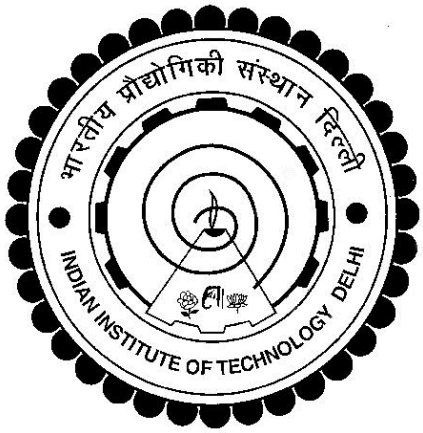
STUDIES ON THE FOAMING BEHAVIOUR OF SEBS BASED BLENDS AND NANOCOMPOSITES

RITIMA BANERJEE



DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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STUDIES ON THE FOAMING BEHAVIOUR OF SEBS BASED BLENDS AND NANOCOMPOSITES

by

RITIMA BANERJEE

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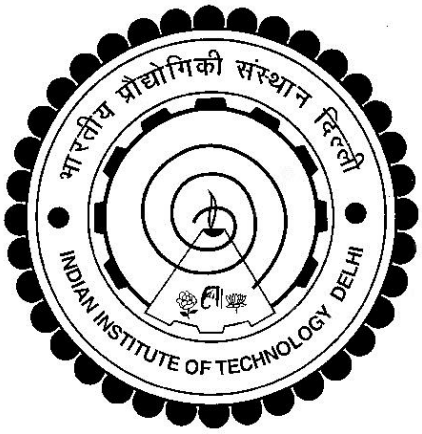
Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

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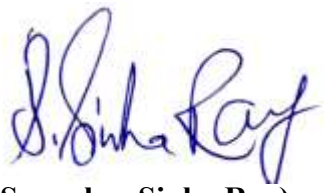
Dedicated with deep adoration to the Supreme Lord

Certificate

This is to certify that the thesis entitled **"Studies on the foaming behaviour of SEBS based blends and nanocomposites"** being submitted by **Ms. Ritima Banerjee** to the Indian Institute of Technology Delhi**,** for the fulfillment of award of the degree **"Doctor of Philosophy**" is a record of bonafide research work carried by her under our supervision. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi. We further certify that the thesis has attained a standard required for a Ph.D. degree of the institute. The research reported and results presented in the thesis have not been submitted in part or full to any other institute or university for the award of any other degree or diploma.



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Date: *(Ritima Banerjee)*

Abstract

Styrene-ethylene-butylene-styrene/polystyrene blends (containing 10, 20, 30 and 50 wt % polystyrene) and styrene-ethylene-butylene-styrene nanocomposites (containing 0.5, 1, 2 and 4 wt% Cloisite® 20A) were melt compounded, injection moulded, characterised and subsequently foamed.

Scanning electron microscopy of the blends in back-scattered imaging mode revealed that a portion of the added polystyrene was miscible with the styrene blocks of styrene-ethylene-butylene-styrene (SEBS), thereby increasing the domain size whereas the remaining portion got phase separated forming micrometer-sized aggregates. Blends with a higher polystyrene (PS) content (30 and 50 wt% polystyrene) possessed a fibrillar morphology, resulting in a remarkable increase in tensile modulus and storage modulus (in dynamic mechanical analysis).

The nanocomposites exhibited a mixed morphology in transmission electron microscopy. The clay was dispersed in both the polystyrene and the elastomeric phases, as indicated by shift in tan δ peak of both phases in dynamic mechanical analysis. An increase in clay content resulted in an increased formation of agglomerates as well as 3D mesoscopic structures. The nanocomposite with 1 wt% nanoclay exhibited maximum intercalation and delamination, with minimum agglomeration, resulting in maximum tensile modulus and storage modulus (in dynamic mechanical analysis).

The compositions were batch foamed using carbon dioxide. The foaming behaviour of both blends and nanocomposites depended on material characteristics and foaming temperature. At foaming temperatures close to the glass transition temperature of the polystyrene phase, when foaming of both the polystyrene and the ethylene-butylene phases occurred, compositions with higher storage modulus and complex viscosity produced foams of higher volume expansion ratio and lower shrinkage. However, unlike foams of the blends, where shrinkage was completely eliminated in case of blends of a higher polystyrene content, foams of all the nanocomposites shrank. But shrinkage of all nanocomposite foams was significantly lower than that of neat SEBS foam. Also, nanocomposites with well-dispersed nanoclay produced foams having morphology superior to that of foams of the blends, attributed to enhancement of melt strength and occurrence of heterogeneous nucleation by the nanofiller,

At foaming temperatures close to room temperature, the elastomeric phase was selectively foamed. The polystyrene particles (polystyrene domains of the copolymer and phase separated

aggregates of the blends) and the nanoclay in the elastomeric phase (in case of nanocomposites) served as sites of heterogeneous nucleation. Irrespective of rheological properties, all foams showed prominent shrinkage. Greater the number of polystyrene particles (in case of the blends) or the stiffness of the polystyrene phase (in nanocomposites, due to the dispersed clay), lower was the volume expansion ratio and higher was the shrinkage.

