



# Enhancement of Mechanical Properties of High Melt Flow Polypropylene & Ethylene - Octene Copolymer Blends

Amresh Kumar Singh<sup>1</sup>, Manjit Singh Chhetri<sup>2\*</sup>, Pushyamitra Mishra<sup>3</sup>

## Abstract

In this current study, we have investigated and compared the improvement on the mechanical properties of high melt flow polypropylene copolymer (PPCP<sub>1</sub>) and ethylene-based  $\alpha$ -olefin elastomer i.e. Polyolefin elastomer by incorporating intermediate melt flow index polypropylene copolymer (PPCP<sub>2</sub>IF) and changing the composition of ethylene octene impact modifier (E.O<sub>1</sub> & E.O<sub>1</sub>/ E.O<sub>2</sub>/ HDPE) while keeping the matrix copolymer (PPCP<sub>1</sub>) as such. This paper reports the experimental issues associated with data measurement, and a procedure for determining properties by modeling and extrapolation is proposed. Impact modifiers explored are olefinic copolymers i.e. ethylene - octene elastomer having different melt flow index of, 5 gm/10 min (EO<sub>1</sub>) and ethylene - octene elastomer of 0.5 gm/10 min (EO<sub>2</sub>). The inclusive performance of high melt flow polypropylene (PPCP<sub>1</sub>) - EO<sub>1</sub> & high melt flow polypropylene (PPCP<sub>1</sub>) - (E.O<sub>1</sub>/ E.O<sub>2</sub>/ HDPE) blends are compared in terms of various mechanical and rheological properties by varying intermediate M.F.I. PPCP (PPCP<sub>2</sub>IF) content from 0% - 20%. Results shows that at low PPCP<sub>2</sub>IF content (<10%), the intensification in impact strength is insignificant while extra high toughness observed in the range of 10% - 20 % PPCP<sub>2</sub>IF when added to PPCP<sub>1</sub> & E.O<sub>1</sub>/ E.O<sub>2</sub>/ HDPE system . Presence of HDPE plays a huge role in preventing coalescence of the rubber particles leading to better and finer dispersion of the rubber particles. Our research will give a new combination of PPCP and POE blends for perfect balance of toughness and stiffness which is a very essential requirement for automotive TPO application.

100

**Keywords:** Thermoplastic Olefin, POE, Polypropylene, Impact strength, Tensile strength, Flexural Strength

**DOI Number:** 10.48047/nq.2021.19.1.NQ21014

**Neuroquantology 2021; 19(1):100-106**

## 1. INTRODUCTION

Mixing of two or more different kind of polymers is method for the developments of blends with better characteristics which can't be obtain from individual polymer. Properties of a polymer blends mainly depends on the matrix phase but other factors like, shape, size, and phase morphology of the constituent materials, their interaction and interfacial adhesion of the discontinue phase also are important<sup>1</sup>. The blends of polypropylene and rubber component are defines as thermoplastic elastomer (TPE). Thermoplastic elastomeric materials (TPEs) can be produce by blending polypropylene with various natural or synthetic

rubbers. Depending upon the rubber and thermoplastic compositions the TPEs have been synthesized along two different procedures. One consists of a simple blending and this is known a thermoplastic olefin (TPO), while in second method, the elastomeric phase is dynamically vulcanized, and known as thermoplastic vulcanizates (TPVs)<sup>2,3</sup>. Thermoplastic olefins (TPOs) are mainly immiscible blends containing a dispersed phase of polyolefin elastomer. Thermoplastic polyolefins (TPOs), consisting of a polypropylene matrix with a dispersed rubbery phase, display improved properties over their virgin components<sup>4</sup>. One of the most widely used commodity thermoplastics is polypropylene (PP). Polypropylene possesses

**\*Corresponding Author:** Manjit Singh Chhetri

**Address:**<sup>1</sup>Department of Chemistry, Arunachal University of Studies, Namsai, Arunachal Pradesh, , India

<sup>2</sup>Department of Chemistry, Arunachal University of Studies, Namsai, Arunachal Pradesh, India ,

