



Kaunas University of Technology

Faculty of Mechanical Engineering and Design

An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives

Master's Final Degree Project

Bhagyalaxmi Shivangouda Patil

Project author

Lect. Vaidas Bivainis

Supervisor

Kaunas, 2020



Kaunas University of Technology
Faculty of Mechanical Engineering and Design

An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives

Master's Final Degree Project
Industrial Engineering and Management (6211EX018)

Bhagyalaxmi Shivangouda Patil

Project author

Lect. Vaidas Bivainis

Supervisor

Assoc. prof. Ramūnas Česnavičius

Reviewer

Kaunas, 2020



Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Bhagyalaxmi Shivangouda Patil

An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives

Declaration of Academic Integrity

I confirm that the final project of mine, Bhagyalaxmi Shivangouda Patil, on the topic “An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives” is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand)

(signature)



Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Task of the Master's final degree project

Given to the student – Bhagyalaxmi Shivangouda Patil

1. Title of the project –

An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives

(In English)

HDPE ir perdirbto HDPE plėvelių su priedais paviršinių savybių bei plėvelių sudėties tyrimai

(In Lithuanian)

2. Aim and tasks of the project –

The aim of this research is to evaluate the influence of additives in HDPE and RHDPE, by testing surface wetting angle, ink adhesion, tensile strength and to perform FTIR analysis.

1. To measure the contact angle of all the eight different types of materials.
2. To carry out advanced ink adhesion test using Peel tester and adhesive tape.
3. To perform a basic ink adhesion test using adhesive tape.
4. To do SEM images for the ink peeled surface of the materials.
5. To carry out, FTIR analysis for all the samples.
6. To perform the tensile test on all the materials.

3. Initial data of the project –

N/A

4. Main requirements and conditions –

Pocket Goniometer, Friction peel/tester, Digital pocket microscope (DPM 300), Tesa 4104 tape, Tesa 4965 tape, Nicolet iS10 (FTIR).

Project author Bhagyalaxmi Shivangouda Patil
(Name, Surname) *(Signature)* *(Date)*

Supervisor Vaidas Bivainis
(Name, Surname) *(Signature)* *(Date)*

Head of study field programs Regita Bendikiene
(Name, Surname) *(Signature)* *(Date)*

Patil, Bhagyaxmi Shivangouda. An Investigation of Surface Properties and Composition of HDPE and Recycled HDPE with Additives. Master's Final Degree Project, supervisor Lect. Vaidas Bivainis; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area (study field group): Production and Manufacturing Engineering (E10), Engineering Sciences (E).

Keywords: HDPE, Recycled HDPE, wetting angle, ink adhesion, film tensile properties; FTIR analysis, SEM images.

Kaunas, 2020. 60p.

Summary

Plastics have become an essential and inseparable part of human life. High-Density Polyethylene plastics are most commonly used plastics globally because of its properties like density, long life, designs, strength and mainly the low cost. HDPE plastics are non-biodegradable plastics that take centuries to decompose, recycling of plastics is necessary. There are many benefits of recycling of plastics such as it reduces landfill waste and it takes less cost to produce recycled plastics than virgin plastics. Recycling of plastics comes with several concerns for the manufacturers, it is necessary to meet the properties of virgin materials. This research is focused on HDPE and recycled HDPE films with different concentration of additives (metallocene) and to check the influence of additive materials to the properties. Contact angle measurement was done for all the materials to understand the surface wettability property, HDPE materials contact angle for printing sides is around 28° to 33° and non-printing sides is 39° to 51° and for RHDPE materials contact angle for printing sides is around 29° to 37° and non-printing sides is 40° to 44° . Ink adhesion test was performed in two ways one with the measured force and other manually, the force at which there is a deformation of ink is seen. It is necessary to understand the composition of the materials especially for recycled HDPE as it should meet the composition of virgin HDPE, so FTIR spectroscopy was carried out on all the materials in which all the materials showed same compositions as HDPE. Mechanical properties of the materials are of great concern especially of recycled HDPE because with the different concentration of additives materials might show different strength properties with this concern Tensile test was carried out to understand the force, strength and elongation of the materials.

Patil, Bhagyalaxmi Shivangouda. HDPE ir perdirbto HDPE plėvelių su priedais paviršinių savybių bei plėvelių sudėties tyrimai. Magistro baigiamasis projektas, Lekt. Vaidas Bivainis; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: HDPE, Perdirbtas HDPE, paviršiaus drėkinimo kampas, dažų adhezija, plėvelės tempimo savybės, FTIR analizė, SEM vaizdai.

Kaunas, 2020. 60p.

Santrauka

Pastaruoju metu plastikų bei polimerinių medžiagų naudojimas įvairiose srityse didėja netgi kartais. Viena iš plačiausiai naudojamų polimerinių medžiagų pakavimo ir kt. pramonės srityse yra aukšto tankio polietilenas arba HDPE. Šio plastiko ar plėvelės platų panaudojimą lemia gana geros fizikinės savybės; tankis, ilgas degradavimo laikotarpis, stipruminės barjerinės ir kt. savybės. Ši polimerinė medžiaga yra gamtoje yra beveik nedegraduojanti. Vienas iš būdų mažinti naudojamo HDPE plastiko kiekius – keisti biodegraduojančiais, pagamintais iš atsinaujinančių šaltinių arba tą patį HDPE plastiką panaudoti kelis kartus. Tam reikalingas švaraus plastiko rūšiavimas, surinkimas, perdirbimas ir pakartotinis perdirbtų plastiko medžiagų panaudojimas panašių savybių plastikinių plėvelių gamybai. Darbe yra atlikti tyrimai, siekiant įvertinti papildomos medžiagos (metaloceno) panaudojimo įtakos įprastinės HDPE plėvelės pagrindinės fizikinėms ir eksploatacinėms savybėms kaip paviršiaus drėkinimo kampas, atspausdintų fleksografinių solventinių dažų adhezijos stipris, plėvelių stipris tempiant. Taip pat atlikti HDPE ir perdirbto HDPE plastiko, įvedant tuos pačius priedus fizikinių ir eksploatacinių savybių tyrimai. Polimerinių plėvelių drėkinimo kampas buvo tiriamas spausdinamajai (aktyvuotai spausdinimui) ir nespausdinamajai pusei. Atliktų tyrimų metu gauta, kad HDPE iš perdirbto plastiko ir naudojant (15, 30 ir 50%) priedus, drėkinimo kampas didėjant priedo masei nežymiai mažėja. HDPE didėjant priedų masei drėkinimo kampas nespausdinamai pusei ženkliai mažėja, o spausdinamai pusei nežymiai didėja. Atlikus polimerų FTIR spektroskopijos tyrimus, nustatyta, kad pagal šiuos duomenis nėra didelio skirtumo tarp HDPE ir HDPE iš perdirbtos medžiagos. Atlikus visų šių plėvelių stiprio tempiant tyrimus gauta, kad didžiausias stipris tempiant yra HDPE plėvelės, visų kitų tirtų bandinių šios savybės yra gana artimos.

Table of contents

List of figures	8
List of tables	10
List of abbreviations and terms	11
Introduction	12
1. Relevance of research	13
2. Materials and methods	18
2.1. Contact angle	18
2.2. Adhesion test with measured force.....	18
2.3. Adhesion test with the visual inspection	19
2.4. FTIR analysis.....	19
2.5. Tensile test.....	20
3. Results	21
3.1. Contact angle	21
3.2. Adhesion test with measured force.....	30
3.3. Adhesion test for visual inspection.....	32
3.4. FTIR analysis.....	36
3.5. Tensile test.....	41
4. Managerial points	50
4.1. Environmental aspects of HDPE	50
4.2. Environmental effects of recycled HDPE (RHDPE).....	51
4.3. Economic aspects of HDPE and RHDPE production	52
Conclusions	54
List of References	55
Appendices	58
Appendix 1. Certificate of participation in International Young Scientists Conference.....	58
Appendix 2. Abstract for participating in upcoming 7 th International Conference IRF2020- INTEGRITY-RELIABILITYFAILURE.....	59

List of figures

Fig. 1. Contact Angle (a) less than 90° angle (b) greater than 90° angle [11]	14
Fig. 2. Surface energy conversion chart [13]	15
Fig. 3. Pocket goniometer PG2 [14].....	16
Fig. 4. Peel adhesion [19].....	19
Fig. 5. Specimen dimension [20].....	20
Fig. 6. View of material fixed between clamps for tension test.....	20
Fig. 7. View of droplets on HDPE material a) printing side, b) non-printing side	21
Fig. 8. Surface wettability for printing and non-printing surfaces for HDPE without additives	21
Fig. 9. View of droplets on HDPE A15 material a) printing side, b) non-printing side	22
Fig. 10. Surface wettability for printing and non-printing surfaces for HDPE with 15% additives .	22
Fig. 11. View of droplets on HDPE A30 material a) printing side, b) non-printing side	23
Fig. 12. Surface wettability for printing and non-printing surfaces for HDPE with 30% additives .	23
Fig. 13. View of droplets on HDPE A50 of material a) printing side, b) non-printing side.....	24
Fig. 14. Surface wettability for printing and non-printing surfaces for HDPE with 50% additives .	24
Fig. 15. View of droplets on RHDPE material a) printing side, b) non-printing side.....	25
Fig. 16. Surface wettability for printing and non-printing surfaces for RHDPE without additives..	25
Fig. 17. View of droplets on RHDPE A15 material a) printing side, b) non-printing side.....	26
Fig. 18. Surface wettability for printing and non-printing surfaces for RHDPE with 15% additives	26
Fig. 19. View of droplets on RHDPE A30 material a) printing side, b) non-printing side.....	27
Fig. 20. Surface wettability for printing and non-printing surfaces for RHDPE with 30% additives	27
Fig. 21. View of droplets on RHDPE A50 material a) printing side, b) non-printing side.....	28
Fig. 22. Surface wettability for printing and non-printing surfaces for RHDPE with 50% additives	28
Fig. 23. Line Chart of contact angle for HDPE.....	29
Fig. 24. Line Chart of contact angle for RHDPE	29
Fig. 25. Ink adhesion test with measured force.....	30
Fig. 26. Ink adhesion test with measured force.....	30
Fig. 27. Average Mean Chart of the Peeling force of HDPE materials with and without additives.	31
Fig. 28. Average Mean Chart for Peeling force of HDPE materials with and without additives	31
Fig. 29. Ink Adhesion Manually (a) HDPE SEM image (b) HDPE A15 SEM image (c) HDPE Digital Pocket Microscope image(d) HDPE A15 Digital Pocket Microscope image.....	32
Fig. 30. Ink Adhesion Manually (a) HDPE A30 SEM image (b) HDPE A50 SEM image (c) HDPE A30 Digital Pocket Microscope image (d) HDPE A50 Digital Pocket Microscope image.....	33
Fig. 31. Ink Adhesion Manually (a) RHDPE SEM image (b) RHDPE A15 SEM image (c) RHDPE Digital Pocket Microscope image (d) RHDPE A15 Digital Pocket Microscope image	34
Fig. 32. Ink Adhesion Manually (a) RHDPE A30 SEM image (b) RHDPE A50 SEM image (c) RHDPE A30 Digital Pocket Microscope image (d) RHDPE A50 Digital Pocket Microscope image	35
Fig. 33. Represents the HDPE spectrum after FTIR analysis	36
Fig. 34. Represents the HDPE A15 spectrum after FTIR analysis	36
Fig. 35. Represents the HDPE A30 spectrum after FTIR analysis	37
Fig. 36. Represents the HDPE A50 spectrum after FTIR analysis	37

Fig. 37. Represents the RHDPE spectrum after FTIR analysis	38
Fig. 38. Represents the RHDPE A15 spectrum after FTIR analysis.....	38
Fig. 39. Represents the RHDPE A30 spectrum after FTIR analysis.....	39
Fig. 40. Represents the RHDPE A50 spectrum after FTIR analysis.....	39
Fig. 42. Force v/s extension graph of HDPE.....	41
Fig. 43. Force v/s extension graph of HDPE A15	42
Fig. 44. Force v/s extension graph of HDPE A30.....	43
Fig. 45. Force v/s extension graph of HDPE A50.....	44
Fig. 46. Force v/s extension graph of RHDPE	45
Fig. 47. Force v/s extension graph of RHDPE A15	46
Fig. 48. Force v/s extension graph of RHDPE A30	47
Fig. 49. Force v/s extension graph of RHDPE A50	48
Fig. 50. Force v/s extension graph for HDPE	49
Fig. 51. Force v/s extension graph of RHDPE	49
Fig. 52. Share of different plastic wastes generated globally [31].....	50
Fig. 53. Comparison of energy required to produce virgin and recycled plastic per unit mass [33]	52

List of tables

Table 1. Description of materials and their density	18
Table 2. Absorption band values and their functional groups	40
Table 3. Results of HDPE tensile strength, Maximum Force, Elongation	41
Table 4. Results of HDPE A15 tensile strength, Maximum Force, Elongation	42
Table 5. Results of HDPE A30 tensile strength, Maximum Force, Elongation	43
Table 6. Results of HDPE A50 tensile strength, Maximum Force, Elongation	44
Table 7. Results of RHDPE tensile strength, Maximum Force, Elongation.....	45
Table 8. Results of RHDPE A15 tensile strength, Maximum Force, Elongation.....	46
Table 9. Results of RHDPE A30 tensile strength, Maximum Force, Elongation.....	47
Table 10. Results of RHDPE A50 tensile strength, Maximum Force, Elongation.....	48

List of abbreviations and terms

Abbreviations:

PE – Polyethylene.

HDPE – High-Density Polyethylene

RHDPE – Recycled High-Density Polyethylene

HDPE A15 – High-Density Polyethylene with 15% of Additives

HDPE A30 – High-Density Polyethylene with 30% of Additives

HDPE A50 – High-Density Polyethylene with 50% of Additives

RHDPE A30 – Recycled High-Density Polyethylene with 15% of Additives

RHDPE A30 – Recycled High-Density Polyethylene with 30% of Additives

RHDPE A30 – Recycled High-Density Polyethylene with 50% of Additives

PET/PETE – Polyethylene terephthalate

FTIR – Fourier-transform infrared spectroscopy

IR – Infrared

LDPE – Low-Density Polyethylene

Introduction

Plastics have become a very important part of human life because it is durable, inexpensive also a lightweight material, they can be easily moulded into plenty of applications. Approximately 100 million tons of plastics are manufactured every year across the globe, and it takes centuries to degrade, so reuse or recycling becomes an important factor. Like other plastics, High-Density Polyethylene is most used plastic because of its lightweight, strong and rigid molecular structures. To enhance the properties and to prolong the life of polymers additives are added. Some quantity of additives in HDPE (High-density Polyethylene) and RHDPE (Recycled high-density Polyethylene) influence the surface properties, composition, mechanical properties, and ink adhesion. The wettability and adhesion of the covering and printing films on the polymer substrates rely upon the surface properties of the detailing fixings and polymer surface. The research was done for HDPE and RHDPE mixed with additives. The main reason for using additives is to increase the impact on the environment and use more recycled materials. Hypothesis – Some quantity of additives in HDPE and RHDPE for plastic bags have an influence on surface energy (contact wetting angle), adhesion of inks and mechanical properties.

The aim of this research is to evaluate the influence of additives in HDPE and RHDPE, by testing surface wetting angle, ink adhesion, tensile strength and to perform FTIR analysis.

To reach the aim of the research, some tasks were performed:

1. To measure the contact angle of all the eight different types of materials.
2. To carry out advanced ink adhesion test using Peel tester.
3. To perform a basic ink adhesion test using adhesive tape.
4. To do SEM images for the ink peeled surface of the materials.
5. To carry out, FTIR analysis for all the samples.
6. To perform the tensile test on all the materials.

1. Relevance of research

In a short time, polymer industries have grown larger than other industries because of the increase in need of polymers [1]. Polymers command every single different class of materials because of their wide range of properties. Most of the materials that are used daily are made from polymers such as plastics, carry bags, bottles, syringes, and furniture many more. Using the polymerization process, polymers are synthesized, where singular units respond together to build greater polymer particles by proper control of the polymers structural properties can be varied [2]. In polymer industries, it has become a common practice to recycle waste materials from the production. By recycling of plastics, the material properties might get affected, so it needs to be quantified [3]. During the production of polymers and using them in different applications, various defects might take place like tears, poor adhesions, cuts, holes [4].

