Research Article

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Thermodynamic Compatibility, Crystallizability, Thermal, Mechanical Properties and Oil Resistance Characteristics of Nanostructure Poly (ethylene-co-methyl acrylate)/Poly(acrylonitrile-co-butadiene) Blends

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Abstract: This paper addresses the compatibility, morphological characteristics, crystallization, physico-mechanical properties and thermal stability of the melt mixed EMA/NBR blends. FTIR spectroscopy reveals considerable physical interaction between the polymers that explain the compatibility of the blends. DSC results confirm the same (compatibility) and reveals that NBR hinders EMA crystallization. Mechanical and thermal properties of the prepared EMA/NBR blends notably enhance with increasing the fraction of EMA in the blends. Morphology study exhibit the dispersed particles in spherical shape in the nanometer level. Swelling and oil resistance study have also been carried out in details to understand the performance behaviour of these blends at service condition

Keywords: EMA, NBR, polymer blend, miscibility, oil resistance, crystallization

1 Introduction

As compared to synthesizing new polymers, blending technique has been broadly followed for fabricating new products with desired properties including physical and mechanical property. It has many benefits over synthesis of new polymers such as economically attractive and simple technique [1,2]. In general, polymer blend (PB) can be described as a macroscopically/ uniform mixture of two or more with structurally varied polymers. PB is divided into three categories according to their compatibility/ morphology: (a) miscible, (b) immiscible, and (c) partially miscible [3]. Literature shows that most of the polymer blends are immiscible because of entropy change. For the miscible blends to be thermodynamically favored, the Gibbs free energy of mixing should be negative [4]. Often, establishment of inter-connected hydrogen bonds among the two macromolecules in the blend would enhance the miscibility of the system [5]. Likewise, polar and non-polar nature of two polymers also can bring out the good miscibility between them. Many characterization tools are available such as TEM, AFM, DMA, DSC, FTIR, etc. to understand more about the miscibility between two polymers [6]. Furthermore, chemical composition, mixing temperature, viscosity, interfacial tension etc are key factors to decide the compatibility of the blends [7]. Nevertheless, there are many factors especially the chemical structures of distinct polymers to define the better interaction between plastics and rubber, for instance, involvement of two polar polymers would provide miscible or compatible blend [8]. Literature studies exhibit that miscible blends are very few.

EMA is copolymer of ethylene and methyl acrylate species [6,9]. The performance of the EMA can be modified by varying the percentage of ethylene and methyl acrylate content in it. It has good low temperature flexibilities as well as low permeability combined with good impact strength; it can be used as a highly stretchable film for the packaging industry as a wrap film for food packaging sectors. In addition, EMA copolymer has better characteristics...
than NBR such as better ageing, thermal stability and resistance to rapid degradation. However, the toughness characteristics of EMA polymer can be enhanced by mixing a minor quantity of a plasticizer/rubber into it while melt mixing/processing. Not only toughness, other technical properties like oil resistance characteristics can be improved by mixing a small amount of polymer which has superior oil resistance characteristics like NBR and acrylic rubbers. Likewise, many reports show that the terpolymers tend to mix with EMA for amending its base characteristics and properties for the suitable with various applications such as automobile, defense, commercial packaging etc. [10,11]

Genovese and Shanks [12] studied poly(propylene) (PP) based blends, which were developed with poly[ethylene-co-(methyl acrylate)] (EMA). Perera et al. [13] investigated the varieties of studies like compatibility of NBR/PVC and binary blends of ENR/PVC, and ternary blends of NBR/ENR/PVC by unique tools such as solid state nuclear magnetic resonance (NMR) and typical DMA. Bhattacharya et al. [9] reported the extensive studies on compatibility of poly(ethylene-co-methyl acrylate) and poly(dimethyl siloxane) blends by rheology. Likewise, Jyoti Sankar Borah and T.K. Chaki [14] investigated the physico-mechanical, surface morphology and rheological behavior of compatible polymer blends of linear low density polyethylene (LLDPE) and ethylene-co-methyl acrylate (EMA). Recently, Bhagabati and Chacki [6] have examined the miscibility of chlorinated polyethylene/ethylene methacrylate blends using various characteristics such as thermal stability, chemical analysis and physico-mechanical properties.