For a given composition, the quality of dispersion, as well as the foaming behaviour of both blends and nanocomposites depended on the primary processing conditions employed during compounding. In case of blends, a lower screw speed (around 100 rpm in a 16 mm twin screw extruder) favoured a finer quality of dispersion of the polystyrene particles. In case of nanocomposites, a screw speed of around 200 rpm resulted in superior quality of dispersion of nanoclay without degradation of the matrix. The blends and nanocomposites produced at 100 rpm and 200 rpm respectively, exhibited better tensile and rheological properties, as well as enhanced foamability at both higher and lower foaming temperatures.

In order to understand whether a synergistic combination of the attributes of the blend foams and the nanocomposite foams can be achieved in foams of ternary compositions, ternary compositions containing 30 wt% polystyrene and 1 wt% nanoclay were prepared and foamed at 100 °C. Though the foams exhibited no shrinkage and had superior volume expansion ratio, morphology was poor, as in case of foams of blends.

सार

स्टायरिन-एथिलीन-ब्यूटिलीन-स्टायरिन / पॉलीस्टीरिन मिश्रण (जिसमें 10, 20, 30 और 50 वाट% पॉलीस्टीरिन युक्त) और स्टायरिन-एथिलीन-ब्यूटिलीन-स्टायरिन नैनोकोमोसाइट्स (0.5, 1, 2 और 4 वाट% क्लॉसाइटा 20 ए युक्त) मिश्रित पिघल गए थे , इंजेक्शन मोल्ड, विशेषता और बाद में foamed।

बैक-बिखरे हुए इमेजिंग मोड में मिश्रणों के इलेक्ट्रॉन माइक्रोस्कोपी स्कैनिंग से पता चला है कि जोड़ा पॉलीस्टीरिन का एक हिस्सा स्टायरिन-एथिलीन-ब्यूटिलीन-स्टायरिन (एसईबीएस) के स्टायरिन ब्लॉक के साथ मिस्सीबल था, जिससे डोमेन आकार में वृद्धि हुई जबकि शेष हिस्से को चरण अलग किया गया माइक्रोमीटर आकार के योग बनाते हैं। एक उच्च पॉलीस्टीरिन (पीएस) सामग्री (30 और 50 वाट% पॉलीस्टीरिन) के साथ मिश्रणों में एक फाइब्रिलर मॉर्फोलॉजी है, जिसके परिणामस्वरूप तन्यता मॉड्यूलस और स्टोरेज मॉड्यूलस (गतिशील यांत्रिक विश्लेषण में) में उल्लेखनीय वृद्धि हुई है।

नैनोकोमोसाइट्स ने ट्रांसमिशन इलेक्ट्रॉन माइक्रोस्कोपी में एक मिश्रित रूपरेखा प्रदर्शित की। मिट्टी को पॉलीस्टीरिन और elastomeric चरणों दोनों में फैल गया था, जैसा गतिशील यांत्रिक विश्लेषण में दोनों चरणों के तन δ चोटी में बदलाव द्वारा इंगित किया गया है। मिट्टी की सामग्री में वृद्धि के परिणामस्वरूप एग्लोमेरेट्स के साथ-साथ 3 डी मेसोस्कोपिक संरचनाओं में वृद्धि हुई। 1 वाट% नैनोकले के साथ नैनोकोमोसाइट ने अधिकतम संचलन और संदूषण का प्रदर्शन किया, न्यूनतम समूह के साथ, जिसके परिणामस्वरूप अधिकतम तन्यता मॉड्यूलस और स्टोरेज मॉड्यूलस (गतिशील यांत्रिक विश्लेषण में) होता है।

कार्बन डाइऑक्साइड का उपयोग करके संरचनाओं को बैच फोमिंग किया गया था। दोनों मिश्रणों और नैनोकोमोसाइट्स का फोमिंग व्यवहार भौतिक विशेषताओं और फोमिंग तापमान पर निर्भर करता है। पॉलीस्टीरिन चरण के ग्लास संक्रमण तापमान के करीब फोमिंग तापमान पर, जब पॉलीस्टीरिन और ईथिलीन-ब्यूटिलीन चरण दोनों का फोमिंग हुआ, उच्च भंडारण मॉड्यूलस और जटिल चिपचिपाहट के साथ रचनाओं ने उच्च मात्रा विस्तार अनुपात और कम संकोचन के फॉम्स का उत्पादन किया। हालांकि, मिश्रणों के फोम के विपरीत, जहां उच्च पॉलीस्टीरिन सामग्री के मिश्रणों के मामले में संकोचन पूरी तरह समाप्त हो गया था, सभी नैनोकोमोसाइट्स के फॉम्स गिर गए। लेकिन सभी नैनोकोमोसाइट फॉम्स का संकोचन साफ सेब एसईबीएस फोम की तुलना में काफी कम था। इसके अलावा, अच्छी तरह फैलाने वाले नैनोकले के साथ नैनोकोमोसाइट्स