Polyethylene

Polyethylene (semi-crystalline polyolefin) is widely used in many customer products, and because of its exquisite thermal properties, it is used for packing, for making pipes, bags etc. It has excellent physical properties and chemical properties [3]. High-density polyethylene (HDPE) is frequently used plastic all over the world, it can be used repeatedly and is easily recyclable. During the production of recycled HDPE, it does not generate any harmful emissions. Recycling of plastics helps in resource consumption and environmental pollution. Recycled HDPE usage is been increasing; therefore, understanding the material behaviour and properties is necessary [2]. Present market demands for the production of polymeric bags are increasing thus the necessity for quality, surface properties, adhesion properties, mechanical properties became higher.

HDPE is successfully applied in various fields of applications but, to be successful it must have special properties like chemical composition, roughness, hydrophilicity and crystallinity properties. Sometimes the ordinary polymers cannot show the specific properties for different applications so surface modification techniques might help to change the properties. The surface of the polymer can be altered by different physical and chemical processes [5].

Additives are the chemical compounds used in plastic materials to enhance the performance and functionality of the polymers [6]. To produce the polymers with different molecular weight ranges catalyst are used. Catalysts are used to speed up chemical reactions. Karl Ziegler developed the first efficient polymerization method by developing a catalyst based on titanium tetrachloride (TiCl_4) and diethyl aluminium chloride $[(\text{C}_2\text{H}_5)_2\text{AlCl}]$ as a co-catalyst for the polymerization of ethylene into high molecular weight HDPE [7]. These are heterogeneous with different active sites, but Metallocene catalysts have only one active site in contrast to Ziegler. Metallocene catalyst produces polymers in which structures can be changed easily with narrow molecular mass and are soluble in hydrocarbons. The catalytic activity of metallocene is 10 to 100 times higher than Ziegler-Natta [8]. In this research HDPE and RHDPE materials with different concentrations of metallocene are studied.

Recycling of plastics

The importance of recycling of plastics is increasing because of the increase in environmental awareness. Utilization of HDPE plastics is growing steadily because of its very good properties. HDPE is one of the largest consumed plastics over all the world. The main reason for HDPE to be the larger consumed is because of its lower price and durability. Some plastic bags or plastic materials

are disposed of in a short time after it is bought. Instead of disposing of the plastics in an area, it can be reused or recycled as it consumes less energy and resources [9]. Recycling of plastics has many advantages such as it reduces the energy consumption, reduces the amount of waste moving to landfill, reduces the emissions of various greenhouse gases like carbon dioxide (CO₂), sulphur dioxide (SO₂), nitrogen oxide (NO). Properties of the recycled materials do not have the same as virgin materials; quality becomes the main issue. The main reason for the discrepancy among the HDPE and recycled HDPE is the depreciation of properties of recycled HDPE when correlated with virgin HDPE [10]. It is necessary to compare the properties of recycled HDPE with the virgin HDPE. The investigation in this research focuses on the surface and mechanical properties of HDPE and RHDPE and their compositions.

To analyse the composition and properties of HDPE and recycled HDPE there are a plethora of methods such as Fourier transform Infrared spectroscopy (FTIR), Surface wettability of the materials are checked by measuring contact angle, Adhesion tests, Tensile test to check the mechanical properties of the materials. In order to gain insight into the effect of surface properties and composition of recycled HDPE and HDPE with different number of additives, the experiments were conducted.

Surface properties

Wetting helps to study of how the liquid deposited on a liquid or solid substrate spreads out. To symbolize the surface wettability, two distinct types of contact angles are correlated [14], the static and dynamic contact angle. The static contact angle is relatively easy to measure, so it is more commonly used. Sessile and pendant drop method are the two ways taken to quantify static contact angle.

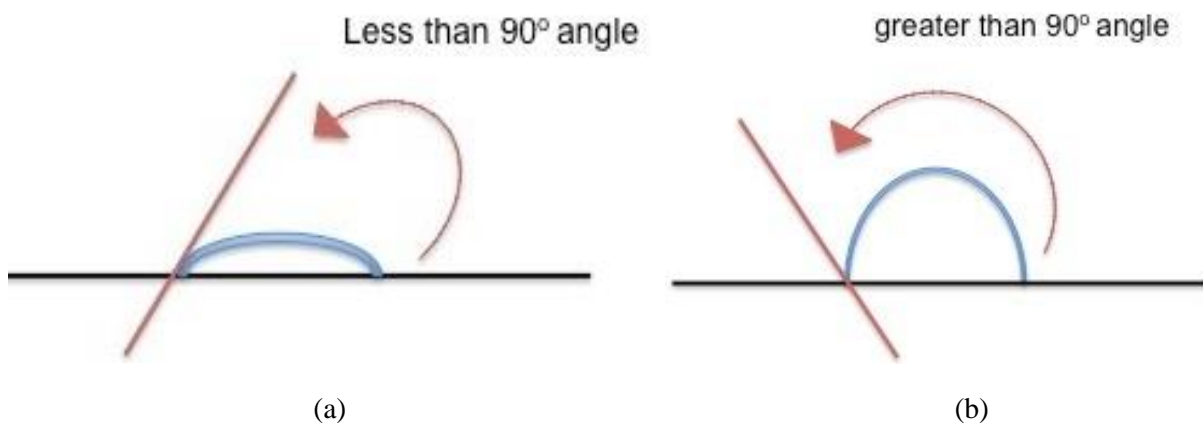


Fig. 1. Contact Angle (a) less than 90° angle (b) greater than 90° angle [11]

The angle measured between the vapour or liquid with the interacting solid surface. The larger the contact angle lesser the surface wetting, i.e., the droplet of liquid will not spread on the surface area of the most surface. The lesser the contact angle higher the wetting, so that droplet of water spreads more on the surface area as shown in Fig. 1. The analysis of the contact angle is taken to estimate surface quality, whereas the quality of liquid can be measured by Surface tension analysis. There are two types of surface tensions concerning contact angle- Liquid and interfacial surface tension among the liquid and the solid. Interfacial tension- the estimation of an adhesive force between liquid and the liquid or solid state of another substance [11]. On the hydrophilic surface, interfacial tension is high and interfacial tension is low on hydrophobic surfaces.

The proper wetting of the substrate is mainly governed by two factors, one is the substrate's surface energy, and the other is the surface energy of ink. Surface tension rises due to the tendency for the molecules of the liquid to stick together more strongly than they stick to air [12]. Surface tension is expressed in dynes/cm. When a strong, attractive force is created by a high wetting surface that has surface energy, to drag the liquid drop-down that happens to spread out is called as wettability [13]. This energy is more substantial than the molecular surface tension that would keep liquid in droplet form. The surface tension, which remains the same, but the solids surface energy is much substantial than the liquids surface tension. Lower contact angle results in much more interfacial tension and surface energy. For a lesser wetting surface, the surface energy should be weakened than the surface tension of the liquid, i.e.; the liquid can manage its shape better [13]. The interaction between the solid and liquid is not too strong, so the interfacial tension between them is less. As higher the contact angle, which leads to low interfacial tension and the surface area.

Flexo-printing surface tension and surface energy

Surface tension and the surface energy affect wettability in flexo printing. If there is liquid with the high surface tension, it will tend to bead-up and will not wet the surfaces that come in contact [12]. If there is a surface with lower surface energy, there will be the same effect it is not the ink substrate reaction that is needed. To get the proper/good print components of the flexographic inking system should have appropriate surface tension and surface energies [12]. To be specific, ink should have lower surface tension than compared to image carrier so it can get adhere to it. To completely pull the ink off to the image carrier substrate must have higher surface energy. There are numerous ways to measure surface tension and energy because of the different test conditions and materials. In flexography, most commonly, the measurement is done using a method called goniometry [12]. This method involves calculating the contact angle formed between a surface and a liquid droplet placed on it [12]. Surface energy conversion chart is shown below Fig. 2.

Water Contact angle	SFE (dyne/cm)
51-53	46
54-56	45
57-59	44
60-62	43
63-65	42
66-68	41
69-71	40
72-73	39
74-76	38
77-79	37
80-81	36
82-84	35
85-87	34
88-89	33
90-92	32
93-95	31
96-97	30
98-100	29

Fig. 2. Surface energy conversion table [13]

A pocket goniometer (Fig. 3) is an automated instrument used to measure static and dynamic contact angles. When the liquid does not penetrate on to the substrate, the interaction can be specified by the static contact angle, and if the liquid penetrates on to the substrate, this interaction can be determined by the dynamic contact angle. The contact angle is an operation at the surface tension(liquid) and surface "free" energy at the substrate.



Fig. 3. Pocket goniometer PG2

The contact angle in this research is used to investigate or to see, how the surfaces of liquid and a substrate interact with each other. The equipment named Pocket goniometer (PG-2), which is an automated instrument is used for measuring the contact angle. By depositing a liquid drop on the surface of the specimen, a contact angle is constructed at the contact area [15]. For a better understanding, the results are displayed graphically in further analysis.

The adhesion of ink on plastic films is of more importance to ensure quality. Evaluation of the strength of ink adhesion on the materials is more challenging. The ink adhesion testing technique permits a quick evaluation of the level of the bond of printing ink. Ink adhesion is then evaluated by the measure of ink that can be evacuated when adhesive tape is attached and peeled off. Peel adhesion can be stated as the force needed to remove the pressure-sensitive coated material, that had been attached to the standard test plate under specific conditions, from the plate at a specific angle, and speed. Peel adhesion is interrelated with the binding firmness of an adhesive to a mating substrate. It is vital to know the peel adhesion factor, as it can help as a guide for picking the correct tape for the application. Regardless of whether the application is transitory or permanent, values of peel adhesion are obtained if the substrates are clean and dust-free. The ink adhesion experiment is performed in this research will show clearly how the peel adhesion is done.

Physical and mechanical properties

Physical properties of polymers usually depend on the chemical composition, crystallinity parameter also the configuration of macro-molecules [16]. There are many spectroscopy techniques available to access all these features, Fourier Transform Infrared Spectroscopy is one among those techniques and is the most widely used technique to find out the composition. In FTIR analysis, the bonds in the molecule absorb the infrared rays, and this IR ray's energy are relatable to the vibrational energy of different bonds in the different functional groups present in a compound. Using ATR-FTIR, it is not necessary to prepare the samples they can be directly used. When the specimen is placed infrared (IR)

beam will absorb some energy at frequencies of the molecules and transmits the rest of the other frequencies, the pattern resulted in shows the absorption spectrum of the sample. The absorption bands ranging from 4000-1500 wavenumbers are usually from the common functional groups such as OH, C=O, N-H and CH₃. The range between 1500-400 wavenumbers is fingerprint region. FTIR is a powerful tool used to identify chemical structure and bonds/functional groups of any polymers [17].

Recycling of plastics is of more concern for the manufacturers of plastics. Plastics recycling usually includes reprocessing of the mixtures of different polymer materials at different states of degradation, it's done not only for economic and environmental factors but also for improvement of fragile properties like impact strength and processability [18]. It is necessary to check mechanical properties like tensile strength, elongation, force maximum of the recycled plastics.

2. Materials and methods

In the experiments, High-Density Polyethylene films are used for testing of surface properties like wetting angle, ink adhesion and mechanical properties like strength also the composition of materials. The additive used in the HDPE and RHDPE is metallocene with 15%, 30%, 50% concentration. The printing side of the films was activated and for the flexographic printing, the solvent black ink was used.

Table 1. Description of materials and their density

Materials	Density
HDPE film without additives (HDPE)	0.9765 g/cm ³
HDPE film with 15% additive (HDPE A15)	0.992 g/cm ³
HDPE film with 30% additive (HDPE A30)	1.068 g/cm ³
HDPE film with 50% additive (HDPE A50)	0.8535 g/cm ³
Recycled material HDPE without additives (RHDPE)	0.9525 g/cm ³
Recycled material HDPE with 15% additives (RHDPE A15)	1.1005 g/cm ³
Recycled material HDPE with 30% additives (RHDPE A30)	1.0625 g/cm ³
Recycled material HDPE with 50% additives (RHDPE A50)	1.1334 g/cm ³

2.1. Contact angle

1. At the centre of the applicator tube, insert the dispensing unit. The dispensing tip will now appear at the top of the live image screen. Once the correct position has been set, hold the applicator tube and tighten it.
2. The specimen to be tested should be placed tightly under the clamping fingers. Should not touch the specimen on the areas that should be tested or do not contaminate it in any other way.
3. The first test is done for the printing side. Using the dispenser fill the water in the tube and place it properly like the tip of the tube will appear on the screen.
4. Very carefully push the plunger forward and place the droplet carefully on the specimen.
5. Change the position of the specimen (give a new position) and place the droplet again repeat the procedure. Repeat the procedure for the non-printing side too.
6. The resulting window is updated with new data after each measurement.

2.2. Adhesion test with measured force

1. Before starting up with the experiment, some friction peel/tester settings must be done like set test type-peel, load unit- N, test time-20 s, speed- 300 mm/min.
2. Keep the sample on a smooth, flatted, hard surface and apply the sticky tape, leave a little piece of the tape not attaching to the test piece, guaranteeing that there are no air bubbles that are caught on the tape.
3. Fix the unattached strip in a machine, and the tape can be pulled away from the printed substrate at a peel angle of 180°. (shown in Fig. 4)
4. The results are calculated automatically, and statistical results are shown for friction and peel testing and results are stored.
5. Data captured during the test includes peel testing (mean, max, min, standard deviation).

6. When the peel test is complete, the crosshead is restored to the starting position, and the procedure is repeated for other specimens.

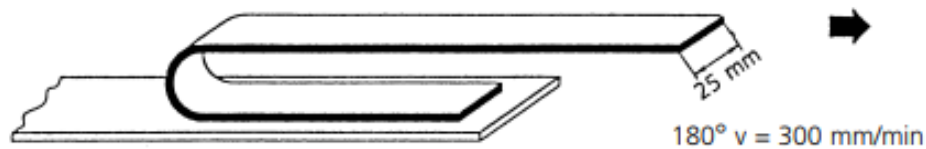


Fig. 4. Schematic view of peel adhesion [19]

2.3. Adhesion test with the visual inspection

1. The ink adhesion experiment is repeated with Tesa 4965 tape (manual).
2. The specimen is kept on the flat surface, with no wrinkles or folds. The surface is cleaned with the ethanol to remove dust particles.
3. Apply the tape onto the surface of the specimen by hand, be sure that there are no wrinkles or folds.
4. Hold the sample and peel the tape by hand with the even motion.
5. Check the specimen for the ink flaking.
6. Using a digital pocket microscope (DPM 300), take a picture of the sample where the ink is removed. DPM 300 has a high-resolution camera, which gives clear images.
7. Repeat the procedure for the other samples.

Tesa 4104 tape is used for ink adhesion with measured force experiment, it determines very good performance on all varieties of plastics and cardboards also protects a safe closure. It is also used in sealing small boxes like cardboard and plastics.

The double-sided tape named Tesa 4965 is used for ink adhesion test with visual inspection which provides high temperature and shear resistance. It is a double-sided mounting tape that is transparent, comprising PET substrate and modified acrylate adhesive mass. Tape can resist the temperature up to 100°C which gives good adhesive strength to the smooth surfaces like tiles, glass and many plastics and also suitable for resistant to damage that are caused by moisture, (certain) chemicals, softening agents and UV light, making it perfect for a broad range of indoor and outdoor applications.

2.4. FTIR analysis

1. Nicolet iS10 is the device used for the FTIR analysis for all the eight samples.
2. First, turn on the instrument and measure the background spectrum without placing the sample, for the good results collect the background spectrum for every four hours.
3. Once the background spectrum is taken, place the sample into the sample compartment, and lock it tight.
4. Wait for a minute for the graph to appear on the screen, with wavelength and absorbance.
5. Once the data collection is finished, add the spectrum to the spectral window.
6. Repeat the same procedure for all the samples.

2.5. Tensile test

1. The first part of the test is to prepare the specimens for the experiment. The specimens are cut longitudinally.
2. Prepare six samples for each material with 15 mm width and 200 mm length. The distance between the gauge is minimum 50 mm, as shown in Fig. 5.
3. The instrument used to test the tensile properties is Tinius Olsen.
4. The specimen is placed and clamped at both sides and is made tight so that the specimen will not slip out from the gripper. It is shown in Fig. 6.
5. To start with the experiment, some settings are done. Load range – 500 N, Extension Range – 1000 mm.
6. The force has been increased consistently, and the specimen is stretched from one side at a pre-programmed rate to apply the tension. The speed with which the experiment was carried out was about 100 mm/min.
7. The maximum force at which the specimen was torn apart was obtained.