NBR is random copolymer with polar moieties in the polymer chains and is amorphous in nature. The existence of nitrile functional groups from neighboring polymer chains and inherency of polar nature, pulls towards each other and bind the chains together, making NBR stronger than other copolymers like ABS, SAN. This can also be a reason for its strong adhesive characteristics. The superior oil-resistance character of NBR makes it useful in a numerous applications including hoses and flexible print roller covers, etc. blending of EMA with NBR can enhance the oil resistance properties combined with good thermal stability. Also, the low temperature flexibility of EMA and cost effectiveness of NBR rubber also can be addressed. However, till date there is no detailed research on the influence of blend composition on thermal stability, physico-mechanical properties and crystallization behavior of EMA/NBR blend system. Hence, in our current research, we have done an in-depth examination on miscibility in terms of thermodynamic, characteristics of crystallization, thermal behavior, physico-mechanical properties, optical, oil and solvent resistance characteristics of EMA/NBR blends developed by melt mixing method.

2 Experimental

2.1 Materials

Acrylonitrile Butadiene Rubber (Perbunan 3445F) having Acrylo nitrile content 33% with specific gravity 0.97, and Mooney Viscosity of 45, ML (1+4) 100°C was supplied by M/s Lanxess Deutschland GmbH. Poly (Ethylene-co-Methyl Acrylate) copolymer (Optema TC 120) having the methyl acrylate content 21%, melting point of 81°C, MFI 6 g/min and density of 0.94 g/cm³ was obtained from M/s Exxon Chemical Corporation, Belgium.

2.2 Method of Blend Preparation

The blends of EMA polymer and NBR having different blend ratios were fabricated in a Brabender Plasticorder (model PLE-330) machine at a rotor speed of 60 rpm for 5 min and at a temperature of 120°C. Briefly, EMA was added first and melted for 1 min, and then subsequently, NBR was mixed into it and melt mixed for extra 4 min in the Brabender machine. In all cases, the total mixing time was maintained at 5 min. Then, the blend was taken out from the Plasticorder machine and sheeted out using laboratory two-roll mill straight away at normal temperature with ambient atmosphere. The blends samples are labelled as Ex (x = 0, 20...100) where x relates the weight percentage of EMA polymer in the blend samples, for example, E20 indicates 20% EMA and 80% NBR in the blend.

3 Characterization of EMA/NBR blends

3.1 FTIR spectroscopy

Fourier transform infrared spectrometer (Bruker Equinox 55, Germany) was used to take the infrared spectra of the control EMA, NBR and its various blends in ATR mode with in the wave number region of 4000-400 cm⁻¹. The spectrometer has a spectral resolution of 0.5 cm⁻¹ and the results reported here are average of 32 scans.
3.2 Differential Scanning Calorimetry

The examination of the glass transition temperature \( (T_g) \) of any blend is important since it decides the basic compatibility characteristics of it. We have carried out DSC study using TA instruments, Model DSC Q200, USA to find out the % crystallinity, \( T_g \) of the neat polymers such as EMA, NBR and their corresponding blends. The experiment was performed in an inert nitrogen atmosphere with 10°C min\(^{-1}\) heating rate from -90°C to 150°C. We also have performed series of preliminary scans to avoid the thermal history in it, especially residual stress. Second heating data were used for further studies. The percentage error related to the measurements of the resultant temperature were within ± 1%. We also made an attempt to find out the % crystallinity of EMA using the integrated area under melting peak by using the standard equation 1:

\[
X_c = \frac{\Delta H_f}{W_i \times \Delta H_{f100\%}} \times 100
\]

Where,

\( X_c = \text{crystallinity (}) \%
\)

\( \Delta H_f = \text{melting enthalpy (J/g) of EMA crystallinity} \)

\( \Delta H_{f100\%} = \text{enthalpy of crystallization of a 100% crystalline PE having a value of 288 J/g} \) \[15\]

