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Research Article

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Production and characterization of thermoplastic elastomer foams based on the styrene-ethylene-butylene-styrene (SEBS) rubber and thermoplastic material

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Abstract: Thermoplastic elastomer foams based on styreneethylene-butylene-styrene (SEBS)/polypropylene (PP) were produced by using different processing techniques such as extrusion and injection molding to achieve optimized mechanical and thermal properties in terms of strength, elongation, and damping capability. Foaming is a method of introducing gas-filled cells into the material and it is considered an effective way to meet the requirements for higher impact resistance with low density and relatively low hardness. In this study, microspheres were used as a foaming agent and were introduced to the system by using an injection molding machine. They were used in different percentages and ranged from 1 and 3%. They decrease the density of the product thereby lowering the weight and cost. Besides improving damping abilities and decreasing the density, inorganic fillers such as talc, silica, and calcium carbonate were used to increase the mechanical strength, and their effectivity was also investigated. It was observed that a higher amount of foaming agent lowered the density by creating voids in the blend, as expected. The introduction of fillers increases the mechanical properties; however, the density had a negative effect even in the presence of foaming agents. About 3% density reduction can be achieved in the presence of talc and a foaming agent whereas the other fillers had an opposite effect on the density. Accordingly, the impact resistance was affected negatively because of the stiffness of the filler materials, and the highest Izod impact value was $50.2 \, \text{kJ/m}^2$. The elastic modulus values for foamed samples and filled with CaCO_3 , talc, and silica were 808, 681, and 552 MPa respectively. Combining foaming and thermoplastic elastomers (TPEs) offers a wide variety of possibilities to new and existing applications. In addition to low hardness and density, foaming provides better damping ability thanks to its morphological structure.

Keywords: TPEs, PP, SEBS, foaming technology, damping

1 Introduction

Thermoplastic elastomer (TPE) is a generic term used to describe a family of polymeric materials that can be processed as a thermoplastic but shows many characteristics normally associated with the traditional thermoset rubbers. They combine the properties of elastomers with the easy processability of thermoplastics [1,2]. As a member of the TPE family, styrene—ethylene—butylene—styrene (SEBS)/polypropylene (PP)/oil blends have been commercialized since the early 1990s for soft-touch applications, such as grips on tools, sports goods, and in automotive and medical domains owing to the fact that the properties of the rubber and the PP phase can be easily combined into a single product [3–7].

SEBS, which is a member of copolymers combining elastomeric properties, thanks to a double carbon bond C–C, has an excellent thermal resistance [8]. SEBS is generally blended with oils, fillers, or other types of polymers to obtain optimum mechanical and physical properties and better processability [9]. SEBS is generally used in combination with PP to obtain compounds of more strength and as a thermoplastic, PP also increases the processability [10].

It is known that there are valuable studies about the foaming of TPEs but reported studies are scarce. Foaming

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and the blend of SEBS/PP have been mostly investigated as two distinct research areas [11–16]. Considering the increasing importance and global usage of the thermoplastic elastomer family, density optimization as well as mechanical properties and processability have become more important recently and need more detailed investigations. Foaming is a highly efficient and preferred method for several purposes in the polymer world and foaming of TPEs is still a virgin area to be deep-dived in. Besides foaming and TPE engagement, microspheres are promising materials as foaming agents in terms of their easy usability, relatively reasonable costs, and efficiency as well. The present work aims to study TPE foams based on SEBS/PP with different fillers and different microsphere ratios as foaming agents to achieve optimized mechanical and physical properties in terms of density, strength, elongation, and also impact properties.

2 Experimental

2.1 Materials and instruments

Globalprene 7551 from LCY Company was used as a SEBS block copolymer in powder form. Borealis HE 125MO PP was used as polypropylene in a pellet form. As a foaming agent, Palmarole EXP 141/168-B from Adeka, which is a microsphere type was used. They can be used for foaming resins like PE, PP, PS, and TPE by injection molding and extrusion process. In order to achieve optimum efficiency, a working temperature in the range of 160-170°C is recommended. An additional level of 1.0-4.0% (depending on the desired degree of foaming) is recommended. Additionally, in order to obtain optimum mechanical and damping results, different types of fillers have been added to the extruder with different loading amounts.

