Advanced Physical Research
Vol.6, No.3, 2024, pp.247-254
https://doi.org/10.62476/apr63247

Jomard Publishing

EFFECTS OF NATURAL FIBERS ON THE COMPRESSIVE STRENGTH PROPERTIES OF HDPE MATRIX COMPOSITES

Nurlan Gurbanov*, Kamala Ismayilova, Yusif Tanriverdiyev

Department of Materials Science and Processing Technology, Azerbaijan State Oil and Industry University, Baku, Azerbaijan

Abstract. The current research reveals the synergistic effect of different ratios of natural fiber concentration and maleic anhydride grafted polyethylene (PE-g-MA) compatibilizer on the compressive strength properties of high density polyethylene (HDPE) matrix composites. Composites containing flax (FF) and palm (PF) short fibers with different weight ratios were processed by melt blending and then compression tests were performed at a compression speed of 2 mm/min. As a result of the tests, the best compressive strength properties were observed in the composite samples using 10% flax fiber and compatibilizer.

Keywords: *Polymer composite, compressive strength, natural fiber, PE-g-MA.*

****Corresponding Author:*** *Nurlan Gurbanov, Department of Materials Science and Processing Technology, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Tel.: +994776060500, e-mail: nurlan.gurbanov@asoiu.edu.az*

Received: *15 July 2024;* ***Accepted:*** *18 September 2024;* ***Published:*** *16 October 2024.*

1. Introduction

It attaches importance to the use of environmentally friendly materials in the industry in order to be protected from the effects of global warming and environmental protection experienced in the world in the twenty-first century. Composites have recently come to the fore as a material group that can be used frequently in every field instead of traditional materials. Composites, which are organic materials with different structures from each component, generally consist of at least two materials: reinforcement and matrix (Hsissou *et al*., 2021; Mohd *et al*., 2017). Composite materials show mechanical properties that cannot be achieved with "fiber or matrix" (Sajan & Selvaraj, 2021) . One of the most commonly used types of composite materials in industry is polymer matrix composites (Thakur *et al*., 2014). These composites are generally hybrid materials consisting of fiber-reinforced polymers that combine polymer properties, bonding and physical properties and the high mechanical and physical performance of fibers (Ku *et al*., 2011).

In recent years, there has been a rapid increase in the use of renewable natural fibers as reinforcement in composite materials (Sanjay *et al*., 2019). Reinforced plastics and cements made from cellulosic materials as fillers are low cost, lightweight, have improved

How to cite (APA):
Gurbanov, N., Ismayilova, K. & Tanriverdiyev, Y. (2024). Effects of natural fibers on the compressive strength properties of HDPE matrix composites. *Advanced Physical Research*, *6*(3), 247-254 https://doi.org/10.62476/apr63247

mechanical properties and do not pose a health hazard. Studies on plastics and cements reinforced with natural fibers such as jute, sisal, coconut, pineapple leaf, banana, sunburst, straw, broom and wood fibers have been reported in various sources (Shahinur & Hasan, 2019; Begum *et al*., 2020). Natural fibers are biodegradable and non-corrosive, unlike synthetic fibers used as reinforcement materials (Thiruchitrambalam *et al*., 2010).

Within composite materials, natural fiber reinforced composites have attracted much attention as an alternative to metals and synthetic fiber reinforced composites due to their lightness in materials and less harmful effects on the environment (Wilson, 2017). Natural fiber-based materials exhibit mechanical properties suitable for technical fields (Shinoj *et al*., 2010). More environmentally friendly and lighter materials such as biocomposites, which replace traditional composite materials, come to the fore. The reason why researchers focus on composite materials reinforced with natural fibers is that these composites have good mechanical properties as well as low density (Abu-Sharkh & Hamid, 2004; Pradhan *et al*., 2022). The use of plant fibers as reinforcement in composite materials is increasing in various fields of activity such as the automotive industry (Sassoni *et al*., 2014). Natural fibers can be obtained from a variety of sources, including plants (such as flax, hemp, jute and cotton), animals (such as wool and silk) and minerals (such as asbestos) (Karthi *et al*., 2020).

As a result of the studies in the literature, it has been seen that natural fibers used as reinforcement materials in polymer matrix composites positively affect the mechanical properties of composite samples. Based on the positive effects of natural fibers on polymer matrix composites, in this study it was planned to examine the compressive strength of HDPE matrix composites with different flax and palm fiber reinforcements and PE-g-MA compatibilizers.