\( W_i = \text{EMA ratio in the blend (weight fraction)} \)

Additionally, the DSC acquired \( T_g \) values were related to theoretically calculated values by using Flory- Fox equation: [16]

\[
\frac{1}{T_g} = \frac{W_p}{T_{g,p}} + \frac{W_r}{T_{g,r}}
\]

Where,

\( T_{g,p} = T_g \) of the prepared blend

\( T_{g,r} = T_g \) of pristine NBR

\( T_{g,p} = T_g \) of pristine EMA

\( W_p = \text{weight fraction of NBR in blend} \)

\( W_r = \text{weight fraction of EMA in blend} \)

3.3 Physico-mechanical properties of the blend

The physico-mechanical properties of the pristine polymers like EMA, NBR and their corresponding blends were performed in Hounsfield make, H10KS, at a stretching rate of 500 mm/min according to ASTM D412 at room temperature. From the results, the tensile strength, % of elongations and various moduli were extracted. Shore A hardness of the pristine polymers and its corresponding blends were also found using Durometer type A (Shore Instrument& Manufacturing INC-New York, USA).

3.4 Thermogravimetric Analysis

The thermal stability of the prepared blends and pristine polymers were examined by using a thermogravimetric analyzer (Mettler-Toledo, model TGA/SDTA 851e) from room temperature to 600°C with 10°C min\(^{-1}\) rate of heating. The analysis was performed in inert nitrogen atmosphere (N\(_2\)).

3.5 X-ray diffraction studies

X-ray diffraction was used to have an idea about the changes in the crystal structure as well as their crystallinity of the pristine polymers: NBR EMA and their corresponding blend. X-ray diffractometer (PW1710, Philips, USA) was used in this study and a monochromatic CuK\(\alpha\) radiation of wave length 1.5418 Å was the configuration of the diffractometer. We have scanned the 2θ range of 10-80° at an operating voltage 40 kV and beam current 20 mA. From the diffracted spectrum, we have calculated the degree of crystallinity \( (X_c) \) with the help of integrated area under crystalline and amorphous peaks as per equation (3).

\[
X_c = \frac{I_c}{I_a + I_c}
\]

Where, \( I_a \) and \( I_c \) are the integrated areas of corresponding amorphous and crystalline peaks, respectively.

In addition, the average size of the EMA crystallite \( (X_s) \) was calculated from full width at half maximum (FWHM) of X-ray diffraction peak as per Scherrer’s equation (4) [17,18]. Likewise, we also have attempted to calculate the inter-planar distance \( (d) \) and also inter-chain distance \( (r) \) by using equations (5) and (6), respectively [19]:

\[
X_s = \frac{k\lambda}{\beta \cos \theta}
\]

\[
r = \frac{5\lambda}{8 \sin \theta}
\]

\[
d = \frac{\lambda}{2 \sin \theta}
\]

where \( X_s \) is the average crystallite size, \( \lambda \) is the X-ray wavelength, \( \beta \) is the FWHM of the diffraction peak, \( \theta \) is the
diffraction angle and k is the Scherrer’s constant of the order of unity and for usual crystals, k=0.9 [20]. The crystallite size was calculated by taking the reference (110) plane.

### 3.6 Solvent swelling Characteristics

Swelling studies were performed by using different solvents such as toluene (δ=18.2), n-hexane (δ=23.3), methanol (δ=29.7), n-butanol (δ=23.3), and acetic acid (δ=20.7) at room temperature. The values in apostrophe are indicating the solubility parameter of the solvents in MPa^{1/2}. Volume swelling in percentage was estimated using the equation (7) [3]:

\[ q = \frac{W_2}{W_1} - 1 \]

Where,
- \( q \) = % of volume swell/100 (swelling index)
- \( W_2 \) = swollen weight
- \( W_1 \) = unswollen weight
- \( \rho_c \) = density of the composition
- \( \rho_f \) = density of the fluid or solvent

\[ \text{% of Swell} = \frac{W_1}{W_0} \times 100 \]  

