100 portion on geometrical parameters of tape yarns: a – width, b – thickness.

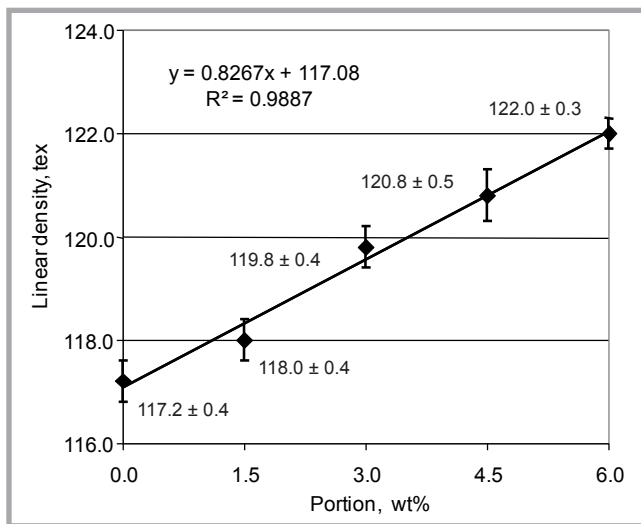


Figure 6. Effect of additive Polycom JB 7100 portion on linear density of tape yarns.

lower compared with those of samples with the greatest PP portions.

The changes in geometry of samples are also evident from **Figure 6**, where effect of the portion of additive Polycom JB 7100 on the linear density of tape yarns is shown. Experimental values of the linear density varied from 117.2 to 122.0 tex. To show the effect, the linear relation was used, where value of R^2 was 0.9887. According to this relation, the linear density increases by 4.2%. The variation coefficients of linear density fluctuated in the range of 0.5 - 0.9%. It is important to note that the changes in linear density of the samples are the integrated results of previously-mentioned changes in the width and thickness. Moreover the densities of additive Polycom JB 7100 are greater if compared with those of the PP component. Therefore the samples with the greatest amounts of additive Polycom JB 7100 have the highest values of linear densities.

Probably the complexity of changes in the geometry of tape yarns is additionally affected by the synergistic interactions of additives. Therefore it is relevant to investigate especially this aspect in the future.

Changes in the tensile properties of tape yarns

The influences of the portion of the additive Polycom JB 7100/PP component on tensile properties are shown in **Figure 7**. Changes in the properties are given for a full range of variable portions (see **Table 1**) of the additives. Comments about the effects are given below.

When the portion of additive Polycom JB 7100 increases and that of the PP component decreases, values of the breaking force, tenacity, work of break, specific work of break and initial modulus of tape yarns have a tendency to decrease, as shown in **Figures 7.a, 7.b, 7.d, 7.e & 7.f**, respectively. For instance, the experimental values of tenacity decreased from 59.9 to 54.9 cN/tex. For the specific work of break, a drop from 46.73 to 42.80 mJ/tex was observed, which were close to the results on [37] of complete systems of PP toughened with calcium carbonate. The introduction of the additive particles into a polymer matrix gives the behaviour of composite tape yarns. Under the effect of a tensile force, heterogeneities of the yarns induce stress concentration, the spread of which depends on the portion of the additive. Sharp edges of the particles, their different sizes and nonhomogeneous dispersion in the matrix polymer are additional reasons for earlier crack initiation and propagation in samples. These results are also in line with previously-mentioned changes in the geometry of yarns. For instance, changes in the linear densities of yarns (see **Figure 6**) obtained at a fixed draw ratio showed that the current additive works as an initiator of a higher than usual melt flow rate during extrusion. Consequently the tensile properties and, most likely, molecular orientation of such tape yarns are worse than those of samples without the additive. Therefore with the aim of achieving a more ordered structure, the possibilities of applications of higher draw ratio values must be verified in the future. One more reason for the reduction in tensile properties can be mentioned. When the amount of additive Polycom JB 7100 is increased, protuber-

ances due to the additive are more pronounced and evident. Therefore they can sometimes abruptly disrupt the continuity of the tape yarn structure.

As indicated in **Figure 7**, linear relations with values of R^2 between 0.5092 and 0.9978 are obtained, and the greatest value of R^2 is shown for tenacity. According to Student's test, significant differences between maximum and minimum experimental values are obtained for the breaking force, tenacity, specific work of break and initial modulus. It is worth noting that in the case of work of break, we have $t = 1.21$, $t_{95} = 2.10$, and therefore $t < t_{95}$. Hence the values of work of break changed without significant differences.

The relations from **Figure 7** were applied to compute the changes in properties with regard to the value computed for sample MA-A. Negative values of changes were obtained for the majority of tensile parameters given below. Because of the additional increase in linear density, the tenacities of the samples (see **Figure 7.b**) decreased more than the breaking forces shown in **Figure 7.a**. Hence the negative changes in breaking forces and tenacities were about 2.1% and 8.3%, respectively. Similarly it is evident from **Figures 7.d** and **7.e** that because of the above-mentioned reason, the decrease in work of break was about 4.4%, and that in the specific work of break was also greater, i.e. 8.3%. **Figure 7.f** shows that values of the initial modulus decreased by about 9.1%. The elongations at break, as shown in **Figure 7.c**, varied without a clear trend.

The variation coefficients of the work of break (5.4 - 9.4%) and specific work of break (5.3 - 9.4%) were the greatest among all tensile indices of the current study. This tendency is a summarised result conditioned by the inequalities of force-elongation curve variations, especially by the elongations at break and linear densities of samples.