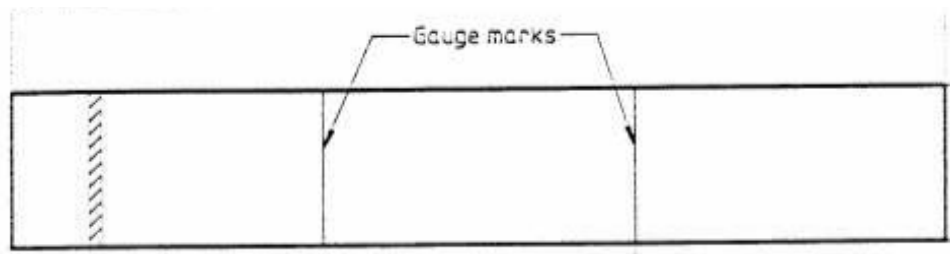


Fig. 5. Specimen dimension [20]



Fig. 6. View of material fixed between clamps for tension test

3. Results

3.1. Contact angle

A drop that has been moved immediately to the specimen upon the contact with its surface is shown in the figures below. It is known that larger the contact angle lesser the surface wetting and lesser the contact angle more the surface wetting.

1. HDPE



Fig. 7. View of droplets on HDPE material a) printing side, b) non-printing side

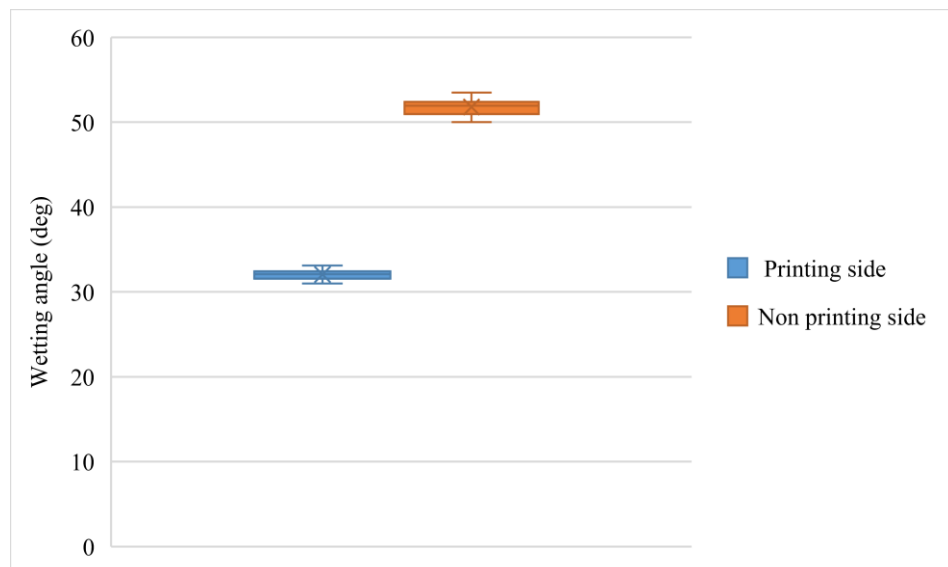


Fig. 8. Surface wettability for printing and non-printing surfaces for HDPE without additives

The graph in Fig. 8 shows the readings of the printing and non-printing side. According to the calculations, the contact angle of the printing side is 32°, and the non-printing side is 51.5°, and the confidence level for the printing side is $\pm 0.88^\circ$, and for the non-printing side is $\pm 1.19^\circ$.

2. HDPE-A15



Fig. 9. View of droplets on HDPE A15 material a) printing side, b) non-printing side

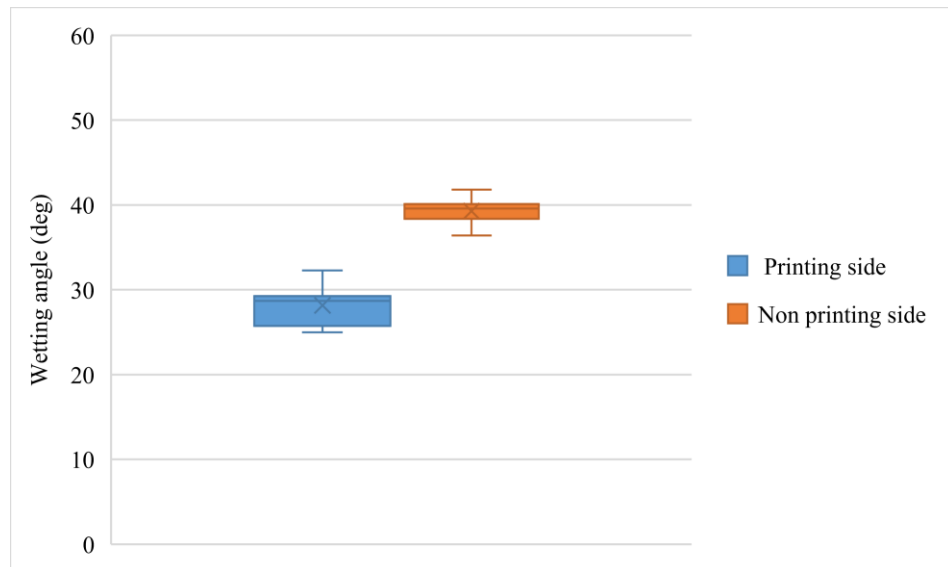


Fig. 10. Surface wettability for printing and non-printing surfaces for HDPE with 15% additives

The graph in Fig. 10 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 28.15° , and the non-printing side is 39.6° , and the confidence level for the printing side is $\pm 1.64^\circ$ and for the non-printing side is $\pm 1.07^\circ$.

3. HDPE A30



Fig. 11. View of droplets on HDPE A30 material a) printing side, b) non-printing side

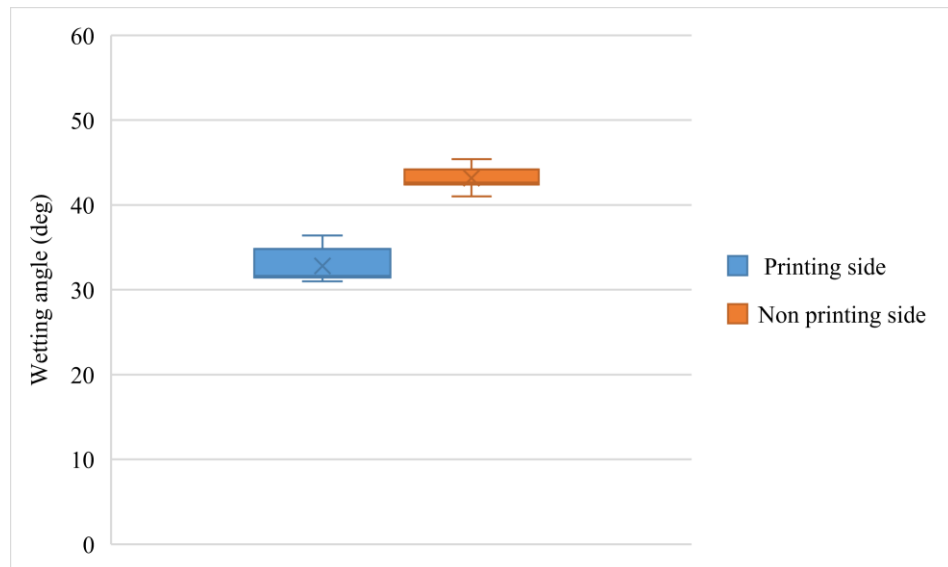


Fig. 12. Surface wettability for printing and non-printing surfaces for HDPE with 30% additives

The graph in Fig. 12 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 32.35° , and the non-printing side is 42.94° . The confidence level for the printing side is $\pm 2.01^\circ$, and the non-printing side is $\pm 1.31^\circ$.

4. HDPE A50



Fig. 13. View of droplets on HDPE A50 of material a) printing side, b) non-printing side

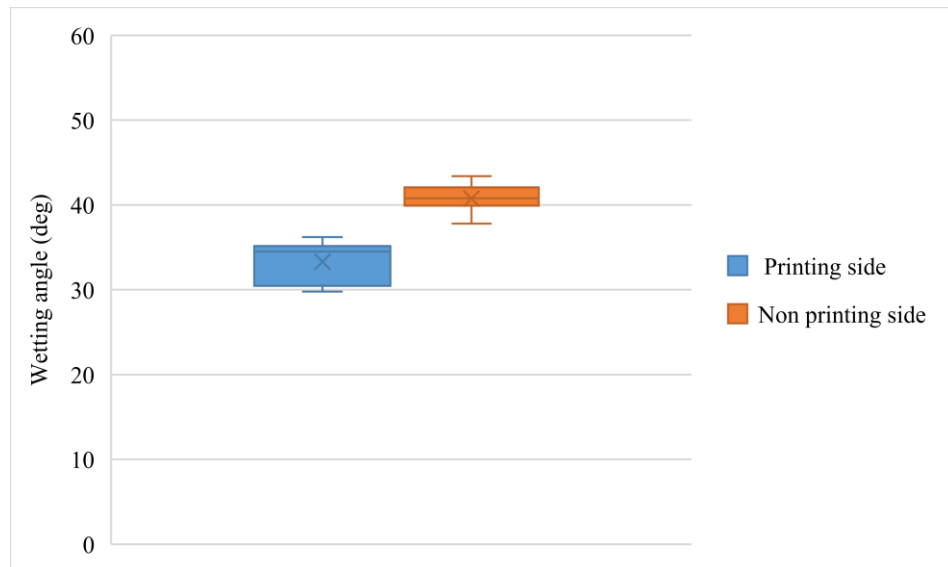


Fig. 14. Surface wettability for printing and non-printing surfaces for HDPE with 50% additives

The graph in Fig. 14 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 34.5° , and the non-printing side is 40.77° , and the confidence level for the printing side is $\pm 1.74^\circ$, and for the non-printing side is $\pm 1.23^\circ$.

5. RHDPE



Fig. 15. View of droplets on RHDPE material a) printing side, b) non-printing side

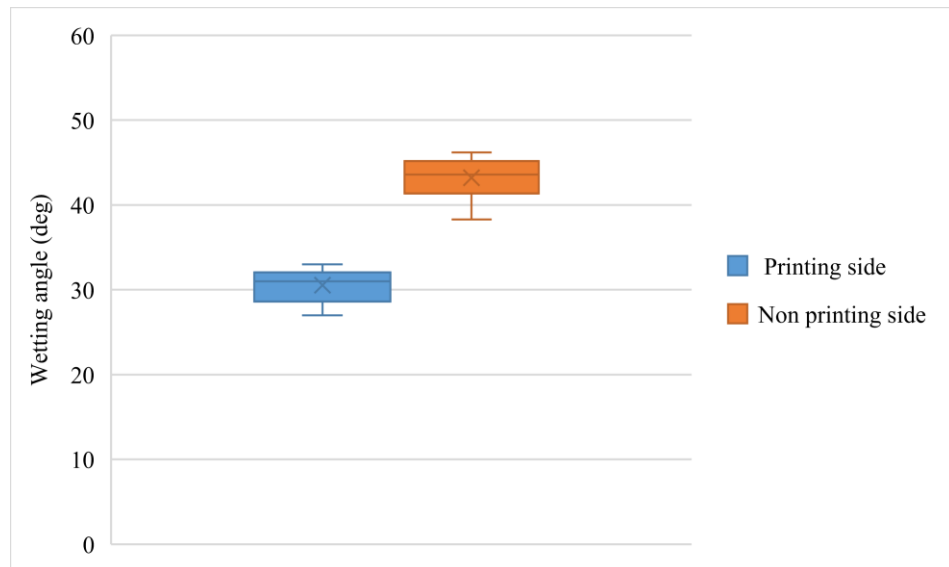


Fig. 16. Surface wettability for printing and non-printing surfaces for RHDPE without additives

The graph in Fig. 16 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 28.62° , and the non-printing side is 43.6° , and the confidence level for the printing side is $\pm 1.36^\circ$, and for the non-printing side is $\pm 1.72^\circ$.

6. RHDPE A15

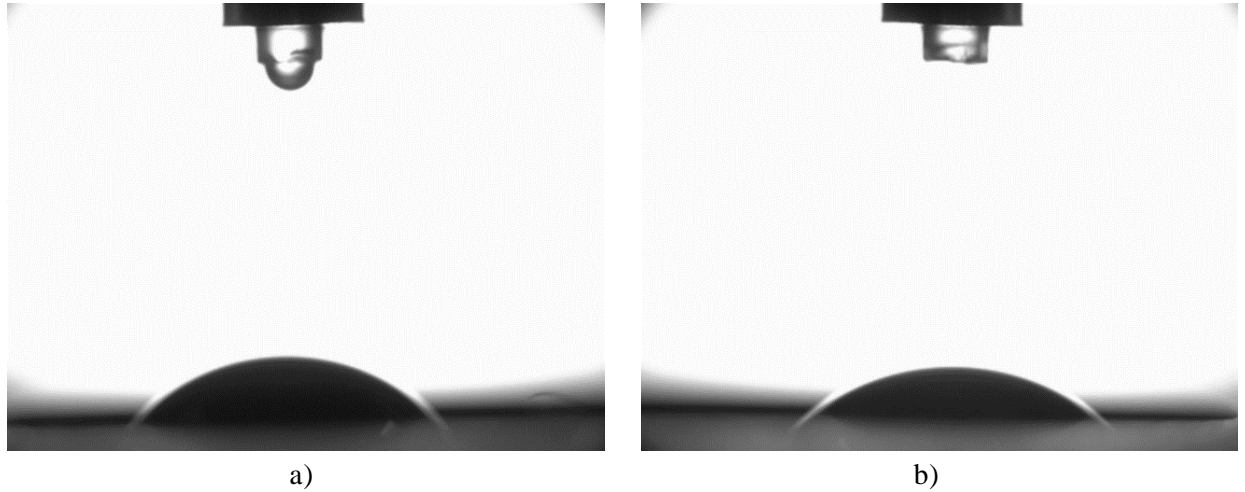


Fig. 17. View of droplets on RHDPE A15 material a) printing side, b) non-printing side

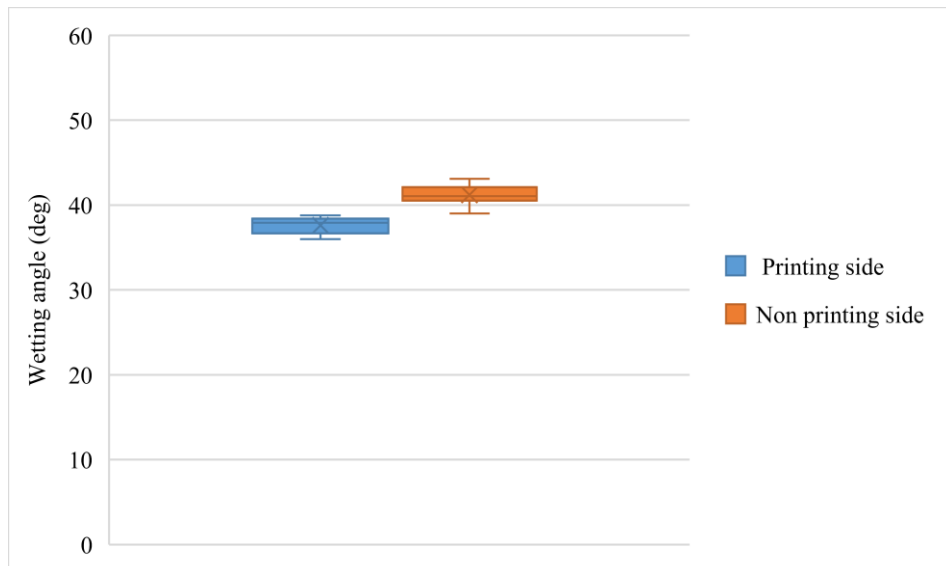


Fig. 18. Surface wettability for printing and non-printing surfaces for RHDPE with 15% additives

The graph in Fig. 18 above shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 37.2° , and the non-printing side is 41.05° , and the confidence level for the printing side is $\pm 1.47^\circ$, and for the non-printing side is $\pm 1.18^\circ$.