Where,
- \( W_1 \) - Weight of swollen sample
- \( W_0 \) - Weight of un-swollen sample

### 3.7 Oil Resistance Characteristics

Oil resistance (oil swelling resistance) of the blends for different ASTM oils #1, #2 and #3, were carried out at room temperature (25°C) and 50°C. Circular test specimens of 10 mm (approx.) diameter were punched out from moulded sheets. Subsequently, these specimens were weighed accurately by using an electronic balance before immersing them into oils. The specimens were weighed at regular time intervals after wiping out the solvents sticking to the surface with a soft tissue paper until reaching the equilibrium weight. Percent (%) of swelling calculated by using the following equation (gravimetric method) [3]:

### 3.8 Morphology Study

Morphological study of the prepared various blend samples was carried out using an intermittent contact mode atomic force microscopy with the help of AFM (Agilent 5500 Scanning Probe Microscope). The resonance frequency of the tip and the force constant was 146–236 kHz and 48 N/m, respectively. The AFM Tip stiffness and radius of the instrument was 40 N/m and 10 nm, respectively.

Ethical approval: The conducted research is not related to either human or animals use.

### 4 Results and discussion

#### 4.1 FTIR spectroscopy

FTIR spectra of the various blends along with their pristine EMA and NBR are shown in Figure 1a. Designated frequency bands of both the pristine polymer and their

![Figure1: (a) FTIR spectra of pristine EMA, NBR and their blends and (b) C=O stretching region of the various EMA/NBR blends with different compositions.](image-url)
various blends are in line with the literature data. More precisely, C–H stretching frequency (olefinic) is located just above 2890 cm⁻¹, ester vibration of C–O–C stretching at 1727 cm⁻¹, the CH₆ bending vibration is located at 1436 cm⁻¹, and steep absorption peaks also received around 2,931 and 2,855 cm⁻¹. Where, the subscript P = plastic and R = rubber phase. Hence, the total free energy change of the absorption of carbonyl at 1738 cm⁻¹ designates the occurrence of ester moieties in EMA polymer [6].

The presence of C=C at 1611 cm⁻¹ corresponds to butadiene structure of NBR. The absorption of carbonyl at 1738 cm⁻¹ designates the occurrence of ester moieties in EMA polymer [6].

Fowkes relationship was used to have more idea about the miscibility between two polymers and the Fowkes equation is as follows [3-5]:
It reveals that EMA and NBR are well compatible throughout the blends, with the increased concentration of NBR, the $T_c$ value is shifted towards low temperatures and consequently, $\Delta H_f$ also diminishes as the blends become more amorphous (literally) and the outcome hindrance to the crystallization of EMA (semi crystalline polymer) also increases. Moreover, the $\Delta H_f$ reduction of EMA is primarily at the onset of the crystallization of ethylene component in the blends. In general, growth rate of EMA crystallites are inhibited with the addition of amorphous NBR due to four probable factors: reduction in the chain mobility, crystalline polymer dilution at the growth face, free energy change of nucleation due to specific interactions, and morphology of the blend i.e., amorphous and crystalline polymer which results in competition amongst the advancing spherulite front and the diffusion of amorphous component into interlamellar and interfibrillar regions.