2. Materials and methods

2.1. Materials

Trademarked HDPE with a density of 0.956 g/cm^3 (SABIC® HDPE M200056) was used as the matrix material in the composites and maleic anhydride terpolymer (PE-g-MA) obtained from Nanocar was used as the compatibilizer material. Flax and palm natural fibers were used as reinforcement materials in the preparation of HDPE matrix composite samples (Figure 1).

Flax and palm fibers in the form of yarn, supplied from Mir-Arge company, used as reinforcement material, were chopped into 6 mm size and brought into fiber form. Since chopped flax and palm fibers are natural fibers, they were subjected to surface modification before being used as reinforcement materials. Before the modification process, the fibers were washed in tap water to remove foreign material from the fibers and left to dry for 24 hours in a shaded area. The mixture was prepared by adding 15% NaOH (sodium hydroxide) into 1000 ml of pure water. Flax and palm fibers were kept in this mixture for 1 hour and 10-15 drops of ASC (acetic acid) were used in the final rinsing stage. After the final rinsing process was completed, it was left to dry in a shaded area.

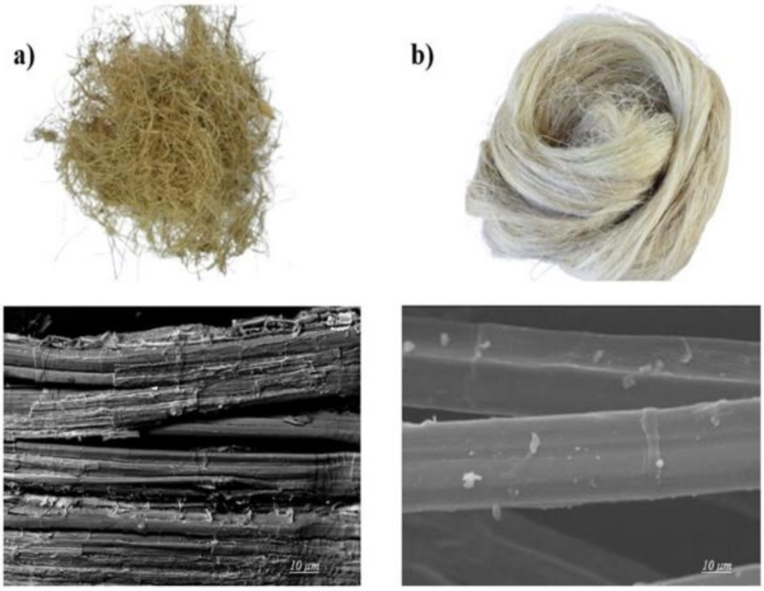

Figure 1. Images of natural fibers used as reinforcement material; a) palm fiber; b) flax fiber

2.2. Production method of composites

For the preparation of composite samples, the HDPE matrix material, flax, palm fibers and PE-g-MA compatibilizer were pre-dried in an oven at 80 °C for 24 h to remove moisture. Polymer matrix composite samples were prepared in accordance with the compositions given in Table 1.

Table 1. Composite compositions used in the study

Matrix Composition (wt%.)	Reinforcement Composition (wt%.)	Compatibilizer Composition (wt%.)
100 HDPE	-	-
90 HDPE	10 FF	-
80 HDPE	20 FF	-
70 HDPE	30 FF	-
87 HDPE	10 FF	3 PE-g-MA
74 HDPE	20 FF	6 PE-g-MA
61 HDPE	30 FF	9 PE-g-MA
90 HDPE	10 PF	-
80 HDPE	20 PF	-
70 HDPE	30 PF	-
87 HDPE	10 PF	3 PE-g-MA
74 HDPE	20 PF	6 PE-g-MA
61 HDPE	30 PF	9 PE-g-MA

Composite samples were produced by the melt blending technique using a twin-screw extruder with a screw diameter of D=16 mm and a length/diameter (L/D) ratio of 40, whose screws rotate in the same direction. During the production phase, the temperature profile of the bottom region of the extruder was set to 50, 200, 205, 210, 215 and 220 °C, respectively, from the feeding zone to the heating zones and the production mold pressure was set to 6.7 bar. The extruded material was removed from the mold in rod form, passed through a water bath at room temperature and pelletized using a granulator. It was then dried in an oven at 80 °C for one night. Pellets were then prepared using a 12 ml micro injection molding device.