Email: manjitpdf@gmail.com

<sup>3</sup>Department of Chemistry, Research Center, Shri Lal Bahadur Shastri Degree College Gonda, UP, India

**Relevant conflicts of interest/financial disclosures:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Received:** 02 November 2020 **Accepted:** 15 December 2020



Polypropylene (PP). Polypropylene possesses some disadvantages, such as a low impact resistance, particularly at or below room temperature limits some of its applications<sup>5, 6,7,8,9</sup>. Therefore, other elastomers are often incorporated into the PP matrix in order to improve the impact strength. PP has been toughened by rubber modification to overcome its brittleness at low temperatures. In polypropylene modification, the major application is in the area of the automotive TPOs<sup>10</sup>.

The Polyolefin-based elastomers (PBEs) are widely used in impact modification of polypropylene because of their low density, recycling ability, good chemical resistance, better processing advantages, they do not require vulcanization as require in rubber. A new polyolefin elastomer (POE), which is ethylene octene Copolymer (EO) which has used metallocene catalysis, is a typical example of PBEs<sup>11, 12</sup>. POE is a thermoplastic elastomer which posses excellent advantage, such as high melt strength, good impact, good processability, good compatibility with other polyolefins such as polyethylene and PP<sup>13,14</sup>. Metallocene catalysts for olefin polymerization have allowed the control of molecular weight distribution and the proportion and distribution of comonomer incorporation. In other alternative method HDPE is used as the third component in PP/POE blend since it is expected to improve the adhesion between the disperse rubber phase and the polyolefin matrix. Thus, aim for use of HDPE is to find out its synergistic effect on toughening of PP/ POE blends. It has been reported by Elliott that the addition of small amounts of HDPE to the blend of PP and NR improved the adhesion between the disperse rubber phase and the polyolefin matrix<sup>15</sup>.

Although the majority of research on thermoplastic olefins involved low melt flow rate (high molecular weight) PP with ethylene- $\alpha$ -olefin copolymer blends, high melt flow rate of PP/ethylene- $\alpha$ -olefin blends are less explored<sup>16</sup>. They are significant because of their applicability in injection molding applications in the automotive industry<sup>17</sup>. In this paper, an attempt was made for the improvement in mechanical property of high melt flow polypropylene copolymer matrix (PPCP<sub>1</sub>), and EO<sub>1</sub> blends by employing another copolymer of intermediate melt flow Index (PPCP<sub>2</sub>IF). In

another experiment aim is to be investigation of an alternative method of improving mechanical properties by changing the composition of impact modifier (EO<sub>1</sub>/EO<sub>2</sub>/HDPE) while keeping the matrix copolymer (PPCP<sub>1</sub>) and copolymer of intermediate M.F.I (PPCP<sub>2</sub>) as such. Obtained data is then related and interpreted in terms of the basic structure property relationship, by varying the percentage of an intermediate melt flow polypropylene copolymer (PPCP<sub>2</sub>IF) for perfect balance of toughness and stiffness which is an essential requirement for automotive application.

## 2. Material and Experimental

### 2.1 Polyolefin modifiers

Impact modifiers studied are olefinic copolymers having different melt flow index. An ethylene-based  $\alpha$ -olefin elastomer (POE), produced by Dow chemical's, i.e. ethylene octen elastomer ENGAGE™ 8200 (EO<sub>1</sub>) which has a melt flow index of 5 g/10min at 190°C. Another impact modifier which are used for this characterization are ENGAGE™ 8150 Ethylene - octene elastomer (EO<sub>2</sub>) has melt flow rates 0.5 g/10min at 190°C. HDPE grade HD 50MA180 produced by reliance industries of melt flow rates 20 g/10min at 190°C is also used as to enhance the impact property of blends.