Furthermore, the rate of crystallization and the heat of fusion ($\Delta H_f$) of EMA decreases as the amorphous NBR phase increases. Several researchers have reported the same phenomenon [28]. From further analysis, it can be observed that the interaction between EMA and NBR is at the molecular level thus leading to their mutual compatibility. Beside this, the theoretically calculated $T_s$ values from Flory-Fox equation are close to that obtained experimentally. Table 2 discloses a positive difference of the experimental values of $T_s$ obtained using the equation. This slight change is because intermolecular hydrogen bonds are weaker than the intramolecular ones in the blends [29,30]. Figure 3a illustrates the $T_m$ of neat EMA and their various blend ratios. The increased proportion of NBR in blends leads to an overall crystallization disruption of EMA, which in turn results in disappearance of melting peaks. The depression in melting point of EMA in the blends is also a beneficial evidence of the existence of mutual compatibility between NBR and EMA. This behavior can be attributed to the introduction of amorphous NBR chains into the crystal growth front, which in turn, hinders the three-dimensional crystal growth in EMA, in that way diluting the lamellar thickness or crystal perfection in EMA phase. In addition, $T_m$ also strongly depends on
crystallization temperature. It is evident from Figure 3b that NBR also decreases Tc of EMA as the former affects lamellar thickness and melting behavior of the latter. A similar process was also reported for LLDPE/EVA blends [31,32]. Moreover, both morphological and thermodynamic effects also caused the reduction in Tm. In thermodynamics, when two polymers are miscible, the chemical potential and free energy associated with crystalline polymer decrease with the addition of amorphous polymer. It leads to a reduction in the equilibrium melting temperature of the blend. The decrease in free energy is attributed to strong dipole–dipole attraction between EMA and NBR [3,6]. This statement is corroborated by the FTIR spectroscopy results as discussed in previous section. The percentage crystallinity (Xc) of the blends are tabulated in Table 2. It shows that there is a substantial change in the percentage crystallinity of the blends. Blend containing 70 wt% of NBR (E30) exhibits a drastic reduction in the crystallinity. The reason for this trend in Xc is also the same as explained in the preceding paragraph.

4.3 Physico-mechanical properties of NBR/EMA blends

The stress-strain behavior of NBR/EMA blends having different blend compositions are shown in Figure 4. The NBR/EMA blend (E30) display a typical behavior of elastomers, whereas the EMA shows analogous to that of thermoplastic elastomers. Blending of NBR and EMA changes the stress-strain pattern considerably. The E50 blend shows intermediate behavior. It is observed that with increase in EMA content in the blend, the stress increases and strain decreases compared to pristine NBR as expected.

Moreover, with increase in the EMA contents, tensile strength of the blend increases, and interestingly a sharp increase in tensile strength is observed when the EMA content exceeds 50 wt%. This may be associated with the better interaction or good compatibility between EMA and NBR. The blend having 70 wt. % of NBR (E30) has lower tensile strength due to lower modulus of amorphous NBR and because of non-interaction between the blend constituents the blend exhibit (70:30 NBR: EMA) lower tensile strength. The elongation at break increases gradually with increase in NBR proportion in the blend, EMA changes turns from dispersed phase into the continuous matrix phase is expected to bear all the loads of the blend system. Furthermore, Young’s modulus value obeys the same trend as observed in case of stress at break and beyond 50-wt% of EMA, it increases sharply.

| Sample ID | Tensile Strength (MPa) | Elongation @ 100% elongation (% | Stress (MPa) @ 100% elongation | Elongation @ 200% elongation (%) | Stress (MPa) @ 200% elongation | Elongation @ 300% elongation (%) | Stress (MPa) @ 300% elongation |
|-----------|------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| E100      | 9.7±.2                 | 852±21                          | 3.3±.25                         | 3.7±.1                          | 4.1±.04                         | 3.2±.02                         |
| E80       | 7.8±.3                 | 860±35                          | 2.4±.12                         | 2.7±.09                         | 3.2±.02                         | 2.1±.02                         |
| E60       | 7.9±.1                 | 858±14                          | 2.5±.1                          | 2.7±.04                         | 3.2±.08                         | 2.1±.02                         |
| E50       | 2.9±.3                 | 604±09                          | 1.5±.15                         | 1.8±.06                         | 2.1±.02                         | 1.8±.01                         |
| E40       | 2.5±.2                 | 582±11                          | 1.3±.2                          | 1.5±.03                         | 1.8±.01                         | 1.8±.01                         |
| E20       | 0.6±.07                | 450±23                          | 0.6±.07                         | 0.6±.07                         | 0.6±.01                         | 0.6±.01                         |
| E0        | 0.3±.05                | 881±19                          | 0.4±.05                         | 0.4±.02                         | 0.5±.06                         | 0.5±.06                         |

Hence, it can be inferred that EMA rich blends exhibit good mechanical properties. Young’s modulus, tensile strength, and modulus at 100% elongation, 200% elongation and 300% elongation of the various blends ratios along with the pristine NBR and EMA are summarized in Table 3.