2.3. Mechanical and Structural characterization

To determine the compressive strength properties of polymer matrix composite samples, compression tests were carried out on a Zwick/Roell Z600 branded test device in accordance with the ASTM D5467 standard at a compression speed of 2 mm/min. Compression tests were carried out in a laboratory environment by taking 3 test samples from each composite.

Scanning electron microscope (SEM) was used to examine the changes in the structure of the composite samples after the compression tests. Before the samples were examined in SEM, their surfaces were coated with Pb in the Q150r molding device.

3. Results and discussion

3.1. Mechanical properties and structural

Compressive strength is defined as the highest compressive stress that a material can withstand without disintegrating. The composite sample was prepared according to the components given in Table 1 and the compression tests were carried out at a compression speed of 2 mm/min according to the ASTM D5467 standard. The results of the compression tests of the composite samples were calculated according to formula 1 and the compressive strength limits of the samples were determined.

$$\sigma_c = \frac{F_{max}}{S_0}, \tag{1}$$

where σ_c -compressive strength value of the composite sample, (MPa), F_{max} − maximum force load damaging the specimen, (N), S_o − deformation value occurring in the sample, (mm).

The compressive strength strength values of HDPE matrix composite samples calculated according to formula 1 are shown graphically in Figure 2.

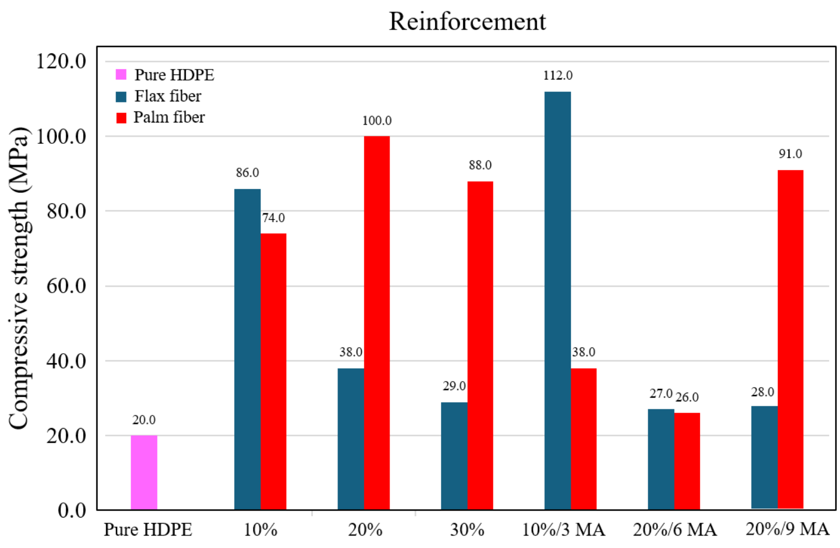

Figure 2. Compressive strength values of HDPE matrix composite samples

Graph in figure 2 shows the value of the strength on compressio. The compressive strength value of HDPE matrix polymer composite samples is 20 MPa. When 10% flax and palm fibers were used as reinforcement materials in HDPE matrix polymer composites, it was observed that the compressive strength values of the samples were 86 MPa and 74 MPa. It was determined that flax fibers had the highest compressive strength value among composite sample groups with the same concentration. It was observed that when 20% flax and palm fibers were used at medium concentration as reinforcement material in HDPE matrix polymer composites, the compressive strength of the samples was 38 MPa and 100 MPa. When high concentration 30% flax and palm fibers were used as reinforcement materials in HDPE matrix polymer composites, it was observed that the compressive strength values of these samples were 29 MPa and 88 MPa. As a result of the experiments, it was observed that as the ratio of flax fibers (10%, 20%, 30%) used as reinforcement material increased, there was a reduce in the compression reinforcement of the composite samples due to agglomeration. The palm fibers used as reinforcing material in polymer matrix composite are known for their relatively high strength and stiffness compared to some other natural fibers (Ramachandran *et al*., 2022). The reason for this is that palm fibers used in different proportions in HDPE matrix polymer composites have a positive effect on the compressive strength properties of the samples. As a result of the experiments, it was observed that the compressive strength properties of palm and polymer composites strengthened with flax fiber reinforced vary depending on various factors such as fiber types and ther processing, the type of polymer matrix used and the volume ratio.