In this study, an intermeshing co-rotating twin-screw extruder was used, which is PRISM TSE 24 HC with two K-Tron feeders, with a screw diameter of 24 mm and an L/D ratio of 28:1 (shaft length/screw diameter). An Arburg 370S 800-150 injection machine was used to produce specimens according to ISO standards. Tensile strength measurements were conducted according to the ISO 37 standard test method by using a Zwick Universal Tensile Test Machine Z020 with a load cell of 2.5 kN. Density measurements were conducted according to ISO 2781-2018. For each mechanical test, up to six replications were made and reported as average results. For the determination of morphological properties, a JSM 6400 JEOL scanning electron microscope was used in this study. All test specimens were covered with carbon and then analyzed. Different resolution and zoom values were chosen.

2.2 Production of SEBS/PP TPE specimens and addition of fillers

The powder form SEBS and 125MO PP pellets were used and blended in a twin-screw extruder. Sample plates were produced for primary tests and characterization was performed in an injection molding machine. Different PP/SEBS ratios in percentages of 70/30, 80/20, and 90/10 as well as neat PP (90/0) were prepared in a twin-screw extruder. Processing temperatures were around 200°C through the extrusion zones and 225°C at the die. As already known from the literature, the addition of fillers into plastomeric blends increases the processability, thermal stability, and mechanical strength [17]. For this purpose, talc, silica, and CaCO₃ (calcium carbonate or calcite) were used in different amounts in a base elastomer formulation. The filler addition was settled as 10% of the total amount for all filler types. Fillers are introduced into the extrusion by using a side feeder and they were used in a powder form. The PP and SEBS were fed from main feeders simultaneously and blended with different fillers through the screw.

As a first step, before starting the extrusion process, both PP and SEBS were weighed in the required weight percentages. Also, all powder form filler materials were kept in the oven for 6 h at 60°C to dry them and then they were sent through the twin-screw extruder for mixing.

2.3 Preparation of foamed SEBS/PP samples

For this study, foaming is considered to be an effective way to meet the requirements of a high impact resistant material with low density and relatively low hardness. Foaming is a method of introducing gas-filled cells into the material. It decreases the density of the product by lowering the weight and the material cost. Combining foaming and thermoplastic elastomers offers a wide variety of possibilities to new and existing applications. In addition to low hardness and density, foaming provides better damping ability thanks to its morphological structure [1]. Several voids are formed during the foaming process, which will create damping areas in the polymeric matrix. The foaming agent from Adeka Palmorole EXP 141/168-B was used in different amounts ranging from 1 to 3%. It was



Figure 1: Samples of test plates after foaming (randomly selected samples).

introduced to the system by injection molding and dry mixed with the pelletized SEBS/PP/filler blend coming out from the extrusion step. The zone temperatures were around 220°C with an injection speed of 90 ccm/s and an injection pressure of 900 bar (Figure 1). The system temperatures for foaming are crucial as known from the previous research work about microsphere foaming. Riou et al. stated that the temperature dependency of foaming is clear. As expected, foaming efficiency is lower at lower temperatures and higher at an elevated temperature scale of 200–210°C according to Riou and coworker's experiments.

Table 1: Density values of samples containing talc, CaCO₃, silica, and foaming agent of 1 and 3%

Density (g/cm ³)	90-10 PP SEBS	80-20 PP SEBS	70-30 PP SEBS
Neat SEBS/PP blend	0.962	0.981	0.990
CaCO ₃ 10%	1.058	1.079	1.089
CaCO ₃ + FA 1%	1.025	1.035	1.055
CaCO ₃ + FA 3%	0.953	0.952	0.980
Talc 10%	1.029	1.028	1.058
Talc + FA 1%	1.007	1.017	1.036
Talc + FA 3%	0.936	0.935	0.963
Silica 10%	1.049	1.069	1.079
Silica + FA 1%	1.016	1.026	1.045
Silica + FA 3%	0.945	0.944	0.971

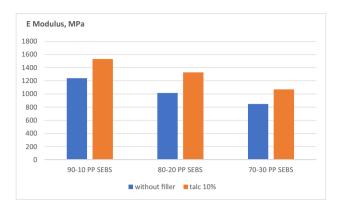


Figure 2: Elastic modulus of neat and 10% talc-containing samples.