7. RHDPE A30

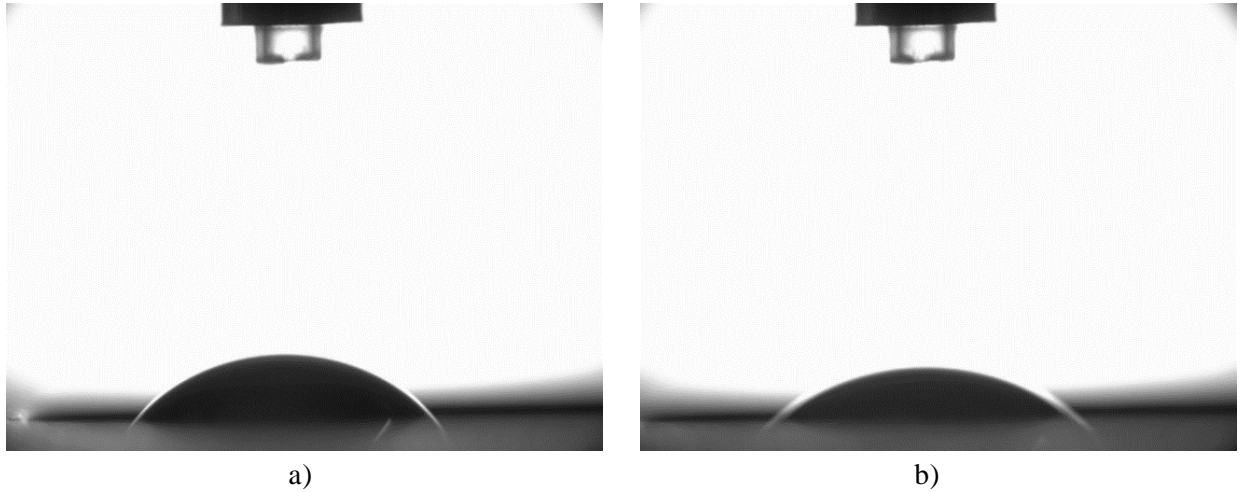


Fig. 19. View of droplets on RHDPE A30 material a) printing side, b) non-printing side

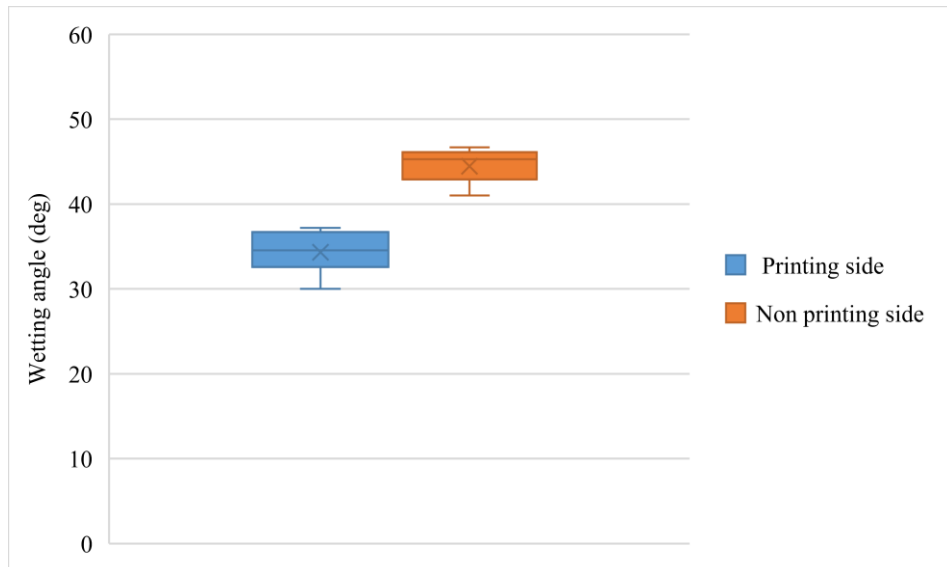


Fig. 20. Surface wettability for printing and non-printing surfaces for RHDPE with 30% additives

The graph in Fig. 20 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 34.55° , and the non-printing side is 46.12° , and the confidence level for the printing side is $\pm 1.70^\circ$, and for the non-printing side is $\pm 1.45^\circ$.

8. RHDPE A50

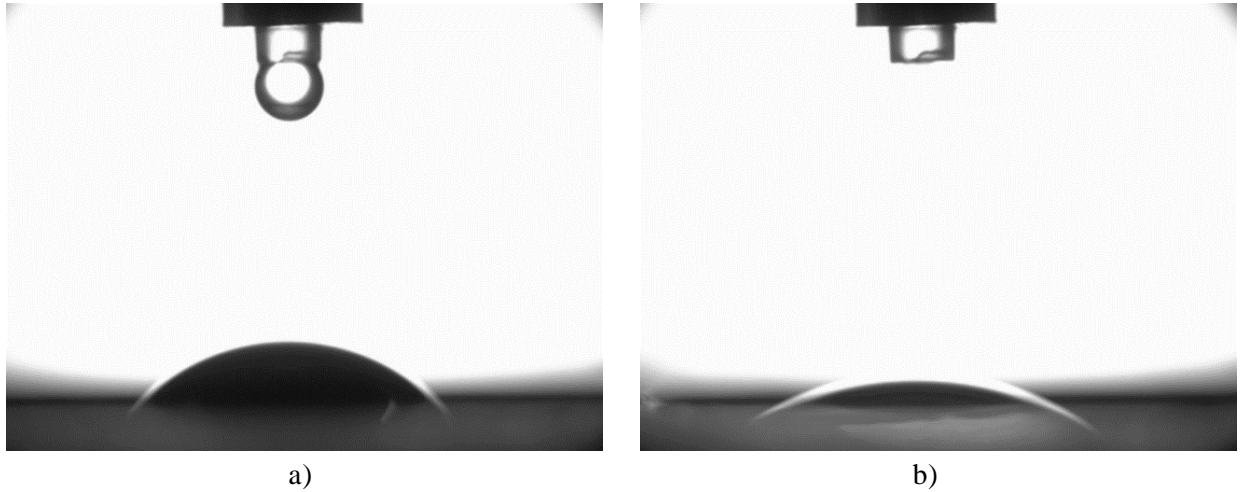


Fig. 21. View of droplets on RHDPE A50 material a) printing side, b) non-printing side

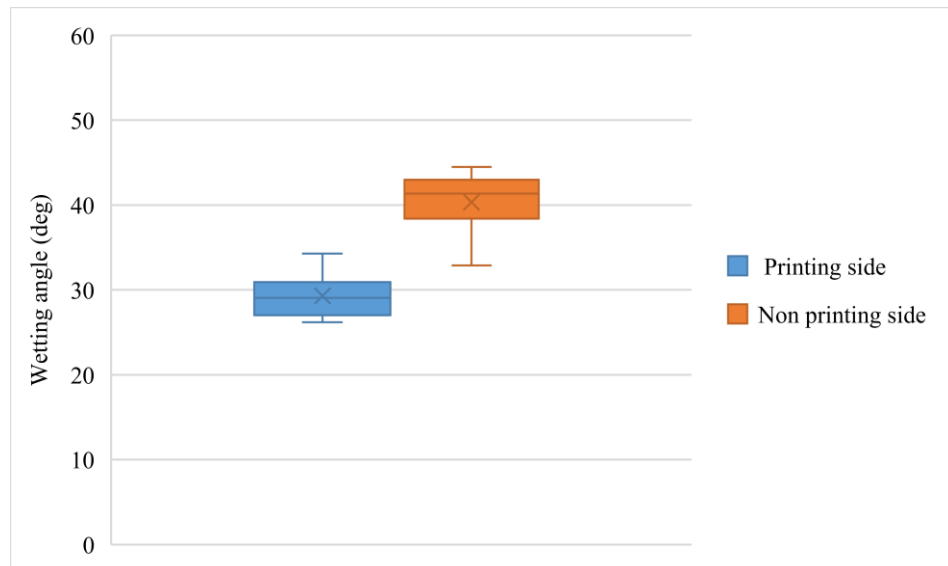


Fig. 22. Surface wettability for printing and non-printing surfaces for RHDPE with 50% additives

The graph in Fig. 22 shows the readings of the printing and non-printing side. According to the calculations, the average contact angle of the printing side is 30° , and the non-printing side is 41.35° , and the confidence level for the printing side is $\pm 1.88^\circ$, and for the non-printing side is $\pm 2.47^\circ$.

The scatter chart of contact angle for all the 8 materials is presented in Fig. 23 and Fig. 24.

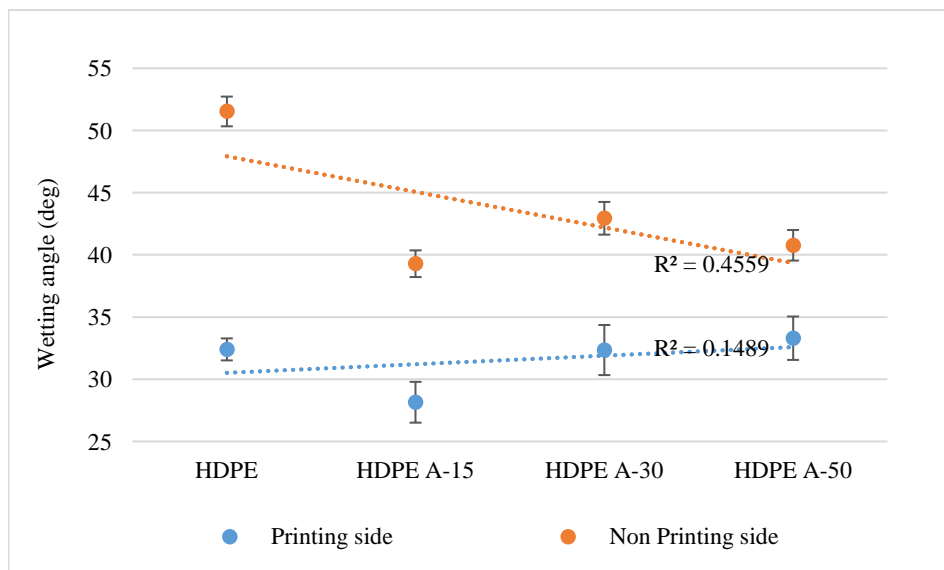


Fig. 23. Scatter chart of contact angle for HDPE

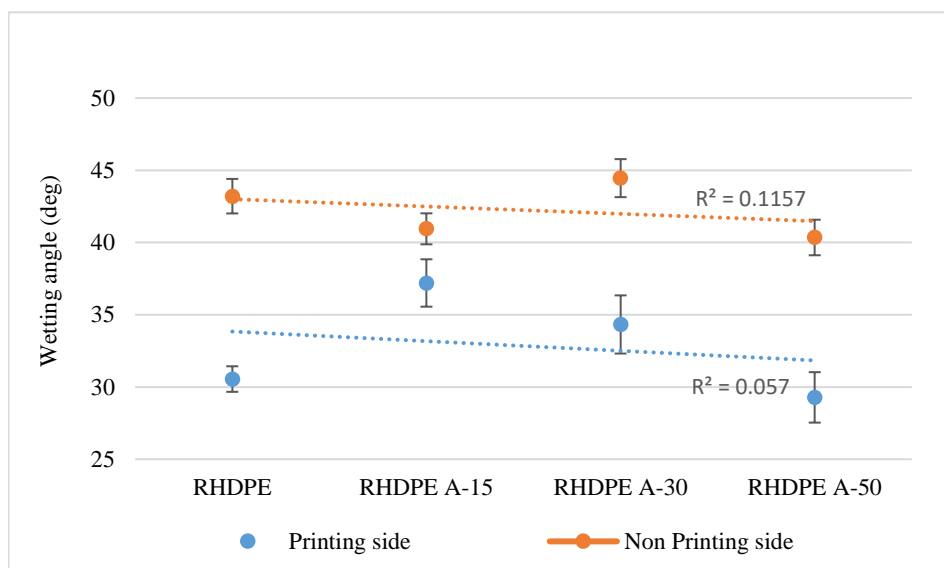


Fig. 24. Scatter chart of contact angle for RHDPE

The graph in Fig. 23 and Fig. 24 shows contact angle measurement of the HDPE and RHDPE with additives of 15%, 30%, and 50%. It is observed that HDPE materials contact angle on printing side is around 28° to 33° but RHDPE materials is 29° to 37° which is less than HDPE and for non-printing sides RHDPE has lesser contact angle that is 40° to 44° and HDPE is 40° to 51°. It is predicted that the RHDPE surface is hydrophilic than HDPE. The linear trend line is plotted in Fig. 23 and Fig. 24 which shows a general pattern or overall direction of the materials. The R^2 value in the graphs tells how better the trend line corresponds with the material data. Tendency of the contact angle for the graphs is discrete in RHDPE materials but is more discrete in HDPE materials.

The contact angle shows how the two materials (namely ink and polyethylene films) react with one another. If they repel each other, the contact angle will be high, and wettability will be lower, and vice versa. Therefore, for good printing, the lower contact angle is preferred. The sample RHDPE

A50 is showing the second-lowest contact angle, which is 29.28° , which, combined with the work of peeling (adhesion value) of 2.19 N/cm Fig. 28, makes it the best-suited material for printing.

3.2. Adhesion test with measured force

Fig. 25 shows how the specimen to be tested should be placed on the friction peel tester. It is before the force is applied, or at the start of the experiment.



Fig. 25. Ink adhesion test with measured force

Fig. 26 shows the end image of the specimen after the ink adhesion. When the force is applied, some amount of ink is peeled on the surface of the films.



Fig. 26. Ink adhesion test with measured force

The results of the adhesion test with Tesa 4104 tape for all the specimen are obtained. The following graph (Fig. 27 and Fig. 28) shows the average mean for all the specimens.

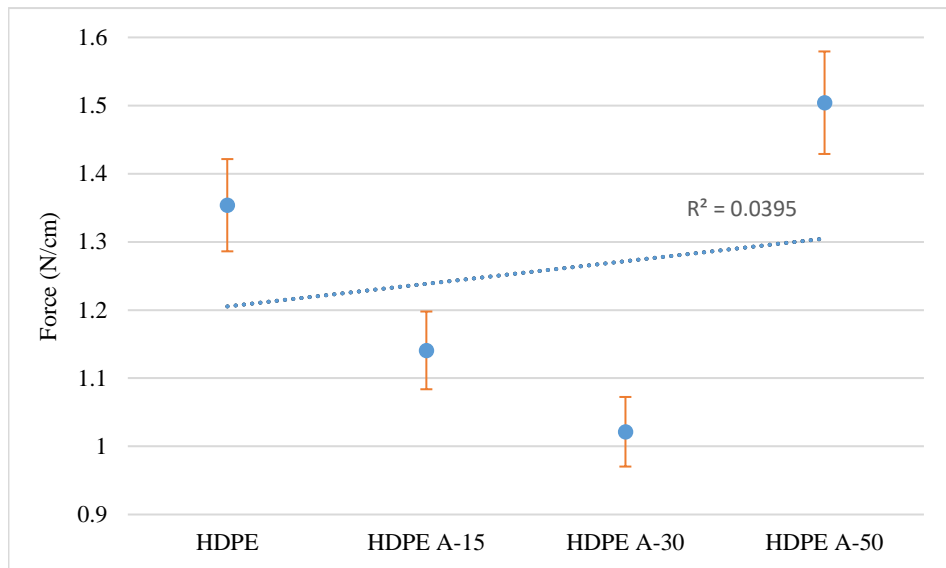


Fig. 27. Average Mean Chart of the Peeling force of HDPE materials with and without additives

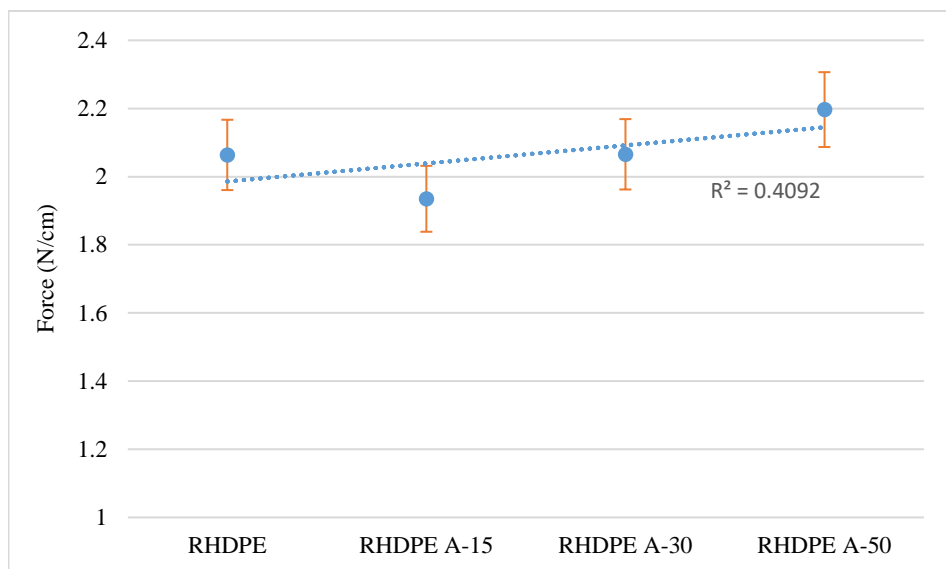


Fig. 28. Average Mean Chart for Peeling force of HDPE materials with and without additives

The graph in Fig. 27 and Fig. 28 shows the average mean for all the specimens. The average mean for the HDPE is 1.3538 N/cm, for HDPE A-15 is 1.1408 N/cm, for HDPE A-30 is 1.0214 N/cm, for HDPE A-50 is 1.5042 N/cm, for RHDPE is 2.0638 N/cm, for RHDPE A-15 is 1.935 N/cm, for RHDPE A-30 is 2.0656 N/cm, for RHDPE A-50 is 2.1968 N/cm. The adhesion test results for different materials reveal how hard it is to remove the flexographic ink from the films. Therefore, N/cm represents work or force required to remove a cm of the dried ink from the substrate. It is observed that RHDPE A-50 is showing the maximum value of 2.19 N/cm, which makes itself the strongest connecting of binding material of all to the printing ink. In the set of HDPE materials, the sample HDPE A-50 shows the maximum binding force with the printing ink, but less than the sample RHDPE A-50. R^2 value in Fig. 27 and Fig. 28 it is observed that the tendency of strength is similar in RHDPE but in HDPE it is more discrete. It was found that the adhesion strength of RHDPE was approximately 60.62% higher than HDPE.