Different chemical methods and substances are have been applied to make better and optimize fiber or matrix interfaces which are weak inside of natural fibers strengthened composites. Within the scope of the study, 3%, 6% and 9% PE-g-MA compatibilizers were used to make better fiber or matrix interfaces. It was observed that when 10% flax and palm fibers were used as reinforcement materials in composites and 3% PE-g-MA was used as a compatibilizer between the matrix, the compressive strength values of the samples were 112 MPa and 38 MPa. Similar studies in the literature have shown that when natural fibers are used as coating agents for the surface modification of PE-g-MAs, they significantly impact greatly mechanical properties of flax fiber reinforced composites such as tensile strength, elasticity modulus, bending strength, compressive strength, hardness and impact resistance (Singh *et al*., 2020; Choudhari & Kakhandki, 2020). Developing interface between 20% flax and palm fibers compatibilizier of 6% PE-g-MA used as reinforcement materials in composites and the HDPE matrix element, it was observed that the compressive strength values of the samples were 27 MPa and 26 MPa. It was observed that the values of compression strength of the samples have been 28 MPa and 91MPa when 30% flax was used as reinforcement material and 9% PE-g-MA was added compatible material in the composites to make better interface located between the palm fibers and the HDPE matrix and to form covalent bonds.

In fiber-reinforced composite materials, the load applied during mechanical tests is passed to the fiber by using interface containingfiber and matrix. Therefore, the interface structure and properties play a very important role on the mechanical and physical characteristics of the compositions. In particular, interfacial shear strength is an important parameter in controlling the strength and rigidity of the composite material. In order to obtain a composite with good mechanical properties and to benefit from the fiber properties at the maximum level, optimum adhesion must be ensured along the interface.

It has been observed in the experiments that the maleic anhydride grafted polyethylene compatibilizer, which is used to for improving the interfacial linking in compositions on the basis of polymer matrix composites and to modify the fiber surfaces as used in the matrix, is not as effective as expected on the composite samples.

Figure 3 (a, b, c) - Figure 4 (a, b, c) SEM images of the deformed surfaces of polymer matrix composite samples after compression tests are given. When SEM images are examined, it is seen that natural fibers are evenly distributed throughout the HDPE matrix. The response of composite materials to external loading is very complex. Impact damages that occur in composite samples due to the effect of static loads are matrix cracks, delamination (Figure 3e, Figure 4 (a, c, e)) and fiber damage (Figure 3b, Figure 4 (a, b, e)). The damage that started with matrix cracking during low-speed compression tests in composites caused delamination and it was observed that fiber damage (brittle fracture in fibers) occurred due to the impact energy applied to the composite and continuing to increase. When the surface of the stripped fibers was examined, it was seen that there were areas that were not covered with polymeric matrix (Figure 3 (a, b, c) – Figure 4(a, b, c)) and the surface was clean. This indicates poor interfacial adhesion between the fiber and matrix. Dark rings around the fibers indicate local deformation in the matrix around the fibers. At the same time, traces of PE-g-MA, which was used as a compatibilizer material to increase the adhesion between the polymer matrix element and the reinforcement phases, are also seen in the microstructure (Figure 3 (d, e, f) and Figure 4 (d, e, f)).