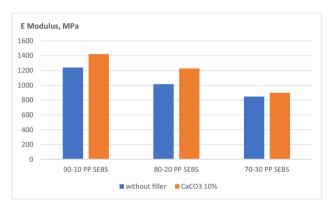


Figure 3: The elastic modulus of neat and 10% CaCO₃ containing samples.

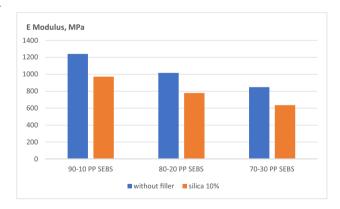


Figure 4: Elastic modulus of neat and 10% silica-containing samples.

In fact, Riou stated that there is a lack of information for the true experimental temperature profile and also an approximation for the microsphere foaming dynamics [18].

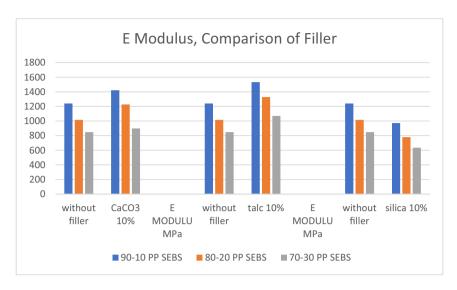


Figure 5: Elastic modulus of neat and 10% filler containing samples.

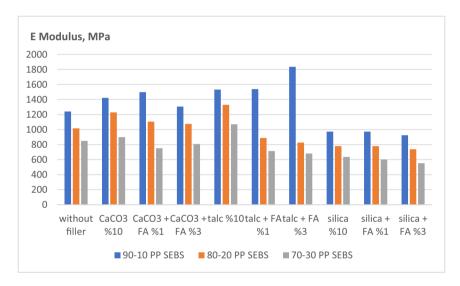


Figure 6: Elastic modulus of neat, 10% filler containing samples, and foamed samples with 1 and 3% foaming agents.

3 Results and discussion

3.1 Density results

After the extrusion and injection molding process and foaming, samples were investigated in terms of their densities. As already known from the previous studies about density reduction in polymers via foaming technology, our results are highly compatible in terms of lower density with higher foaming amounts [19] (Table 1).

The lowest density results were achieved by talc addition into the TPE matrix and foaming with a higher amount of foaming agent (3%). It was observed that increasing

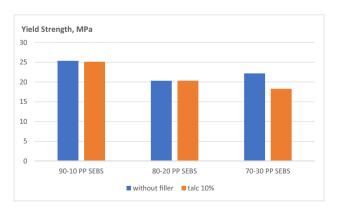


Figure 7: Yield strength of neat and 10% talc-containing samples.

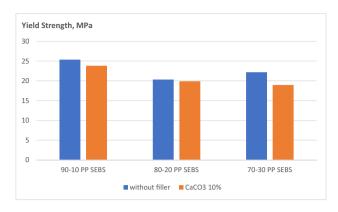


Figure 8: Yield strength of neat and 10% CaCO₃ containing samples.

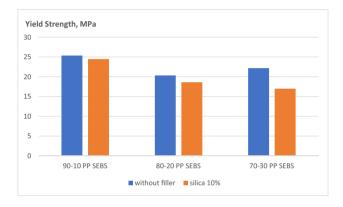


Figure 9: Yield strength of neat and 10% silica-containing samples.

the elastomer amount yields higher density results in all specimens.

Comparing the neat SEBS/PP blend with only filler-added blends without foaming agents such as SEBS/PP/ $CaCO_3$ 10%, SEBS/PP/talc 10%, and SEBS/PP/silica 10%,

Table 2: Izod impact resistance of neat and 10% talc, CaCO₃, and silica-containing samples

Izod impact resistance (kJ/m²)	90-10 PP SEBS	80-20 PP SEBS	70-30 PP SEBS
Neat	5.10	10.91	51.25
Talc 10%	4.89	9.90	48.51
CaCO ₃ 10%	4.54	9.42	50.25
Silica 10%	4.33	8.14	23.64

it was clearly seen that filler addition increases the overall density as expected. CaCO₃ gave the highest density value whereas talc had the lowest density value.

3.2 Elastic modulus test results

The effects of the foaming and filler content on the elastic modulus (Young's modulus), *E*, as a measure of blend and composite stiffness are shown in Figures 2–6.