### 2.2 Polypropylene

The polypropylene matrix studied is a high melt flow impact co-polymer (PPCP<sub>1</sub>) Moplen EP640T produced by the Lyondell basel has a melt flow index of 51 gm /10 at 230 °C. Besides, the matrix copolymer PPCP<sub>1</sub>, copolymer of intermediate melt flow index (PPCP<sub>2</sub> IF) grade Moplen EP 540P produced by lyondell basel are used having a M.F.I of 15g/10 min at 230°C.

### 2.3 Blend Formation

Various blends are formed by varying the percentage ratio of the two copolymers (PPCP<sub>1</sub>) & (PPCP<sub>2</sub>) while keeping the impact modifier constant. The various compositions of the blend to be formed are shown in the table below table.

**Table - 1** E.O<sub>1</sub> blend formation

PPCP <sub>1</sub> HF (%)	80	75	70	65	60
E.O <sub>1</sub> Impact Modifier (%)	20	20	20	20	20
PPCP <sub>2</sub> IF (%)	0	5	10	15	20



**Table – 2** E.O1/E. O<sub>2</sub>/HDPE blend formation

PPCP <sub>1</sub> HF (%)	80	75	70	65	60
E.O <sub>1</sub> Impact Modifier (%)	15	15	15	15	15
E.O <sub>2</sub> Impact Modifier (%)	3	3	3	3	3
HDPE (%)	2	2	2	2	2
PPCP <sub>2</sub> IF (%)	0	5	10	15	20

## 2.4 Blending and specimen preparation

Thermoplastic polyolefin compounds featuring olefinic, co-polymer were compounded in co rotating omega 20, twin screw extruder with a screw diameter of 19.7 mm. Typical PP extrusion condition maintained, with extrusion melt temperature set at 190 - 220 deg c. Finally, compounds were palletized and injection molded into test specimens sample pellets were injection molded into test specimen using a 100 -ton kaptiva injection molding machine using standard PP molding conditions.

## 2.5 Conditioning

Injection-molded samples were conditioned for 48 hours in a humidity chamber before testing. 23 deg c ambient temperature and 65% relative humidity were maintained.

## 2.6 Mechanical testing

Mechanical properties such as notched izod impact strength, flexural modulus, and tensile strength data were obtained from 3.2 mm thickness injection molded samples. Tensile strength, Flexural modulus, and Impact strength are determined as per ASTM D 638, ASTM D 790 & ASTM D 256 respectively by using LLOYD, LR 10 PLU series Universal testing machine (UTM) & JJ impact tester, XJDU- 5.5 series. Melt Flow Index of the blend was also determined as per ASTM D 1238 by using JJ melt flow indexer model 1221.

## 3. RESULT & DISCUSSION

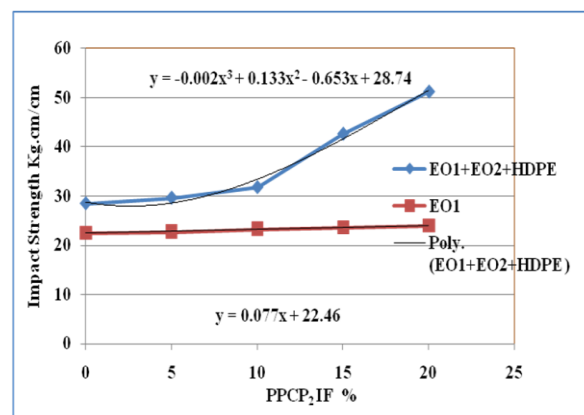
### 3.1 Izod Impact Strength

Impact strength of both polypropylene blends was compared against % PPCP<sub>2</sub> IF added.

**Fig. 1** shows the variation of impact strength of different impact modified systems as PPCP<sub>2</sub> IF content changes from 0% to 20% for both the blends. Contrary to our expectations, the impact strength does not improve significantly with addition of copolymer of intermediate M.F.I nor is the change following a set pattern in case of 1<sup>st</sup> blend composition (EO1).