3.3. Adhesion test for visual inspection

The main principle of the Visual inspection technique is to inspect the delamination of inks with the naked eye [21]. The investigation of ink adhesion to the printed side was measured according to FINAT FTM 21 process by using tape Tesa 4965 [19]. By touching films surfaces by hands it was noticeable that some surface of materials was coarse.

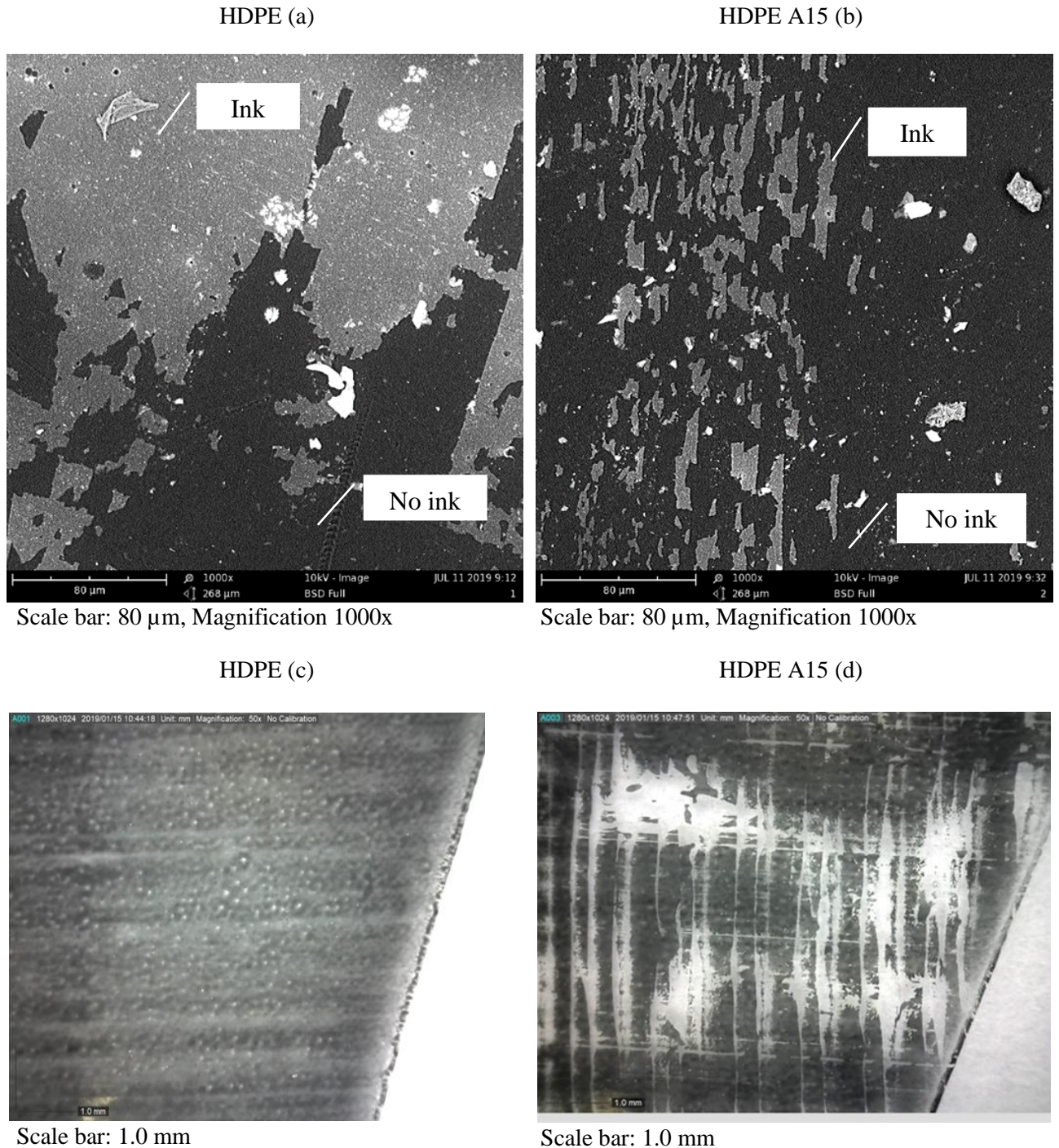


Fig. 29. Ink Adhesion Manually (a) HDPE SEM image (b) HDPE A15 SEM image (c) HDPE Digital Pocket Microscope image (d) HDPE A15 Digital Pocket Microscope image

The test for ink adhesion manually on HDPE (Fig. 29a) shows ink flaking. By visual inspection, there is more than 20% peel of ink from the surface of HDPE. Hence, it can be concluded that there is

delamination of ink. By visual inspection for HDPE A15, there is ink flaking of around more than 70%, so it is observed that there is delamination. The SEM images of HDPE and HDPE A15 show the roughness of the surfaces.

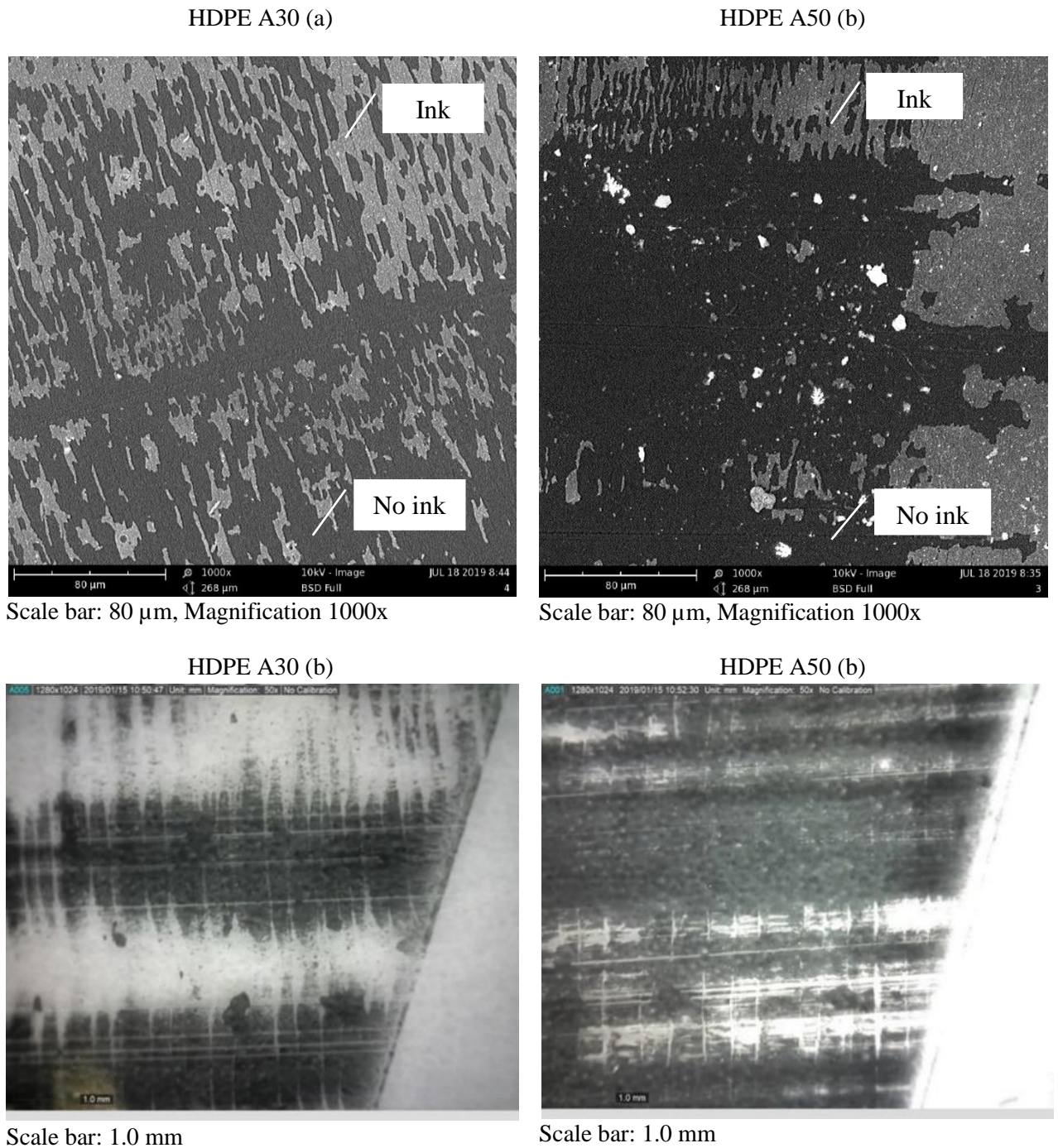
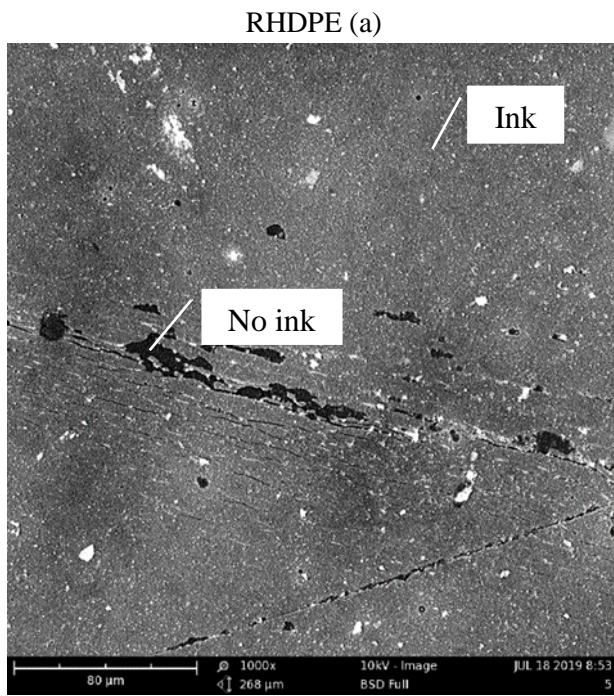
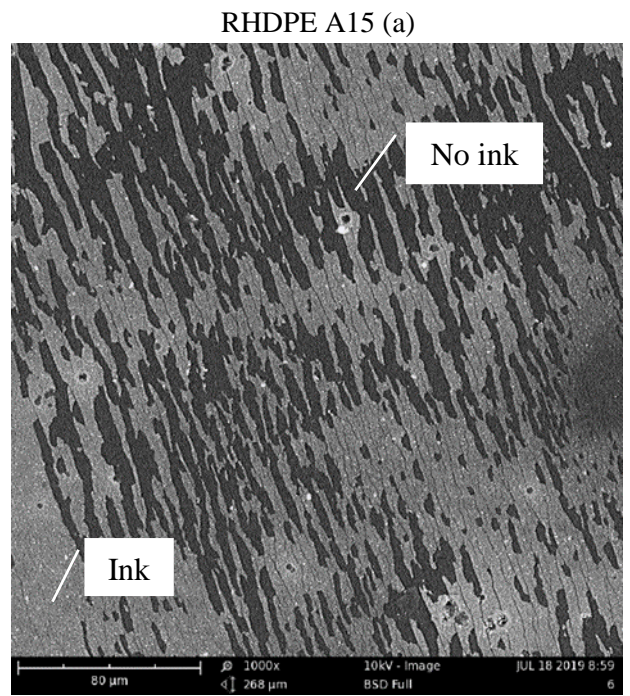


Fig. 30. Ink Adhesion Manually (a) HDPE A30 SEM image (b) HDPE A50 SEM image (c) HDPE A30 Digital Pocket Microscope image (d) HDPE A50 Digital Pocket Microscope image

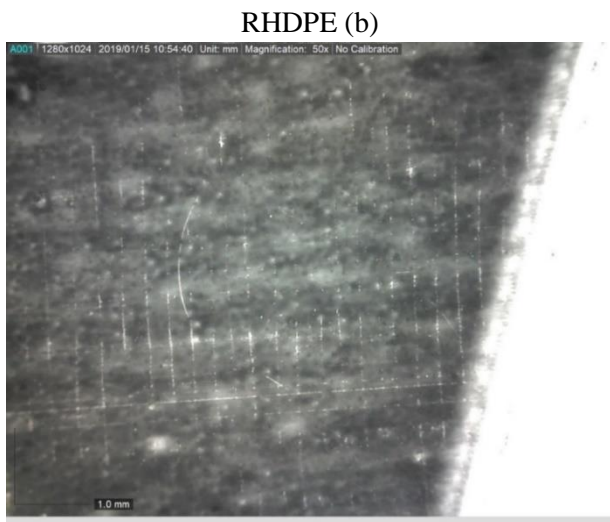
The test for ink adhesion manually on HDPE A30 shows ink flaking of around 40%, hence it is understood that there is more delamination of the ink. HDPE A50 also shows delamination, there is flaking of ink at more than 50%. The images of HDPE A30 and A50 from the digital pocket microscope also show the removal of ink after ink adhesion test.