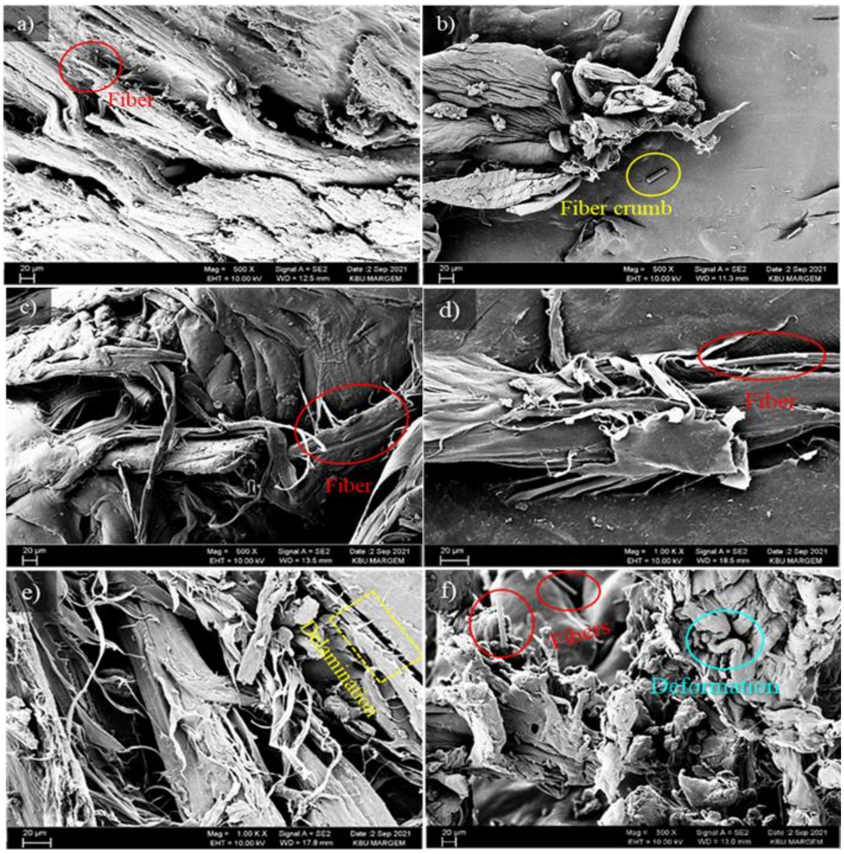

Figure 3. SEM images of a) 10%FF, b) 20%FF, c) 30%FF, d) 10%FF/3%MA, e) 20%FF/6%MA, f) 30%FF/9%MA reinforced HDPE matrix composite samples

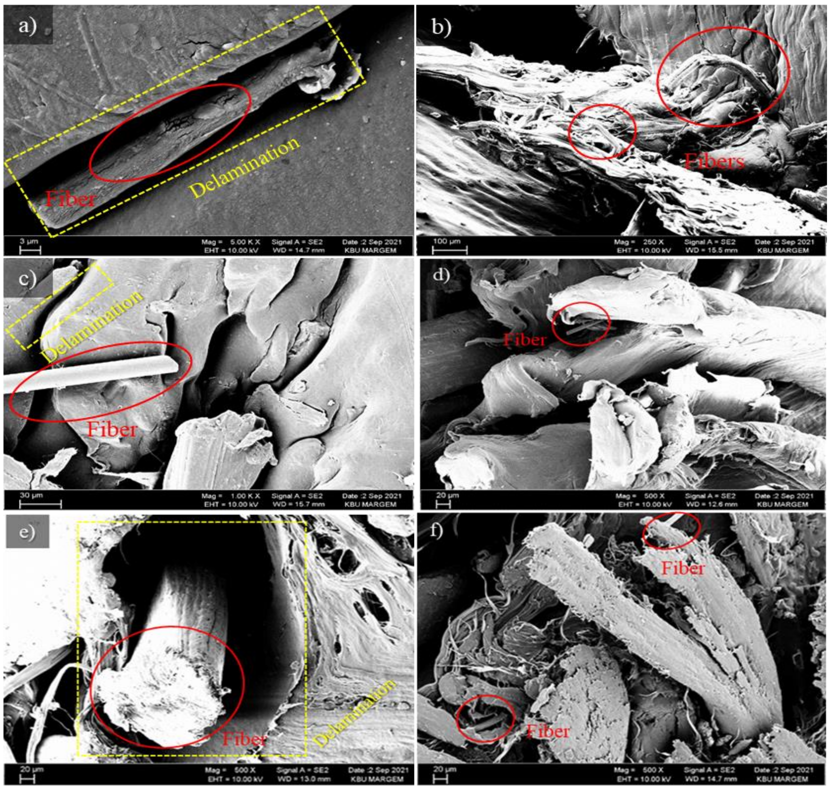

Figure 4. SEM images of a) 10%PF, b) 20%PF, c) 30%PF, d) 10%PF/3%MA, e) 20%PF/6%MA, f) 30%PF/9%MA reinforced HDPE matrix composite samples

4. Conclusion

Compression tests were carried out in accordance with ASTM D5467 standards to determine the effects of natural fibers used in different proportions as reinforcement material in HDPE matrix composite on the compressive strength properties of the samples. The following results were observed during these tests.

- The best compressive strength value in flax fiber reinforced HDPE matrix composite samples was seen in the samples using 10% FF and 3% PE-g-MA compatibilizer. In palm fiber reinforced composites, the best compressive strength value was observed in samples using 20% PF.
- As a result, flax and palm fibers, which we call natural fibers, can be used for the structural and manufacturability of composite materials. Although natural fibers do not seem to be a mechanically advantageous material, it can be said that they are more advantageous in terms of cost and applicability.