This can be explain as, after sample molding coalescence of rubber domains takes place leading to a decrease in the effective surface area of the rubber domains. Thus, the occurrence of shear yielding is reduced leading to low crazing. Finally more cavitations take place due to stress concentration around the rubber-matrix boundary leading to failure. In a nutshell, the rubber domains, due to their reduced surface area now absorb less energy before crack formation leading to lower Impact Strength. While the copolymer of intermediate M.F.I (PPCP<sub>2</sub> IF) reduces the flow mismatch and hence tries to minimize the gathering of rubber domains, the high M.F.I of EO<sub>1</sub> Rubber proves a deterrent and tries to enhance coalescence.

Consequently, the end result is a balancing of both effects leading to no significant improvement in impact Properties, which we have seen in fist combination of EO<sub>1</sub> impact modifier blend. In case of 2<sup>nd</sup> blends combination (E.O<sub>1</sub>/E. O<sub>2</sub>/HDPE) the impact strength improves significantly with addition of PPCP<sub>2</sub>IF although the change is neither linear nor gradual. Besides, the observed impact values for E.O1/ E.O<sub>2</sub>/ HDPE Impact modified blends are much higher than those for simple High E.O<sub>1</sub> modified blends.



**Fig.1** Variation of Impact Strength vs PPCP<sub>2</sub>IF

This phenomenon can be explain as, the extent of coalescence depends on two factors - the extent of thinning of the rubber domains and the extent of packing of the domains. The former depends on the M.F.I of the elastomeric rubber while the latter is dependent on the flow properties of the entire blend. The presence of low M.F.I Impact Modifier (E.O<sub>2</sub> Rubber) leads to less thinning out of the rubber domains. Low M.F.I implies high viscosity,



implying lesser tendency to physical changes under shear as compared to a low viscosity material. Consequently, from extrusion process till the molding is complete, there is less thinning in case of E.O<sub>2</sub> Rubber (M.F.I = 0.5g/10min) as compared to E.O<sub>1</sub> Rubber (M.F.I = 5g/10min). Further, the presence of HDPE plays a huge role in preventing coalescence of the rubber particles as it forms a thin shell around the core rubber particle leading to better and finer dispersion of the rubber particles. One of the fact that finer and better the dispersion more is the toughness of the blend, this is the reason that for the same PPCP<sub>2</sub> IF content the impact properties of E. O<sub>1</sub>/E.O<sub>2</sub>/HDPE Impact modified blends are better than those of E.O<sub>1</sub> Impact Modified blends as evident from fig 1.

Lastly, the PP Copolymer of intermediate M.F.I (PPCP<sub>2</sub> IF) reduces the flow mismatch and further minimizes the gathering of rubber domains. Thus, other factors being held constant i.e. impact modifier content, an increase in % PPCP<sub>2</sub> is bound to increase the impact strength of the blend. The trend for impact strength of E.O<sub>1</sub>/ E.O<sub>2</sub>/ HDPE Impact modified blends shows a sharp change after a particular PPCP<sub>2</sub> IF content. Thus we see the occurrence of region with extra-high impact strength in the range of 10% - 20 % which is essential for automotive applications. The occurrence of this region can be attributed to the increase in the number and lesser size of elastomeric droplets due to less coalescence, which ultimately reaches a critical value, beyond which elastomer globules and mean distance between two droplets are small enough. This increases the probability that when energy associated with impact is flowing through the matrix, these globules impose effective spots of energy absorption and minimize crack growth and improves toughness of the system. Further at low PPCP<sub>2</sub> IF content (<10%), the increase in impact strength is insignificant. This is because at low PPCP<sub>2</sub> IF content the rubber domains are too less to cause crazes even after significant shear yielding has occurred. Thus, the shear yielding is immediately followed by rapid energy propagation forming a crack. As PPCP<sub>2</sub> IF increases, lesser coalescence takes place leading to more and smaller rubber domains are formed favoring crazing which absorbs

energy locally in great quantities and impose restrictions on crack growth. It is only after crazing that 'open cracks' form leading to failure.