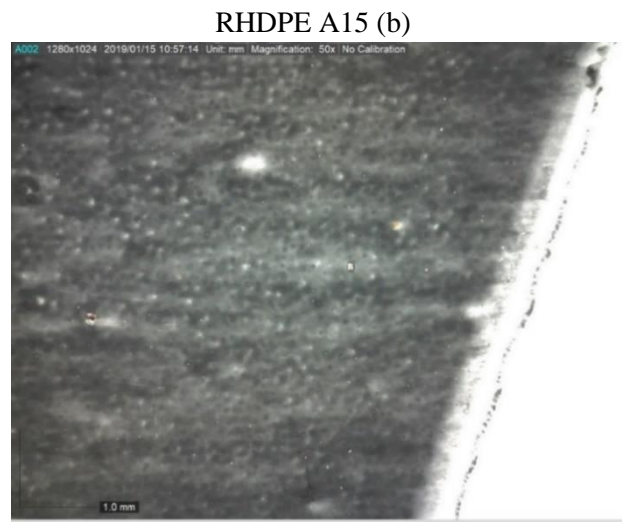
Scale bar: 80 μm, Magnification 1000x



Scale bar: 80 μm, Magnification 1000x



Scale bar: 1.0 mm

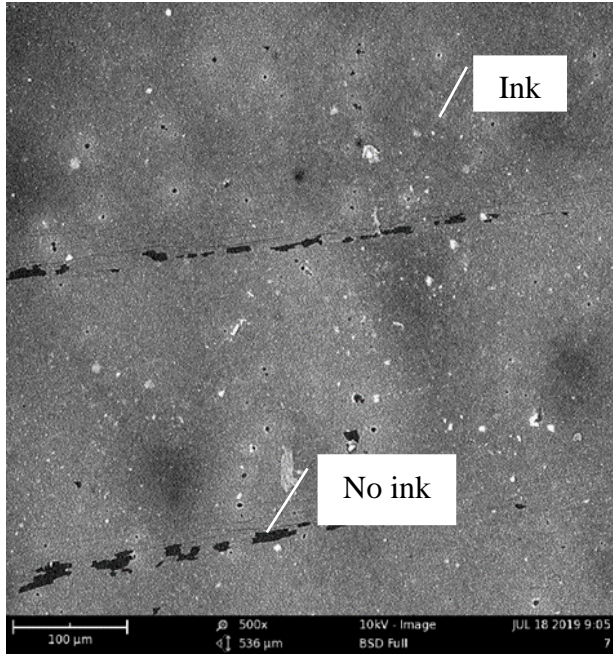


Scale bar: 1.0 mm

Fig. 31. Ink Adhesion Manually (a) RHDPE SEM image (b) RHDPE A15 SEM image (c) RHDPE Digital Pocket Microscope image (d) RHDPE A15 Digital Pocket Microscope image

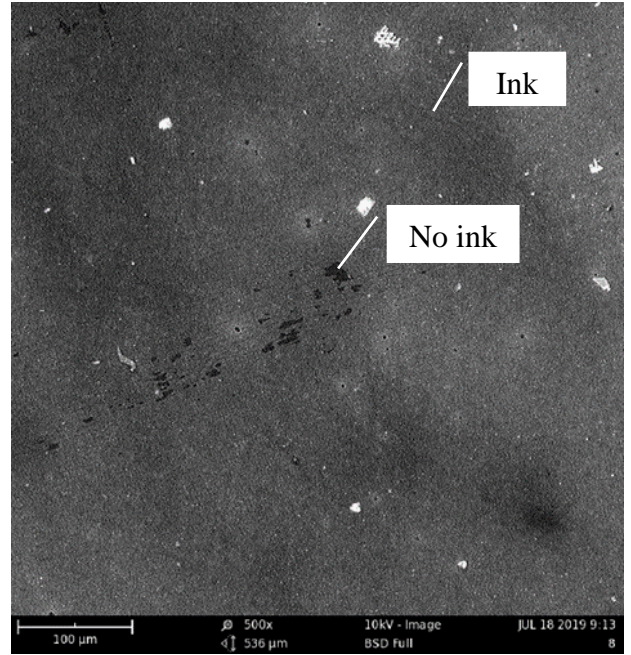
The test for ink adhesion manually on RHDPE shows small delamination of ink, less than 20%, and for RHDPE A15 shows ink flaking around 30%. The inking area of RHDPE shows some spots maybe because of ink which is not applied properly or because of the roughness of the material. Even in the images taken from the digital microscope uneven surface of the material is seen. It is difficult to see the removal of ink from the images of digital microscope.

RHDPE A30 (a)



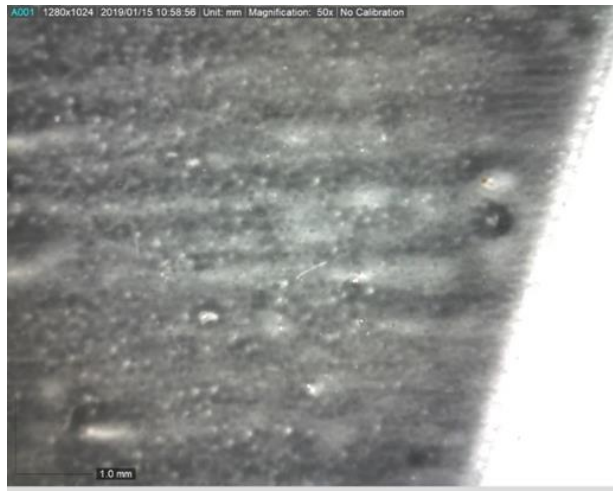
Scale bar: 80 μm, Magnification 1000x

RHDPE A50 (a)



Scale bar: 80 μm, Magnification 1000x

RHDPE A30 (a)



Scale bar: 1.0 mm

RHDPE A50 (a)



Scale bar: 1.0 mm

Fig. 32. Ink Adhesion Manually (a) RHDPE A30 SEM image (b) RHDPE A50 SEM image (c) RHDPE A30 Digital Pocket Microscope image (d) RHDPE A50 Digital Pocket Microscope image

The test for ink adhesion manually on RHDPE A30 shows the delamination of ink, less than 10%, and RHDPE A50 shows ink flaking less than 5% compares to all materials there is very less delamination. Comparing HDPE and RHDPE materials, RHDPE has very less delamination of ink than HDPE materials. RHDPE materials have good adhesion of inks.

3.4. FTIR analysis

In this research, FTIR analysis is carried out to characterize the samples. The IR spectrum gives knowledge about the structural appearance of polymers like chemical composition and structural configuration [22]. All the eight samples have similar results just with the slight differences. Fig. 33 is the graph of the HDPE IR spectrum, where the major absorbance bands are located on 2915 cm^{-1} , 2848 cm^{-1} , 1471 cm^{-1} , 1462 cm^{-1} , 718.26 cm^{-1} , 729.49 cm^{-1} .

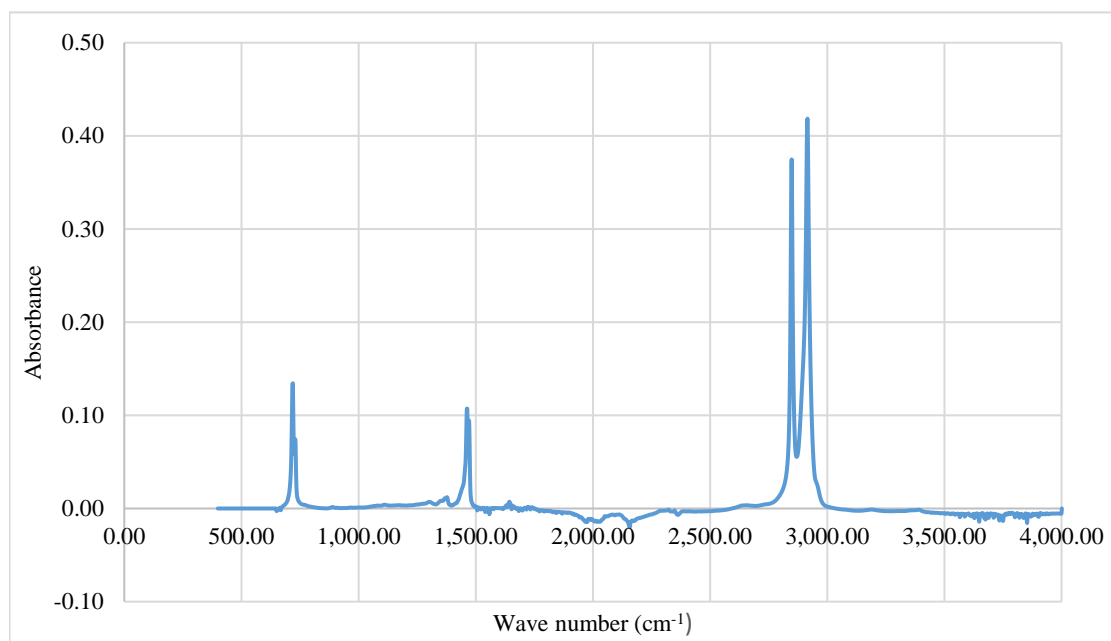


Fig. 33. Represents the HDPE spectrum after FTIR analysis

Fig. 34 shows the graph of the major absorbance peaks of HDPE A15 at 2915.12 cm^{-1} , 2848 cm^{-1} , 1471 cm^{-1} , 1462.72 cm^{-1} , 718.57 cm^{-1} , 729.47 cm^{-1} .

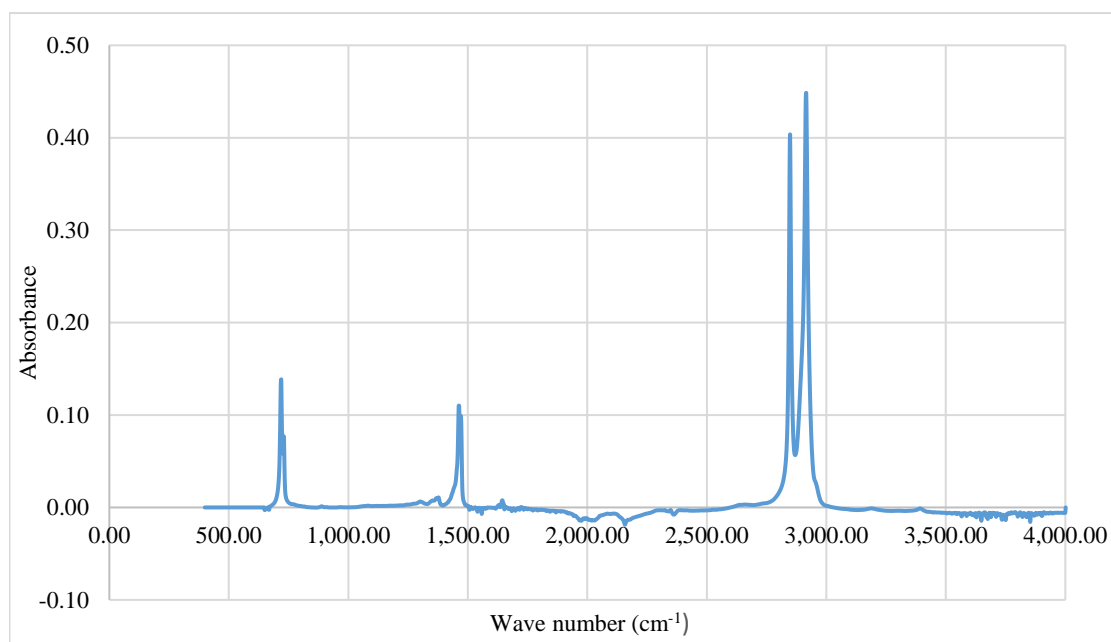


Fig. 34. Represents the HDPE A15 spectrum after FTIR analysis

Fig. 35 shows the graph of HDPE A30 spectrum with absorbance peaks at 2914.82 cm^{-1} , 2848.96 cm^{-1} , 1471.14 cm^{-1} , 1462.90 cm^{-1} , 718.42 cm^{-1} and 729 cm^{-1} .

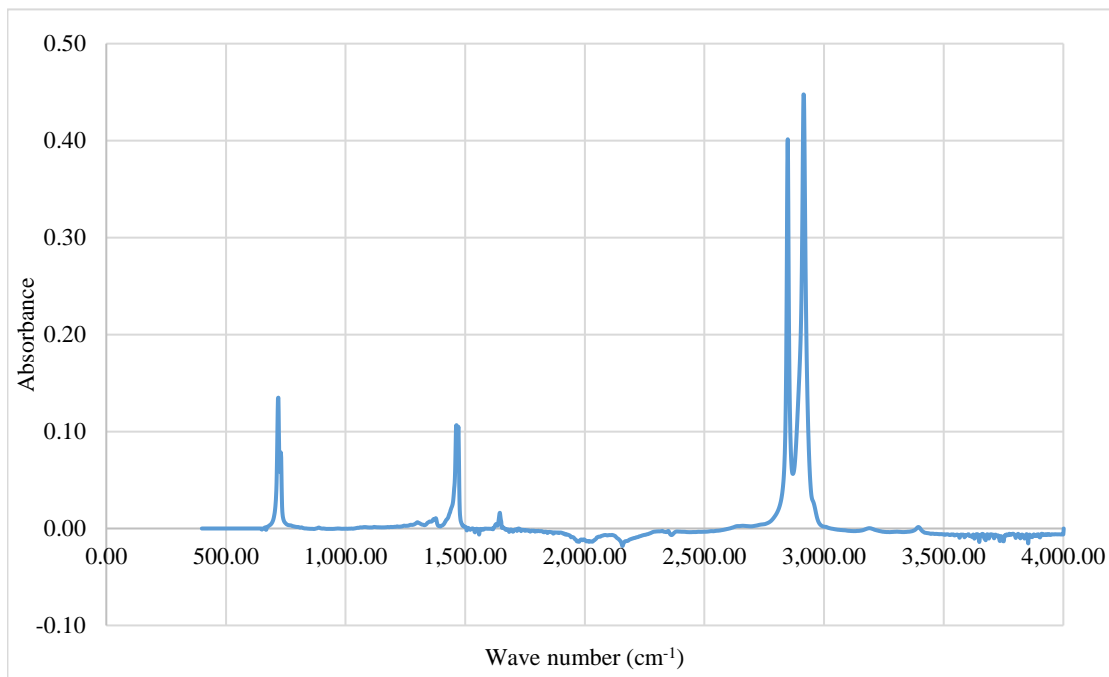


Fig. 35. Represents the HDPE A30 spectrum after FTIR analysis

Fig. 36 shows the graph of HDPE A50 spectrum with absorbance peaks at 2914.93 cm^{-1} , 2847.81 cm^{-1} , 1471.31 cm^{-1} , 1462.43 cm^{-1} , 718.64 cm^{-1} .

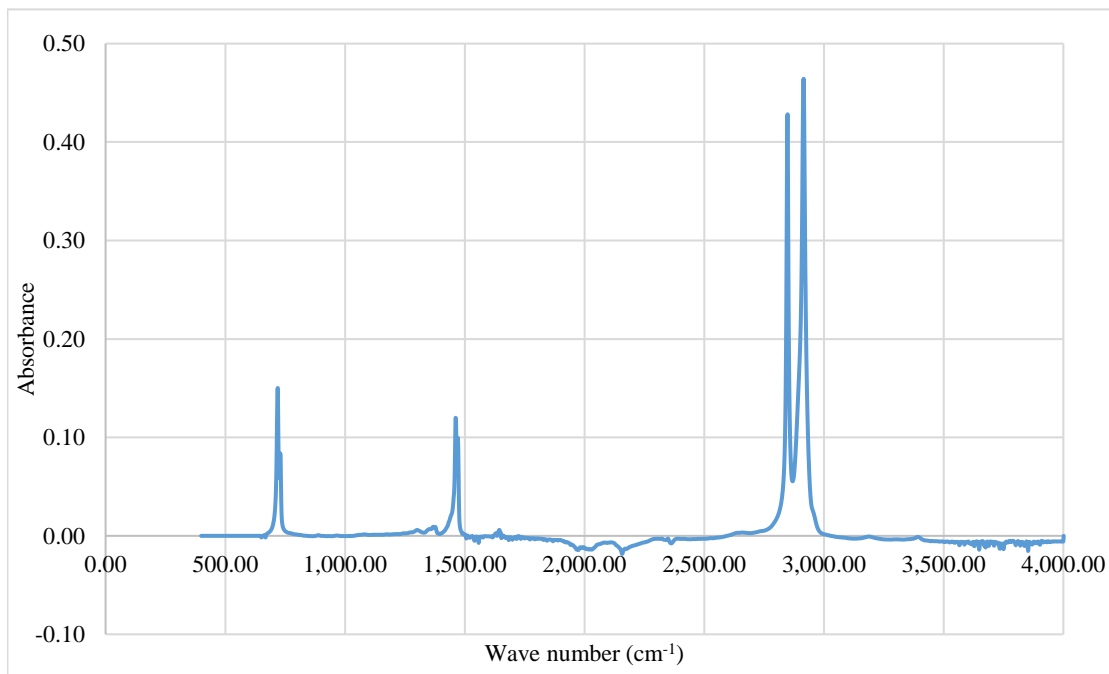


Fig. 36. Represents the HDPE A50 spectrum after FTIR analysis

Fig. 37 shows the graph of RHDPE spectrum with absorbance peaks at 2914.59 cm^{-1} , 2848.14 cm^{-1} , 1471.12 cm^{-1} , 717.84 cm^{-1} and 729.59 cm^{-1} .