References

Abu-Sharkh, B.F., Hamid, H. (2004). Degradation study of date palm fibre/polypropylene composites in natural and artificial weathering: Mechanical and thermal analysis. *Polymer Degradation and Stability, 85*(3), 967-973.

Begum, S., Fawzia, S. & Hashmi, M.S.J. (2020). Polymer matrix composite with natural and synthetic fibres. *Advances in Materials and Processing Technologies*, *6*(3), 547-564.

Choudhari, D.S., Kakhandki, V.J. (2021). Comprehensive study and analysis of mechanical properties of chopped carbon fibre reinforced nylon 66 composite materials. *Materials Today: Proceedings*, 44, 4596-4601.

Hsissou, R., Seghiri, R., Benzekri, Z., Hilali, M., Rafik, M. & Elharfi, A. (2021). Polymer composite materials: A comprehensive review. *Composite Structures*, 262, 113640.

Karthi, N., Kumaresan, K., Sathish, S., Gokulkumar, S., Prabhu, L. & Vigneshkumar, N. (2020). An overview: Natural fiber reinforced hybrid composites, chemical treatments and application areas. *Materials Today: Proceedings*, 27, 2828-2834.

Ku, H., Wang, H., Pattarachaiyakoop, N. & Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. *Composites Part B: Engineering*, *42*(4), 856-873.

Mohd N., Khalina, A., Sapuan, S.M., Dayang Laila, A.H., Rahmah, M. & Hanafee, Z. (2017). A review: Fibres, polymer matrices and composites. *Pertanika Journal of Science & Technology*, *25*(4), 1085-1102.

Pradhan, P., Purohit, A., Mohapatra, S.S., Subudhi, C., Das, M., Singh, N.K. & Sahoo, B.B. (2022). A computational investigation for the impact of particle size on the mechanical and thermal properties of teak wood dust (TWD) filled polyester composites. *Materials Today: Proceedings*, 63, 756-763.

Ramachandran, A., Mavinkere Rangappa, S., Kushvaha, V., Khan, A., Seingchin, S. & Dhakal, H.N. (2022). Modification of fibers and matrices in natural fiber reinforced polymer composites: A comprehensive review. *Macromolecular Rapid Communications*, *43*(17), 2100862.

Sajan, S., Selvaraj, D.P. (2021). A review on polymer matrix composite materials and their applications. *Materials Today: Proceedings*, *47*(15), 5493-5498.

Sanjay, M.R., Siengchin, S., Parameswaranpillai, J., Jawaid, M., Pruncu, C.I. & Khan, A. (2019). A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. *Carbohydrate Polymers*, 207, 108-121.

Sassoni, E., Manzi, S., Motori, A., Montecchi, M. & Canti, M. (2014). Novel sustainable hemp-based composites for application in the building industry: Physical, thermal and mechanical characterization. *Energy and Buildings*, 77, 219-226.

Shahinur, S., Hasan, M. (2019). Natural fiber and synthetic fiber composites: Comparison of properties, performance, cost and environmental benefits. In *Reference Module in Materials Science and Materials Engineering*.

Shinoj, S., Visvanathan, R. & Panigrahi, S. (2010). Towards industrial utilization of oil palm fibre: Physical and dielectric characterization of linear low density polyethylene composites and comparison with other fibre sources. *Biosystems Engineering*, *106*(4), 378-388.

Singh, A.K., Bedi, R. & Kaith, B.S. (2020). Mechanical properties of composite materials based on waste plastic–A review. *Materials today: proceedings*, *26*, 1293-1301.

Thakur, V.K., Thakur, M.K. & Gupta, R.K. (2014). Raw natural fiber–based polymer composites. *International Journal of Polymer Analysis and Characterization*, *19*(3), 256-271.

Thiruchitrambalam, M., Athijayamani, A., Sathiyamurthy, S. & Thaheer, A.S.A. (2010). A review on the natural fiber-reinforced polymer composites for the development of roselle fiber-reinforced polyester composite. *Journal of Natural Fibers*, *7*(4), 307-323.

Wilson, A. (2017). Vehicle weight is the key driver for automotive composites. *Reinforced Plastics*, *61*(2), 100-102.