Also, based on the trend lines obtained the equations for modified impact is 3<sup>rd</sup> order and can be given as:

**E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE System:**

$$I_M = -0.002x^3 + 0.133x^2 - 0.653x + 28.74$$

**E.O<sub>1</sub> System:**

$$I_M = 0.077x + 22.46 \quad \text{Where, } C = \% \text{ PPCP}_2 \text{ Content}$$

The trend line observed for High M.F.I E.O<sub>1</sub> system may be linearly increasing but a closer look reveals that the coefficient determining the extent of improvement i.e. "0.077X" is negligible as compared to "22.46". Hence, our conclusion of "Almost No Increase" is justified. However, when the same values of Impact Strength are plotted against the Volume Fraction of PPCP<sub>2</sub> present (**Fig. 2**) the equations for modified impact based on the trend lines observed come out to be as shown:

**E.O<sub>1</sub> E. O<sub>2</sub>/HDPE System:**

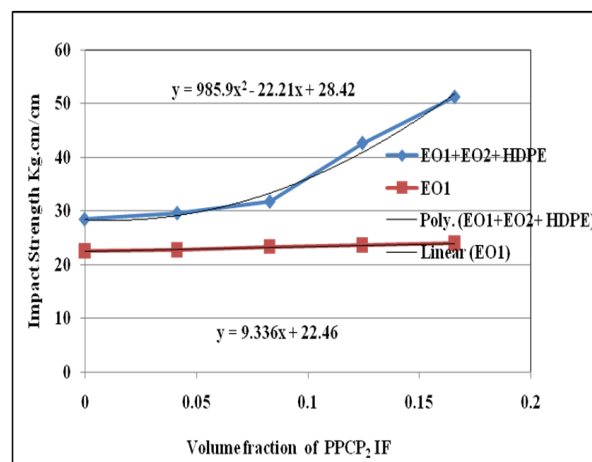
$$I_M = 985.9V^2 - 22.21V + 28.42$$

**E.O<sub>1</sub> System:**

$$I_M = 9.336V + 22.46$$

Where, V = Volume Fraction of PPCP<sub>2</sub>

Once again the trend line observed for High M.F.I E. O<sub>1</sub> system may be linearly increasing but the coefficient determining the extent of improvement i.e. "9.336V" is negligible as compared to "22.46". Hence, our conclusion of "Almost No Increase" is justified.



**Fig. 2** Volume fraction of PPCP<sub>2</sub> IF vs Impact Strength





### 3.2 Tensile Strength

Fig 3 shows the variation of tensile strength of different impact modified systems as PPCP<sub>2</sub> IF content changes from 0% to 20%. As expected, in E.O<sub>1</sub> blends system the tensile properties of the blend are better when PPCP<sub>2</sub> IF is present as compared to a system without PPCP<sub>2</sub> IF but with same impact modifier content. However, the tensile strength increases only marginally with an increase in PPCP<sub>2</sub>IF content and the change is not linear and gradual.

As the % PPCP<sub>2</sub> IF increases, the flow mismatch due to high M.F.I of matrix copolymer (PPCP<sub>1</sub>) and comparatively very low M.F.I of impact modifier (EO Rubber) is minimized resulting in better tensile properties. The increase however is marginal due to the presence of impact modifier which inherently tries to reduce the stiffness of the blend.

While in case of E.O<sub>1</sub>/ E.O<sub>2</sub>/ HDPE, the tensile properties of the blend do not decrease rather remain constant within the experimental limits. The effect of PPCP<sub>2</sub> however is nullified because with reducing flow mismatch the toughening effect of impact modifier is increasing that counteracts the gain in stiffness of the blend. Further, the values of tensile strength for E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE Impact Modified blends are only slightly lesser than for simple E.O<sub>1</sub> modified blends.

However, in case of E.O<sub>1</sub> Impact Modified blends the effect of copolymer of intermediate melt flow surpasses the counter effect of impact modifier which tries to reduce stiffness. Consequently, the tensile properties are slightly better for E.O<sub>1</sub> Impact Modified blends as compared to E.O<sub>1</sub>/ E.O<sub>2</sub>/LLDPE Impact modified blends.