ने फोमों को मोर्फ़ोलॉजी के मिश्रणों से बेहतर रूप से विकसित किया है, जो पिघलने की शक्ति में वृद्धि और नैनोफिलर द्वारा विषम न्यूक्लियेशन की घटना के कारण जिम्मेदार है,

कमरे के तापमान के करीब फोमिंग तापमान पर, इलास्टोमेरिक चरण को चुनिंदा रूप से फोम किया गया था। पॉलीस्टीरिन कण (कोपोलिमर के पॉलीस्टीरिन डोमेन और मिश्रण मिश्रणों के चरण अलग-अलग होते हैं) और इलास्टोमेरिक चरण (नैनोकोमोसाइट्स के मामले में) में नैनोकले विषम न्यूक्लियेशन की साइट के रूप में कार्य करता है। भौतिक गुणों के बावजूद, सभी फूम्स ने प्रमुख संकोचन दिखाया। पॉलीस्टीरिन कणों (मिश्रणों के मामले में) या पॉलीस्टीरिन चरण (नैनोकोमोसाइट्स में, फैलाने वाली मिट्टी के कारण) की कठोरता जितनी अधिक होती है, मात्रा कम होने का अनुपात कम होता है और उच्च संकुचन होता है।

किसी दिए गए रचना के लिए, फैलाव की गुणवत्ता, साथ ही मिश्रण और नैनोकोमोसाइट्स दोनों के फोमिंग व्यवहार परिसर के दौरान नियोजित प्राथमिक प्रसंस्करण स्थितियों पर निर्भर थे। मिश्रणों के मामले में, एक निचली पेंच गति (16 मिमी जुड़वां पेंच extruder में लगभग 100 आरपीएम) polystyrene कणों के फैलाव की एक बेहतर गुणवत्ता का पक्ष लिया। नैनोकोमोसाइट्स के मामले में, लगभग 200 आरपीएम की एक स्क्रू की गति के परिणामस्वरूप मैट्रिक्स के अवक्रमण के बिना नैनोकले के फैलाव की बेहतर गुणवत्ता होती है। क्रमशः 100 आरपीएम और 200 आरपीएम पर उत्पादित मिश्रण और नैनोकोमोसाइट्स, बेहतर तन्यता और भौतिक गुणों के साथ-साथ उच्च और निम्न फोमिंग तापमान दोनों में बढ़ी हुई फोमबिलिटी प्रदर्शित करते हैं।

यह समझने के लिए कि क्या मिश्रण फूम्स और नैनोकोमोसाइट फॉम्स के गुणों का एक सहक्रियात्मक संयोजन टर्नरी रचनाओं के फोम में हासिल किया जा सकता है, 30 वाट% पॉलीस्टीरिन युक्त टर्नरी संरचनाएं और 1 वाट% नैनोकले तैयार की जाती हैं और 100 डिग्री सेल्सियस पर फॉम्ड होती हैं। हालांकि फॉम्स ने कोई संकोचन नहीं किया और बेहतर मात्रा विस्तार अनुपात था, मिश्रणों के फोम के मामले में रूपरेखा खराब थी।

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Chapter 6 Foaming Behaviour of SEBS Nanocomposites

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List of Symbols

Symbol		Description
$\overline{M}_n$	:	Number average molecular weight
$\overline{M}_w$	:	Weight average molecular weight
T_g	:	Glass transition temperature
ρ	:	Density
T	:	Torque
E	:	Tensile modulus
Φ	:	Volume fraction
τ	:	Shear stress
$\dot{\gamma}$	:	Shear rate
η	:	Shear viscosity
G’	:	Storage modulus in melt state dynamic rheology
G”	:	Loss modulus in melt state dynamic rheology
E’	:	Storage modulus in DMA studies
E”	:	Loss modulus in DMA studies
η^*	:	Complex viscosity
ν	:	Poisson’s ratio
N_0	:	Cell density

List of Abbreviations

Abbreviation		Description
TPE	**:**	Thermoplastic elastomer
SEBS	**:**	Styrene-ethylene-butylene-styrene
PS	**:**	Polystyrene
C20A	**:**	Cloisite® 20A
DSC	**:**	Differential scanning calorimetry
TGA	**:**	Thermal gravimetric analysis
DMA	**:**	Dynamic mechanical analysis
SEM	**:**	Scanning electron microscopy
TEM	**:**	Transmission electron microscopy
WAXD	**:**	Wide angle X-ray diffraction
VE	**:**	Volume expansion ratio