It can be seen from Figure 2 that the talc introduction increases the elastic modulus, which shows a higher strength over less elongation. This type of tensile behavior of all blends is reasonable because incorporation of talc into the PP-SEBS matrix causes a ductile/brittle transition and causes a stiff construction thermoplastic. There is an introduction of filler having significantly much higher stiffness as mentioned in previous studies among thermoplastics [20].

Among TPE samples with PP and SEBS, the E value decreases with the increasing SEBS content. In ternary SEBS/PP/talc composites, the E value decreases with

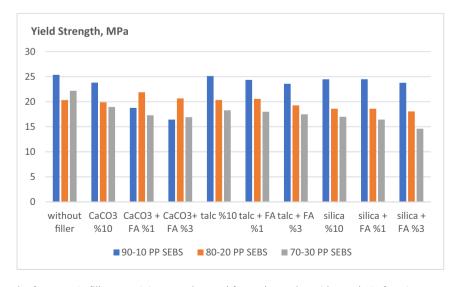


Figure 10: Yield strength of neat, 10% filler containing samples, and foamed samples with 1 and 3% foaming agents.

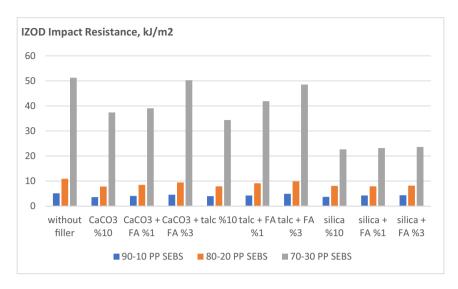


Figure 11: Izod impact resistance of neat, 10% filler-containing samples, and foamed samples with 1 and 3% foaming agents.

the addition of SEBS. It is known from the literature that the addition of even small amounts of SEBS decreases the *E* values considerably [20].

It can be seen from Figure 3 that the introduction of CaCO₃ by 10% caused an increase in the elastic modulus, which shows higher strength over less elongation.

As shown in Figure 4, the introduction of silica gives a lower elastic modulus, which shows lower strength over an increased elongation. The expectation is a higher modulus of silica when introduced into SEBS/PP matrix but in practice, it is lower. Akbari and coworker's study supports that this behavior is directly related to the morphology of the SEBS phase in each component and it can be assumed that the introduction of silica into the polymeric matrix and interaction with SEBS particles is low [21].

Considering the filler effect without the addition of any foaming agents (Figure 5), the highest E value was obtained with talc addition where the lowest value was obtained with the silica usage. Hence, silica and matrix introduction has not been achieved effectively.

From Figure 6. it can be observed that the introduction of the foaming agent into the matrix yields a lower modulus for all types of filler additions. More foaming agent gives lower elastic modulus, which is not a drastic decrease.

3.3 Yield strength results

According to the data of Ling and coworkers, incorporation of an elastomer into the PP matrix causes a decrease in the yield stress and flexural strength [22]. Similarly,

the yield stress is also reduced by $CaCO_3$, which is a result of poor interfacial adhesion between the matrix and filler. The results, as shown in Figures 7–9, supports this statement and an increased elastomer ratio gives lower yield strength compared to the neat SEBS/PP blend and the lower yield strength with the introduction of $CaCO_3$ into the matrix as well. Comparing filler-added SEBS/PP blends, the yield strength was observed the highest with the addition of talc.

As mentioned in Akbari and coworkers' study [23], incorporation of nanoclay into the plastic matrix resulted in a reduction in the yield stress of the samples since the introduction of nanoclay facilitates crazing in plastics (Figure 10).

3.4 Izod (notched) impact results

It is obvious from the results shown in Table 2 that an increase in the elastomer content causes improved impact resistance value as shown in the previous studies [21,24].

When it is evaluated within each SEBS/PP composition, CaCO₃ incorporation yields a slightly lower Izod impact value for each blend because these clays create a higher stiffness area in the TPE matrix.

The introduction of the foaming agent gives a higher Izod impact resistance value, thanks to the damping ability of the foamed cells. Hence, the foaming agent creates voids and these voids increase the impact damping. Optimum results in terms of mechanical strength and impact resistance were observed with the addition of talc and a 3% foaming agent ratio (Figure 11).