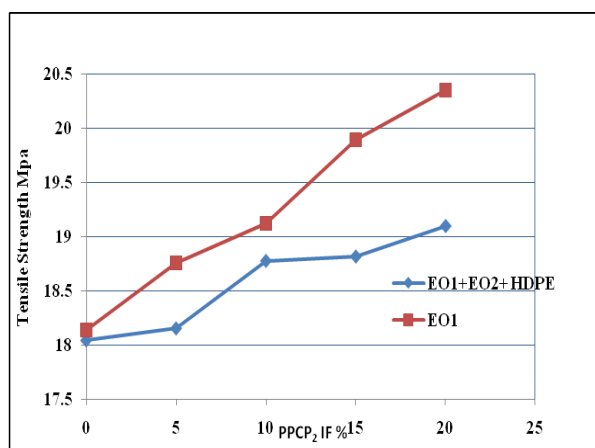


Fig-3 Variation of Tensile Strength vs PPCP<sub>2</sub>IF

### 3.3 Flexural modulus

Fig 4 shows the variation of flexural modulus of different impact modified systems as the PPCP<sub>2</sub> IF content changes from 0% to 20%. Within experimental limits, the result indicated that the flexural modulus remains fairly unchanged with % PPCP<sub>2</sub> added.

No increase in flexural modulus can once again be attributed to balancing out of two opposite parameters - the addition of copolymer of intermediate M.F.I (PPCP<sub>2</sub> IF) to minimize flow mismatch and the presence of impact modifier (EO Rubber) to improve toughness.

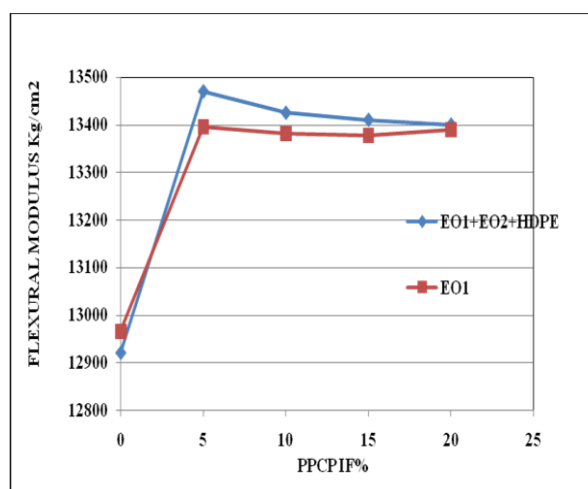


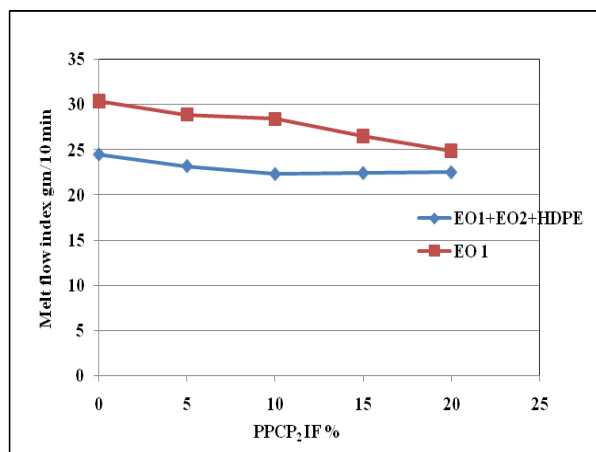
Fig - 4 Variation of Flexural Modulus vs PPCP<sub>2</sub>IF

### 3.4 Melt flow index

Fig. 5 shows the variation of melt flow index of different impact modified systems as the PPCP<sub>2</sub> IF content changes from 0% to 20%. As expected, the melt flow index of the blends is decreasing linearly with increasing content of PPCP<sub>2</sub>. Further, the E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE Impact modified blends are lower than simple E.O<sub>1</sub> modified blends which are obvious on account of the presence of Low M.F.I E.O<sub>2</sub>.