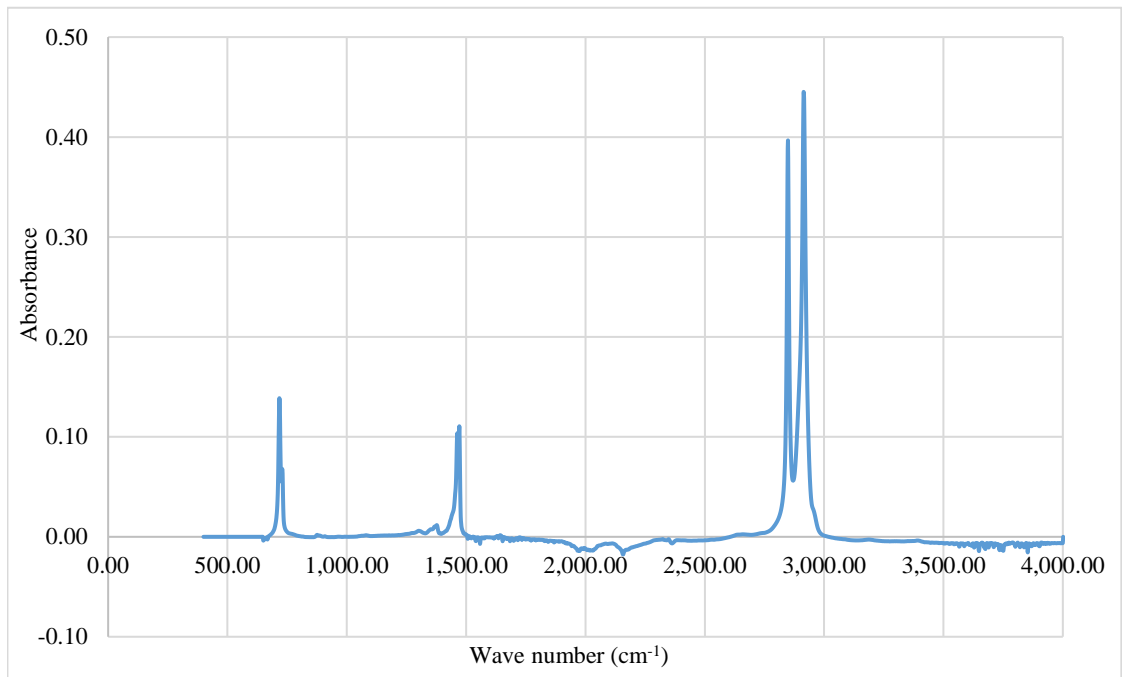


Fig. 37. Represents the RHDPE spectrum after FTIR analysis

Fig. 38 shows the graph of RHDPE A15 spectrum with absorbance peaks at 2914.56 cm^{-1} , 2848.21 cm^{-1} , 1471.02 cm^{-1} , 717.56 cm^{-1} and 729.12 cm^{-1} .

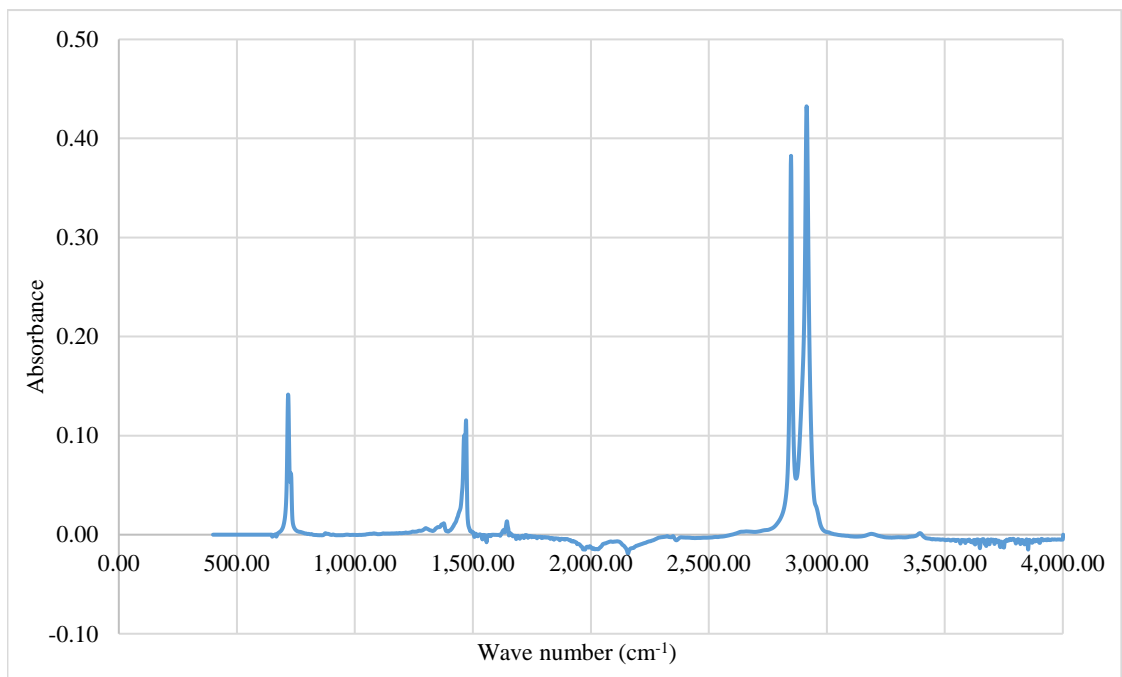


Fig. 38. Represents the RHDPE A15 spectrum after FTIR analysis

Fig. 39 shows the graph of RHDPE A30 spectrum with absorbance peaks at 2914.61 cm^{-1} , 2848.04 cm^{-1} , 1471.08 cm^{-1} , 717.90 cm^{-1} .

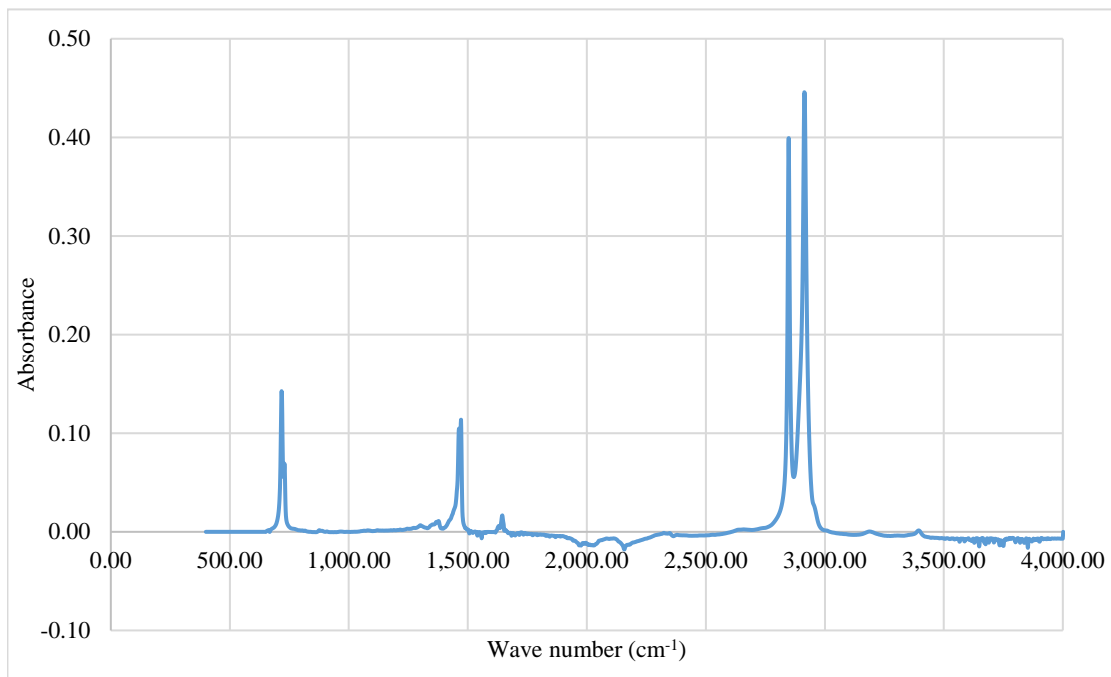


Fig. 39. Represents the RHDPE A30 spectrum after FTIR analysis

Fig. 40 shows the graph of RHDPE A50 spectrum with absorbance peaks at 2914.73 cm^{-1} , 2848 cm^{-1} , 1471.15 cm^{-1} , 1462.67 cm^{-1} , 718.24 cm^{-1} .

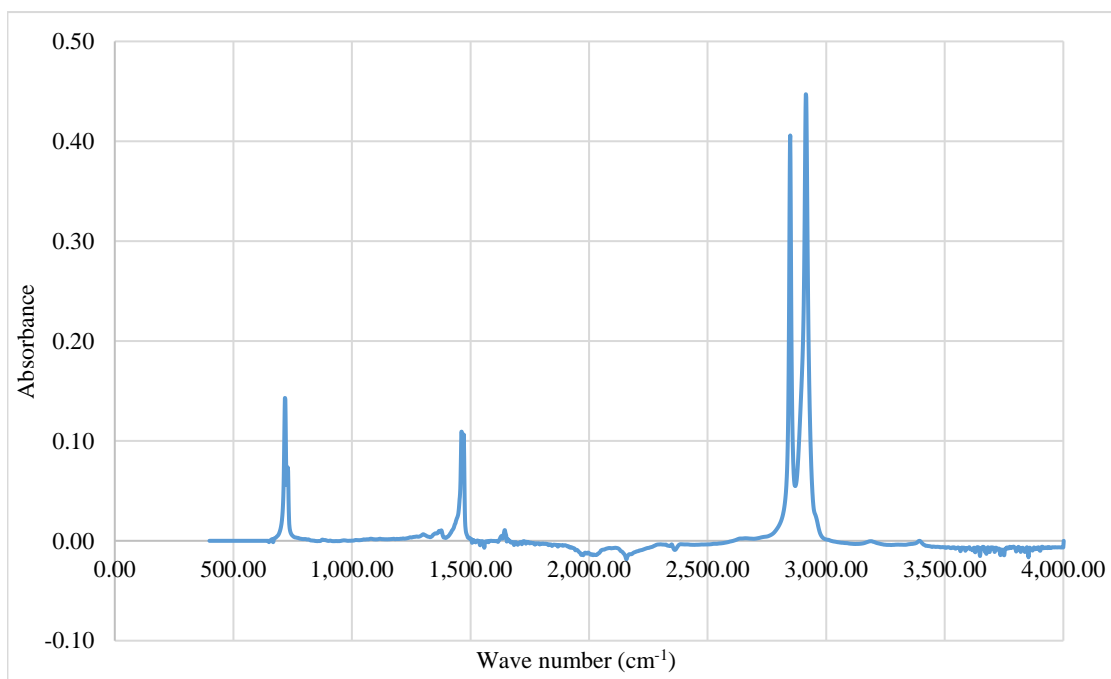


Fig. 40. Represents the RHDPE A50 spectrum after FTIR analysis

The absorption bands, which are between wavenumbers 4000 cm^{-1} to 1500 cm^{-1} , are usually from the functional groups like C=O, CH₃, -OH, N-H. The region between the 1500 cm^{-1} to 400 cm^{-1} is usually specified as a fingerprint region [17]. In FTIR graph the peaks shown at the lower energy areas are known as the fingerprint region and every region is unique for an individual compound which helps to compare different FTIR graphs [23]. FTIR analysis was done for all the materials, Table 2 shows the functional groups of the materials. The major absorbance bands for Polyethylene, are located at 2914 cm^{-1} , 2847 cm^{-1} , 1470 cm^{-1} and 718 cm^{-1} . The 1470 cm^{-1} and 718 cm^{-1} peaks are considered to analyse the presence of polyethylene [24]. In case of our research, the wavenumbers of the samples match with the spectrum of polyethylene as studied by Ronald P. Amelia et al., and Melissa R. Jung et al., [25]. The classification of wavenumbers into the functional groups is shown in Table 2.

Table 2. Absorption band values and their functional groups

Absorption bands (cm^{-1})	Functional Groups	Vibrations
2915	C-H	Stretching Vibrations
2848	C-H	Stretching Vibrations
1467	CH ₂	Bending Vibrations
1471	CH ₂	Bending Vibrations
718-717	CH ₂	Rock
729	CH ₂	Rock

The peaks around 2970 cm^{-1} – 2850 cm^{-1} shows that there is a presence of methyl functional group, and the peaks present around 1600 cm^{-1} – 700 cm^{-1} have methylene as a functional group. Hence, it can be said that the polymer is polyethylene [26]. The peak or a band occurring around 720 cm^{-1} is because of CH₂ rocking vibrations. Sometimes 720 cm^{-1} peaks are split, and an additional peak is seen at 730 cm^{-1} because of the crystallinity of Polyethylene [27]. It was difficult to understand and confirm the functional groups of HDPE because of less clarity of peak lines in the graphs.

The FTIR analysis was done to check if the samples reveal any differences in the functional groups. Comparing the results of the FTIR analysis, it shows that all the samples tested with FTIR say that the functional groups identified of HDPE materials and recycled HDPE materials show the same functional groups as that of HDPE so using of RHDPE would be good for plastic bags.

3.5. Tensile test

The tensile test was performed on all the HDPE and RHDPE samples to understand the mechanical properties. Fig 43 shows the graph which is plotted for force v/s extension for HDPE material. There are six lines in each graph which represent six specimens of HDPE material. Each specimen can hold some amount of force and elongation with the specific values, which are shown in Table 3. The HDPE material can withstand the maximum force of 9.99 N, and the average breaking force is approximately 9.75 N for the samples. The initial length of the specimen was 50mm, but on average, before it breaks, HDPE can extend till 219 mm. The material shows its elastic properties approximately up to 6.8 N, where deformation is minimum, and it regains its original shape and size. After 6.8 N, the material shows plastic properties where deformation goes on increasing with the increase of force. The average stress developed on the HDPE material is 13.01 MPa due to the average force of 9.99 N applied to the material. The maximum force at which the material breaks is 9.75 N.

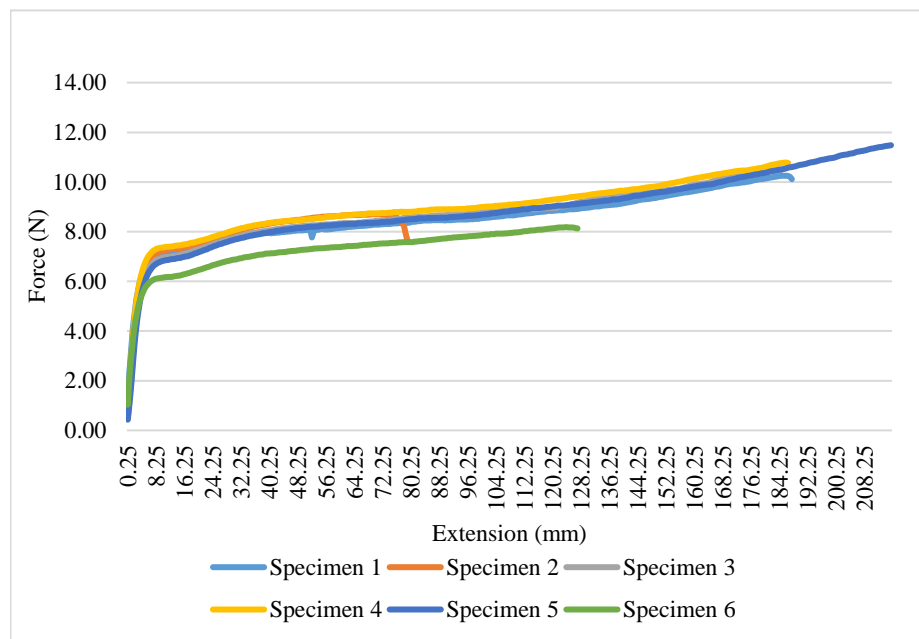


Fig. 41. Force v/s extension graph of HDPE

Table 3. Results of HDPE tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	10.25	369.2	376.0	13.45	10.09
2	8.70	136.6	158.2	10.11	7.58
3	10.51	365.2	370.0	13.98	10.49
4	10.79	371.6	374.0	14.33	10.75
5	11.49	432.0	432.0	15.32	11.49
6	8.18	247.2	254.1	10.84	8.13
Mean	9.99	320.3	327.4	13.01	9.75
Std. Dev	1.277	108.3	101.3	2.066	1.550

The same experimental procedure has been repeated for the material HDPE A15. The maximum force at which the material HDPE A15 can resist is 11.70 N. The size of the material before the elongation was 50 mm, and the average size of the material after the elongation was 225 mm. The average stress at which the material breaks is 13.54 MPa and the force is 10.15 N. The material has its elastic properties up to 9.0 N for the different samples at which it can regain its original properties; after that, there will be deformation as there is an increase in the force.