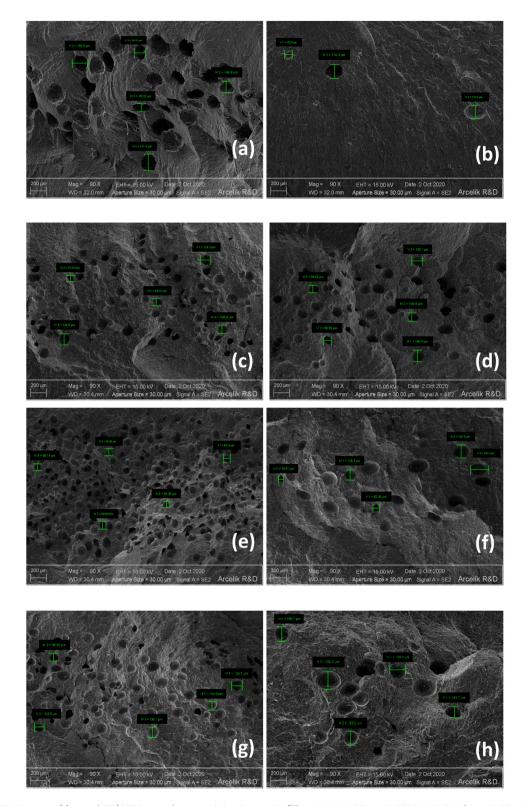


Figure 12: SEM images of foamed PP/SEBS samples containing inorganic filler: (a) 90% PP-10% SEBS-3% FA, (b) 70% PP-30% SEBS-3% $FA,~(c)~90\%~PP-10\%~SEBS-10\%~CaCO_3-3\%~FA,~(d)~80\%~PP-20\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~70\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~FA,~(e)~20\%~PP-30\%~SEBS-10\%~CaCO_3-3\%~PP-30\%~SEBS-10\%~SEBS-10\%~CaCO_3-3\%~PP-30\%~SEBS-1$ $(f) \ 90\% \ PP-10\% \ SEBS-10\% \ talc-3\% \ FA, \ (g) \ 80\% \ PP-20\% \ SEBS-10\% \ talc-3\% \ FA, \ and \ (h) \ 70\% \ PP-30\% \ SEBS-10\% \ talc-3\% \ FA.$

Table 3: Cell diameters from SEM analysis for foamed samples

Sample	Average cell diameter (μm)
90% PP-10% SEBS-3% FA	159.2
70% PP-30% SEBS-3% FA	150.8
90% PP-10% SEBS-10% CaCO ₃ -% 3FA	109.9
80% PP-20% SEBS-10% CaCO ₃ -3% FA	116.4
70% PP-30% SEBS-10% CaCO ₃ -3% FA	88.1
90% PP-10% SEBS-10% talc-3% FA	135.7
80% PP-20% SEBS-10% talc-3% FA	119.4
70% PP-30% SEBS-10% talc-3% FA	212.8

3.5 SEM morphology analysis

The SEM morphology analysis was conducted to investigate structural changes inside the sample body before and after the introduction of the foaming agent. The SEM images of samples are shown in Figure 12.

In terms of foamed cell distribution and size, the finest cells were obtained by using $CaCO_3$ as a filler in the matrix that has a 70/30 SEBS/PP ratio. Smaller cell diameters and well distributed in the matrix were observed during morphological analysis. Without any foaming agent, foaming was also observed but cell diameters were very diverse. The talc addition had also promising foaming ability but closed bubbles were observed (Table 3).

4 Conclusion

Combining foaming and TPEs offers a wide variety of possibilities to new and existing applications. In addition to low hardness and density, foaming provides better damping ability thanks to its morphological structure. In this study, TPE foams based on SEBS/PP were produced by using different processing techniques such as extrusion and injection molding to achieve optimized mechanical and thermal properties in terms of strength, elongation, and damping capability. In order to increase the mechanical strength and optimize the cost, inorganic fillers were also added. Talc, CaCO₃, and silica were used and their effectivity and synergistic effect with foaming agents were also examined. According to the mechanical test results and morphological studies, talc and CaCO3 were the best candidates for better foamed TPE samples in terms of low density, high mechanical strength, and impact resistance.

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