The melt flow Index has no particular role in mechanical properties of the blend. However, it is useful when determining the type of object that can be easily processed with the blend. For e.g. for large objects like bumpers with thin edges and cuts a high M.F.I blend is preferred that can flow easily in the cuts without any flash or edges.





**Fig - 5** Variation of Melt Flow Index vs PPCP<sub>2</sub>IF

## CONCLUSION

It is evident that the addition of PPCP<sub>2</sub>IF to high flow PPCP<sub>1</sub> matrix in EO<sub>1</sub> blends system does not result in any significant improvement of impact properties and toughness. Furthermore, the stiffness of the material increases very slightly as seen from a marginal increase in tensile Strength and almost none in case of flexural properties. While in case of E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE blends system the presence of low M.F.I E. O<sub>2</sub> elastomer and HDPE imparts much needed toughness to the blend which further increased by the addition of copolymer of intermediate M.F.I, i.e. PPCP<sub>2</sub>IF. Existence of region of extra high strength observed in the range of 10% - 20 % PPCP<sub>2</sub> IF when added to E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE system.

Furthermore, for E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE blends system the stiffness of the blend decreases very slightly on addition of low M.F.I E. O<sub>2</sub> Impact modifier and HDPE which further remains unchanged on addition of PP copolymer of intermediate M.F.I, i.e. PPCP<sub>2</sub>IF. The only major change in case of EO<sub>1</sub> blends is that the addition of PPCP<sub>2</sub> IF seems to bring about is in the melt flow properties of the system, which is bound to decrease.

Further in E.O<sub>1</sub>/ E.O<sub>2</sub>/HDPE blends system the addition of low M.F.I E. O<sub>2</sub> impact modifier decreases the melt flow index of the blend which is further reduced on the addition of Polypropylene copolymer of intermediate M.F.I PPCP IF<sub>2</sub>. Thus, we can conclude that in E.O<sub>1</sub> blends system addition of a copolymer having intermediate M.F.I although leads to slight improvement in stiffness of the blend yet its

failure to bring about any significant changes in impact properties renders it ineffective as a whole.

While in case of E.O<sub>1</sub>/E. O<sub>2</sub>/HDPE blends system addition of E.O<sub>2</sub> impact modifier & HDPE prevents coalescence of the rubber domains, hence addition of a PP copolymer having intermediate M.F.I (PPCP<sub>2</sub>IF<sub>2</sub>) leads to a blend with balanced toughness and stiffness which is essential requirement in automotive applications.

As an outcome of this study, an important prophecy is made that the model equation for impact Strength, tensile Strength, and flexural modulus for new PP- elastomer modified system are of third-order with respect to the percentage of PPCP<sub>2</sub>IF content by weight, whereas the same is of second-order with respect to the volume fraction of PPCP<sub>2</sub>IF content.

## ACKNOWLEDGEMENT

AKS gratefully acknowledges Sun Polyblends Pvt. Ltd., Mehsana, Gujarat, India, for providing the necessary laboratory facilities.

## REFERENCES

- Mohamad, N., Zainol, N. S., Rahim, F. F., Ab Maulod, H. E., Abd Rahim, T., Shamsuri, S. R., ... & Abd Manaf, M. E, Mechanical and morphological properties of polypropylene/epoxidized natural rubber blends at various mixing ratio. *Procedia Engineering* 2013;68:439-445.  
<https://doi.org/10.1016/j.proeng.2013.12.204>.
- Bendjaouahdou, C., & Bensaad, S..Aging studies of a polypropylene and natural rubber blend. *International Journal of Industrial Chemistry* 2018; 9(4):345-352  
<https://doi.org/10.1007/s40090-018-0163-2>.
- Yasar, M., Bayram, G. Ö. K. N. U. R., & Çelebi, H. . Effect of carbon black and/or elastomer on thermoplastic elastomer-based blends and composites. In *AIP Conference Proceedings* 2015; (Vol. 1664, No. 1, p. 120003).AIP,Publishing,LLC.  
<https://doi.org/10.1063/1.4918493>.
- Wouters, G. J. U.S. Patent No. 2002, 6,372,847. Washington, DC: U.S. Patent and Trademark Office.
- Jia, E., Zhao, S., Shangguan, Y., & Zheng, Q. . Toughening mechanism of polypropylene blends with polymer particles in core-shell structure: Equivalent rubber content effect related to core-shell interfacial strength. *Polymer*2019;178:121602  
<https://doi.org/10.1016/j.polymer.2019.121602>.
- Keskin, R., & Adanur, S. .Improving toughness of polypropylene with thermoplastic elastomers in injection molding. *Polymer-plastics technology and engineering* 2011;50(1):20-28.  
<https://doi.org/10.1080/03602559.2010.512344>.