The main results of the current study are composition-property relations showing the effects of portions of the functional compound on various properties of composite tape yarns obtained using constant portions of other additives and constant manufacture process parameters. In the future, we intend to evaluate the performances of the other additives and at different manufacture process parameters

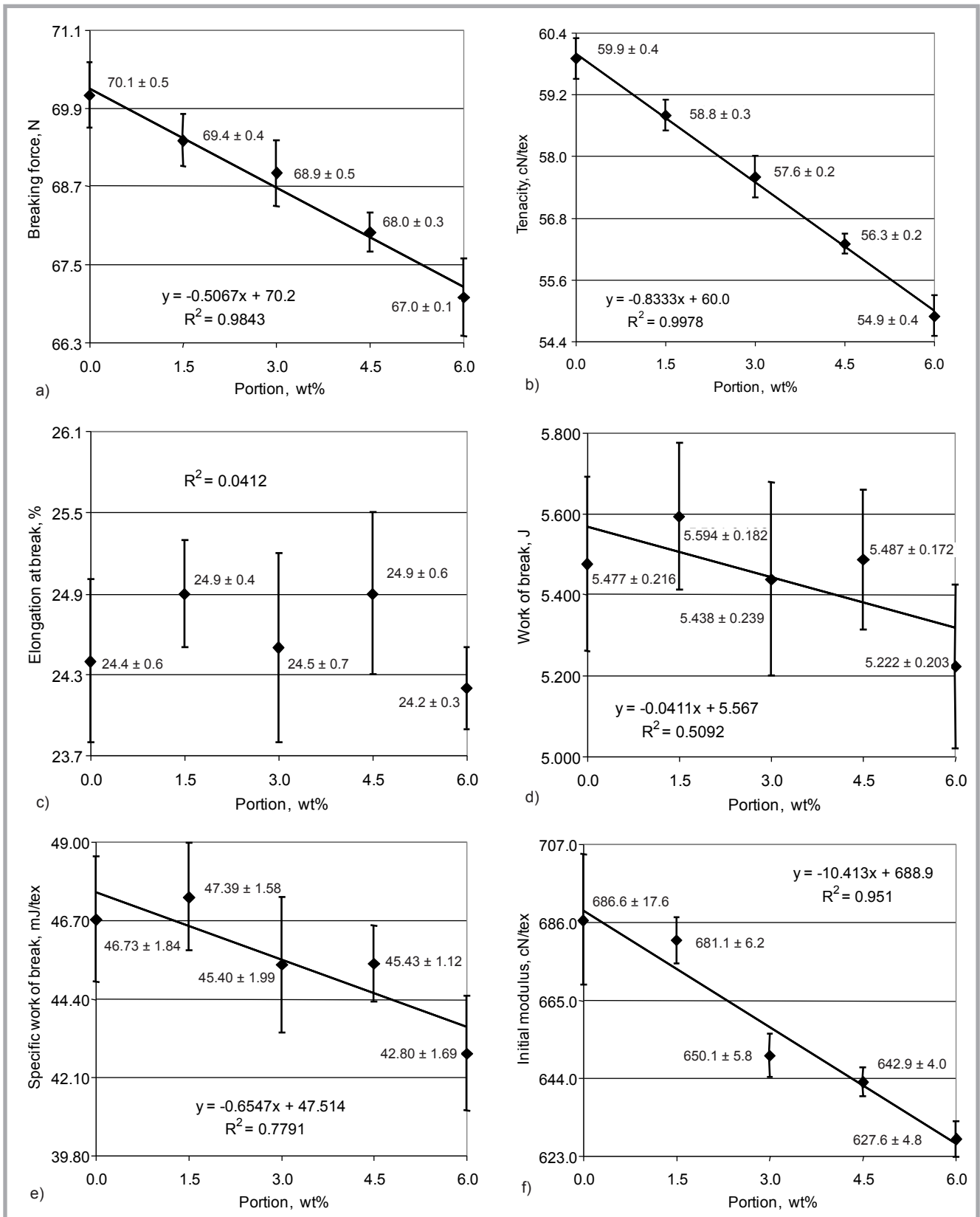


Figure 7. Effect of additive Polycom JB 7100 portion on tensile properties of tape yarns: a – breaking force, b – tenacity, c – elongation at break, d – work of break, e – specific work of break, f – initial modulus.

of composite tape yarns. The synergistic impact of the additives on the tensile properties of the yarns is one more subject, the influence of which needs to be additionally verified.

Conclusions

The effects of variable amounts of functional compound Polycom JB 7100/PP on various properties of polypropylene

(PP) based composite tape yarns were examined. Since this stage of the investigation was realised especially using constant portions of other additives and fixed values of manufacturing parame-

ters, these effects show the additional impact of the above-mentioned compound on the properties. The current research extends knowledge of applications of additives in the manufacture of composite tape yarns.

SEM and EDX micrographs showed that the agglomerations of particles of inorganic materials or the Ca element on the surfaces of tape yarns were greater after application of additive Polycom JB 7100. Linear relations showing the effects of portions of the variable additive on the properties of the samples were proposed. Values of the width, thickness and linear density of the yarns increased by about 3 - 4% with a rise in additive Polycom JB 7100 up to 6 wt%. On the other hand, the current addition reduced values of the breaking force, tenacity, work of break and initial modulus of the yarns by about 2 - 9%. It was revealed that the elongations at break of the yarns varied without a clear trend when additive Polycom JB 7100 was used. The above-mentioned changes in the morphology, geometrical and tensile properties of the yarns after applications of additional portions of the functional compound and corresponding reduction in PP portions can be conditioned by melt flow changes in extrusion, orientation and continuity of the heterogeneous structures.

The individual and synergistic influences of various additives as well as the effects of different manufacturing conditions are the aims for future studies of such materials.



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