4.4 Thermogravimetric Analysis

The thermogravimetric TGA plots of the pristine EMA, NBR and its various blends are shown in Figure 5. From the graphs, it can be understood that pristine EMA, NBR and its blends exhibited single step degradation. The initial degradation temperature (T1), degradation temperature at 50% weight loss (T50), and the percentage of residue content of control EMA, NBR, and their blends are summarized in Table 4. However, control EMA and NBR has vast difference in T1 values, but the existence of single step degradation of the blends indicates that the blends
are not completely immiscible. This was speculated to be because of certain degree of compatibility at its molecular level[3,6]. Furthermore, it was clearly observed from the Table 4 that the addition of NBR to EMA has improved the overall thermal degradation stability. All blends have shown higher T<sub>i</sub> and T<sub>50</sub> values compared to control NBR. This phenomenon can be explained on the basis of the compatibility factor between the constituent polymers. The specific interaction existing between EMA and NBR (as was observed from the FTIR analysis) developed certain degree of compatibility. Such technological compatibility between the constituent polymers of blends causes improvement in thermal degradation stability [14,15]. Hence, the EMA/NBR blends have showed better thermal stability over the constituent polymers, which was the direct consequence of high degree of compatibility between EMA and NBR.

### 4.5 X-ray diffraction

In order to further understand the crystalline behavior, the X-ray studies of pristine EMA, NBR and its blends at various composition ratios were also carried out. In order to study the degree of crystallinity, the X-ray diffractograms of prepared blend samples were recorded and is shown in Figure 6. The pristine NBR did not show any crystalline peak referring to its amorphous nature as already reported in DSC results. Whereas, control EMA showed two strong amorphous halos within the selected range of 20; from 19° to 22.1° and 24.1° to 26.2° with corresponding peak values at 21.07° and 24.14°, respectively. The crystallite size (X<sub>c</sub>), percent crystallinity (X<sub>c</sub>), inter planar distance (d), and inter chain distance (r) were calculated according to equation (3, 4 and 5) and tabulated in Table 5.

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**Table 4: TGA results of pristine EMA, NBR and their various blend ratios.**

| Sample ID | Onset temperature of degradation (°C) (T<sub>i</sub>) | T<sub>50</sub> | Weight % of final residue |
|-----------|--------------------------------------------------|----------------|--------------------------|
| E100      | 433                                              | 460            | 1.3                      |
| E80       | 424                                              | 471            | 1.9                      |
| E60       | 418                                              | 466            | 1.8                      |
| E50       | 414                                              | 468            | 3.1                      |
| E40       | 413                                              | 469            | 4.1                      |
| E20       | 390                                              | 471            | 7.3                      |
| E0        | 369                                              | 463            | 6                        |

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**Figure 5:** TGA profiles of pristine polymers and EMA/NBR blends.

**Figure 6:** X-ray diffraction patterns of pristine EMA, NBR, and their various blend ratios.

Here, the percentage of crystallinity are found to be close to those obtained from DSC analysis. Besides, the peak positions and interplanar separation (d-spacing) values of the two strongest peaks (designated as peak 1 and peak 2) of crystalline phase of EMA are also mentioned in Table 5. The broad peak observed in NBR rich EMA/NBR blends corresponds to its amorphous peak. The significant changes were observed in percent crystallinity upon increasing the NBR content is credited to the unfolding of ethylene chain. Likewise, EMA in the presence of NBR chains, inter planar and inter chain distances remain more or less the same for all the blends [3,5,19]. The variation of % X<sub>c</sub> with the blend composition is comparable to that inferred from DSC data.