- Li, Y., He, S., He, H., Yu, P., & Wang, D. . Study on low temperature toughness and crystallization behavior of polypropylene random copolymer. *Journal of Polymer Engineering* 2017; 37(7): 715-727. <https://doi.org/10.1515/polyeng-2016-0169>.
- Ying, J., Xie, X., Peng, S., Zhou, H., & Li, D. . Morphology and rheology of PP/POE blends in high shear stress field. *Journal of Thermoplastic Composite Materials* 2018 ; 31(9): 1263-1280. <https://doi.org/10.1177%2F0892705717734908>
- Sauter, D. W., Taoufik, M., & Boisson, C. Polyolefins, a success story. *Polymer* 2017; 9(6):185. <https://doi.org/10.3390/polym9060185>.
- Kear, K. E. . Developments in thermoplastic elastomers , 2003.
- Maynard, L. A., DeButts, B. L., & Barone, J. R. Mechanical and thermal properties of polyolefin thermoplastic elastomer blends. *Plastics, Rubber and Composites* 2019; 48(8):338-346. <https://doi.org/10.1080/14658011.2019.1625633>.
- Wang, X., Yin, X., Wang, L., Zhang, C., Gong, W., & He, L. . Dynamic mechanical properties, crystallization behaviors, and low-temperature performance of polypropylene random copolymer composites. *Journal of Applied Polymer Science* 2016; 133 (6). <https://doi.org/10.1002/app.42960>.
- Liang, D., Zhou, L. J., Zhang, Q., Chen, F., Wang, K., Deng, H., & Fu, Q. . Morphology and mechanical properties of poly (ethyleneoctene) copolymers obtained by dynamic packing injection molding. *Chinese Journal of Polymer Science* 2012; 30(4): 603-612. <https://doi.org/10.1007/s10118-012-1159-6>.
- Yokoyama, Y., & Ricco, T.. Toughening of polypropylene by different elastomeric systems. *Polymer* 1998; 39(16), 3675-3681. [https://doi.org/10.1016/S0032-3861\(97\)10358-5](https://doi.org/10.1016/S0032-3861(97)10358-5).
- De, S. K., & Bhowmick, A. K. (Eds.). *Thermoplastic elastomers from rubber-plastic blends*. Ellis Horwood Limited 1990.
- Kukaleva, N., Jollands, M., Cser, F., & Kosior, E. . Influence of phase structure on impact toughening of isotactic polypropylene by metallocene -catalyzed linear low-density polyethylene. *Journal of applied polymer science* 2000;76(7):1011-1018. [https://doi.org/10.1002/\(SICI\)1097-4628\(2000516\)76:7%3C1011::AID-APP4%3E3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1097-4628(2000516)76:7%3C1011::AID-APP4%3E3.0.CO;2-Q).
- Kontopoulou, M., Wang, W., Gopakumar, T. G., & Cheung, C. .Effect of composition and comonomer type on the rheology, morphology and properties of ethylene-  $\alpha$ -olefin copolymer/polypropylene blends. *Polymer* 2003; 44(24):7495-7504. <https://doi.org/10.1016/j.polymer.2003.08.043> .