### 4.6 Solvent swelling behavior

Figure 7 depicts the plots of swelling index of the pristine EMA, NBR and their blend in different solvents at room temperature using equation 7. Pristine EMA shows an excellent resistance to all given solvents as suggested by
its swelling index. The swelling index values increase with increasing proportion of NBR in the blends. It is due to the fact that EMA is semi-crystalline polymer and thus, it is rigid and restricts diffusion of solvent molecules. Moreover, due to the excellent compatibility between EMA and NBR, swelling of NBR is limited in these blends. In addition, the solubility parameters (δ) of NBR and EMA plays a crucial role in restricting the transport of solvent molecules through them. Solubility parameters of the solvents used and EMA (δ = 20.5 MPa1/2) and that of NBR (δ = 13.50 MPa1/2) was calculated by employing Hildebrand equation.

The swelling index in toluene and acetic acid increases significantly with the increase in EMA content. The change in swelling as a function of the blend composition is negligible in n-hexane, n-butanol, and methanol. It is due to the fact that δ values of toluene and acetic acid are close to that of NBR, while the δ values of n-hexane, n-butanol, methanol, and EMA are not comparable. In addition, NBR in the blend was not cross-linked, so the solvent molecules can easily get into the soft phase of NBR. Even though the δ values of n-hexane and n-butanol are close to that of EMA, they cannot easily go into EMA phase since it is a rigid semi-crystalline thermoplastic polymer. Therefore, swelling characteristics of these blends can be tailored by varying the amount of EMA. Also, the flexibility of NBR chains on mixing with EMA is expected to be reduced relative to that of the chains in the bulk polymer of both, with the gradual increase in mobility, the distance from the boundary increases. Thus, a layer of restricted chain mobility is made near to the phase boundaries and due to higher stiffness of the NBR chains in this layer and this zone swells to a small extent than that of the pristine polymer zones.

### 4.7 Oil Resistance Studies

NBR is an elastomer specifically well known for its excellent oil resistance property. However, EMA also have some degree of inherent oil resistance, but the effect of EMA on the oil resistance characteristics of NBR is a matter of concern. Hence, it becomes very important to understand its behavior towards different types of oil. The oil resistance characteristics of control NBR and its blends with EMA were calculated by using ASTM #1, #2, and #3 oil at room temperature as well as at elevated temperature of 50°C (Figure 8) using equation 8. It shows NBR rich blend shows less swelling or better oil resistance characteristics. Moreover, the swelling is decreasing gradually with increasing the proportion of NBR in the blend.

### 4.8 Morphology Study

Morphology of the blends plays a key role in predicting solid-state properties as well as to understand more about the compatibility between two polymers. Phase analysis of atomic force microscopy (AFM) has been carried out for the blend samples (E20 to E80) to reinforce the compatibility of blends and it is shown in Figure 8. It revealed that the blends are well compatible and the dispersed phase shows a particle size of ~200 nm to ~600 nm for the various blend ratios. In addition, E50 blends
show abrupt change in the particle size of the dispersed phase like it shows a size of 2-3 µm. It almost shows co-continuous morphology of EMA/NBR blends. NBR/EMA blends are well technological compatible demonstrated by nanostructured morphology and it is well reflected in the mechanical properties of the blends.

4.8 Morphology Study

Figure 9: AFM Phase analysis of the various blends ratios.

5 Conclusions

The melt mixed EMA/NBR blends show good compatibility at all proportions as evidenced from FTIR spectroscopy, DSC, XRD and AFM. On changing the blend composition, a significant change in the crystallinity was observed.
for those blends having substantial proportion of NBR, but the blends with small proportion of NBR are totally amorphous. EMA rich blends show greater tensile strength and modulus, whereas the elongation at break decreases. The thermal stability of blend increases with the increase in EMA content. Solvent resistances of these blends are improved with EMA content and the betterment in solvent resistance is a function of the proportion of the latter. Oil resistance of the blends is greater for the NBR rich blends. AFM phase morphology further confirms the better compatibility between two constitute polymers and they are nanostructure morphology. Overall, the current investigation unveils that the mechanical thermal and oil resistance characteristics of EMA can be tuned by blending it with NBR and the plausible potential applications of the developed NBR/EMA blends include O-ring, hoses and oil seals applications.

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