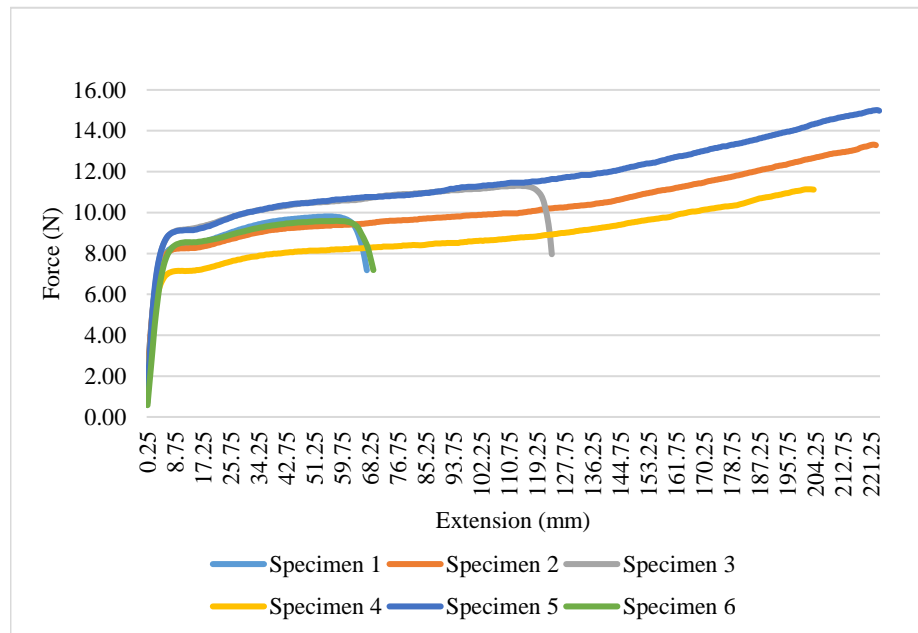


Fig. 42. Force v/s extension graph of HDPE A15

Table 4. Results of HDPE A15 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	9.82	108.2	135.0	9.29	6.97
2	13.32	443.0	446.0	17.72	13.29
3	11.31	225.3	248.0	10.08	7.56
4	11.14	402.0	408.0	14.82	11.11
5	15.02	445.5	448.0	19.95	14.96
6	9.60	112.7	138.6	9.37	7.03
Mean	11.70	289.4	303.9	13.54	10.15
Std. Dev	2.100	160.5	148.8	4.637	3.477

Fig. 43 shows the graph of force v/s extension for the material HDPE A30. The maximum force which the material HDPE A50 can withstand is 11.14 N. Initially, the size of the material before the experiment was 50 mm, and after the test, the material is extended up to 100 mm to 152 mm. The average stress at which the material can break is 10.98 MPa, and the force is 8.23 N. In the case of material HDPE A30, the elastic region is around 8.9 N to 9.9 N, after which there is deformation.

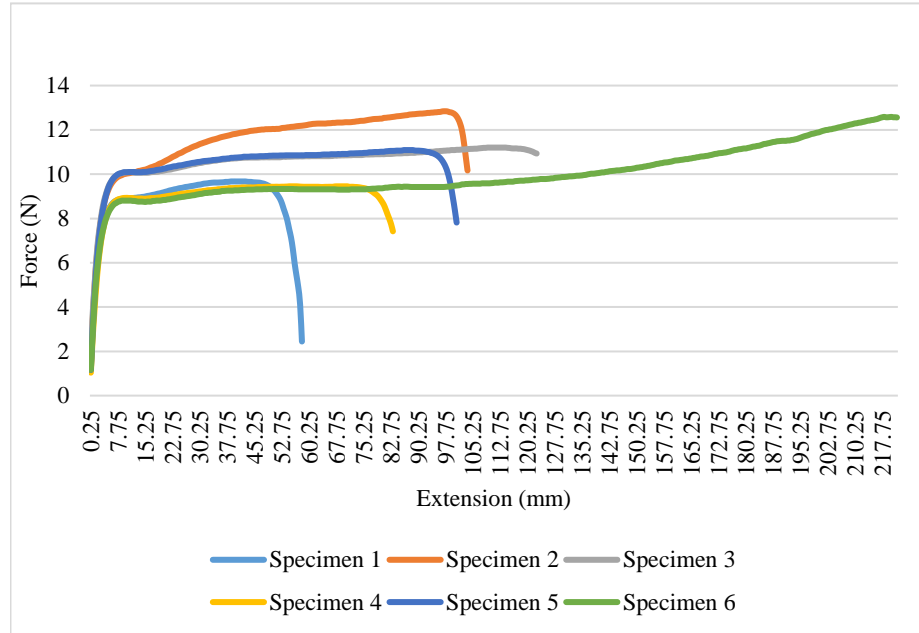


Fig. 43. Force v/s extension graph of HDPE A30

Table 5. Results of HDPE A30 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	9.68	79.8	116.4	1.640	1.230
2	12.84	193.3	207.8	13.20	9.90
3	11.20	218.1	246.0	14.55	10.91
4	9.45	102.8	166.8	9.67	7.25
5	11.09	171.8	202.0	10.07	7.55
6	12.59	436.0	444.0	16.74	12.56
Mean	11.14	200.3	230.5	10.98	8.23
Std. Dev	1.412	127.1	113.3	5.30	3.978

The material HDPE A50 tensile properties were tested. Fig. 44 shows the graph of the force v/s extension of the material. 25.02 N is the maximum force up to which the material can bear. The material size at the start of the experiment was 50mm, and after the test, the material has extended up to 335mm. There is a very minute fracture in two specimens at 41mm and 135mm when it was extended. The material HDPE A50 has an elastic region up to 13 N where it can regain its original shape and size after this point; there is deformation as there is an increase in load. The stress at which the material can break is 33.36 MPa, and the force is 25.02 N.

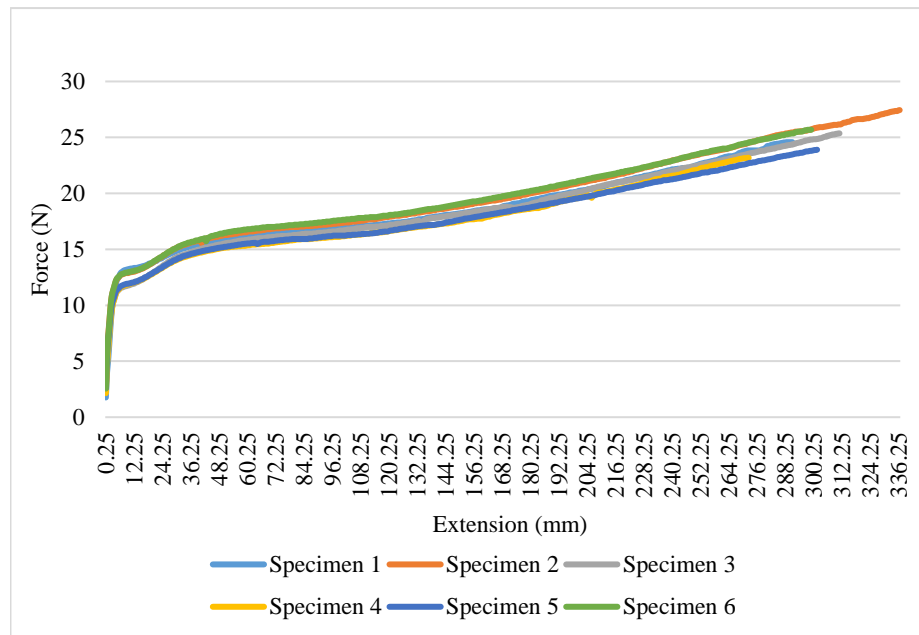


Fig. 44. Force v/s extension graph of HDPE A50

Table 6. Results of HDPE A50 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	24.58	578	582	32.77	24.58
2	27.44	673	674	36.59	27.44
3	25.36	622	622	33.81	25.36
4	23.18	544	546	30.90	23.18
5	23.90	603	604	31.87	23.90
6	25.68	595	598	34.24	25.68
Mean	25.02	602	604	33.36	25.02
Std. Dev	1.501	43.37	42.64	2.001	1.501

Similarly, like HDPE, the recycled HDPE with different additives was tested for the understanding of the mechanical properties. Fig. 45 shows the force v/s extension graph of the material RHDPE. The maximum force at which the material RHDPE can withstand is 11.56 N. The material shows the elastic region up to 8.25 N where it can obtain its original size, and after this point, there is deformation. The material was 50 mm initially and can be extended to a maximum of 80-85 mm approximately. The average stress at which the material RHDPE breaks is 10.34 MPa and force is 7.75 N.

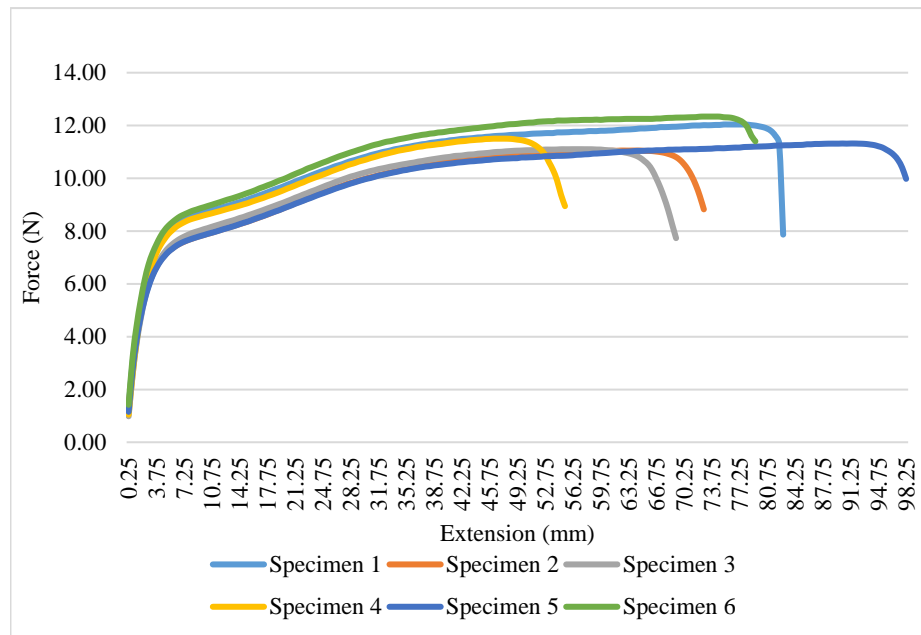


Fig. 45. Force v/s extension graph of RHDPE

Table 7. Results of RHDPE tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	12.04	148.5	165.9	0.583	0.4375
2	11.05	122.4	146.0	11.40	8.55
3	11.11	112.4	138.8	9.95	7.46
4	11.50	91.8	110.3	11.88	8.91
5	11.34	180.4	196.8	13.02	9.76
6	12.34	143.2	158.1	15.20	11.40
Mean	11.56	133.1	152.6	10.34	7.75
Std. Dev	0.519	31.07	28.95	5.09	3.819

Fig. 46 shows the Force v/s extension graph of the RHDPE A15 material. This material RHDPE A15 has the varying graphs it may be because of improper cutting of the samples, or the clamp which was used in the experiment was not tightened properly. Considering the table of results, the average force at which the material RHDPE A15 can withstand is approximately about 12.69 N. The material can be extended 70 mm to 100 mm more than that of the initial size. Until 7-9 N, it is the elastic region of the material. After that, there is a deformation. The average stress at which the material RHDPE A-15 can break is 10.60 MPa, and force is 7.95 N.

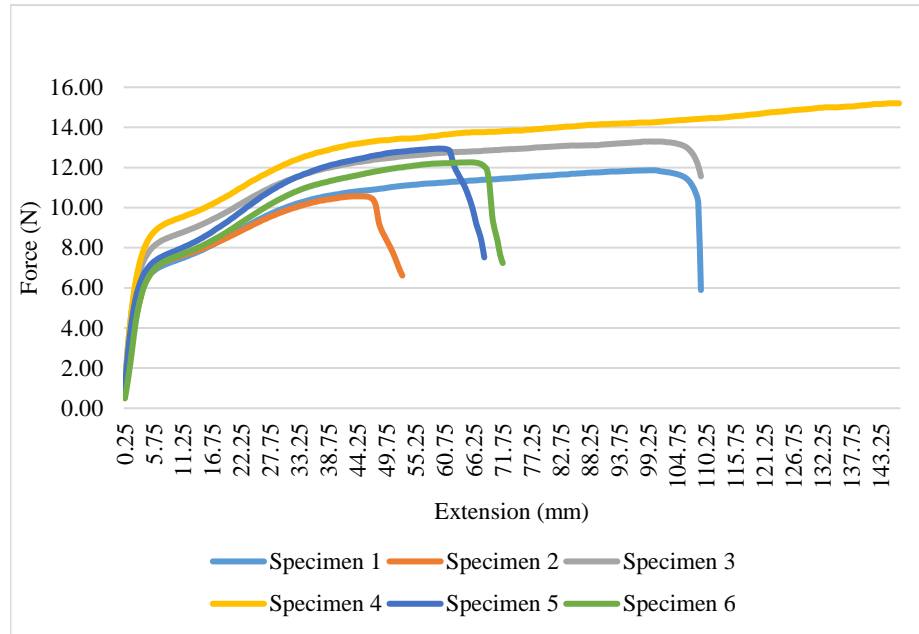


Fig. 46. Force v/s extension graph of RHDPE A15

Table 8. Results of RHDPE A15 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	11.86	197.8	218.5	0.3500	0.2625
2	10.86	86.3	105.2	8.75	6.56
3	13.31	199.3	219.0	15.06	11.30
4	15.20	289.2	294.0	20.27	15.20
5	12.95	118.2	137.0	9.56	7.17
6	12.26	130.2	143.3	9.60	7.20
Mean	12.69	170.1	186.1	10.60	7.95
Std. Dev	1.558	73.6	70.1	6.69	5.02

RHDPE A30 material graph of force v/s extension is shown in Fig. 47. This material has little different extension values. Considering all the values, the maximum force that the material RHDPE A-30 can withstand is 11.79 N. The material can be extended to about 60mm to 100mm from the initial size. The material RHDPE A-30 has the elastic region up to 9 N after this; there is deformation. The average stress at which the material RHDPE A-30 can break is 12.16 MPa, and the force is 9.12 N.

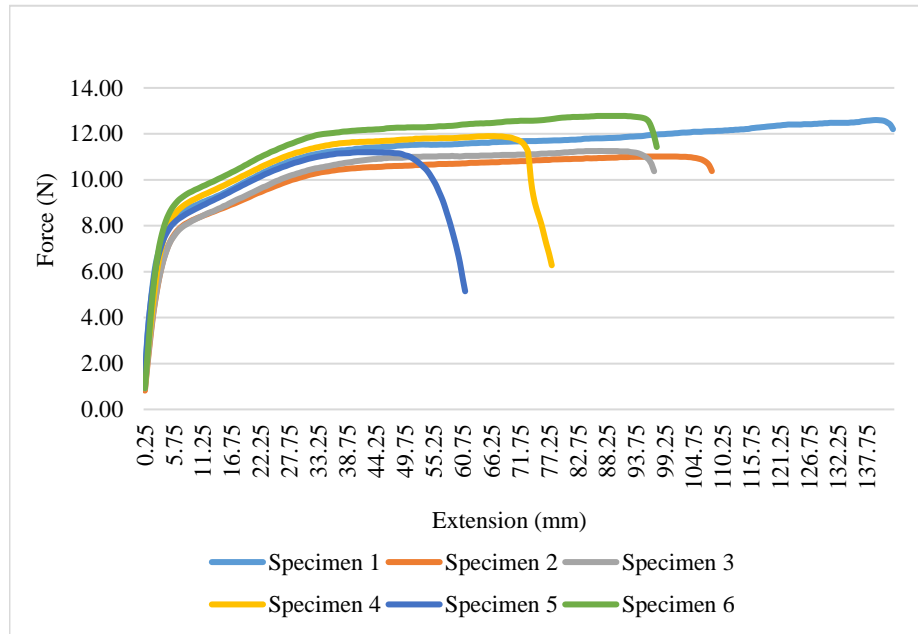


Fig. 47. Force v/s extension graph of RHDPE A30

Table 9. Results of RHDPE A30 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	12.60	277.8	285.9	16.16	12.12
2	11.01	191.3	217.0	13.65	10.24
3	11.26	173.8	194.8	13.60	10.20
4	11.90	128.3	156.0	8.02	6.01
5	11.20	80.7	122.9	6.55	4.913
6	12.78	172.2	195.6	14.96	11.22
Mean	11.79	170.7	195.4	12.16	9.12
Std. Dev	0.759	66.0	55.6	3.918	2.939

Fig. 48 shows the graph of the force v/s extension of the material RHDPE A50. 13.03 N is the average force up to which the material RHDPE A50 can hold. The material size at the start of the experiment was 50 mm, and after the test, the material has extended up to 60-140 mm. The material HDPE A50 has an elastic region up to 9.8 N where it can regain its original shape and size after this point; there is deformation as there is an increase in load. The stress at which the material can break is 8.47 MPa, and the force is 6.35 N.

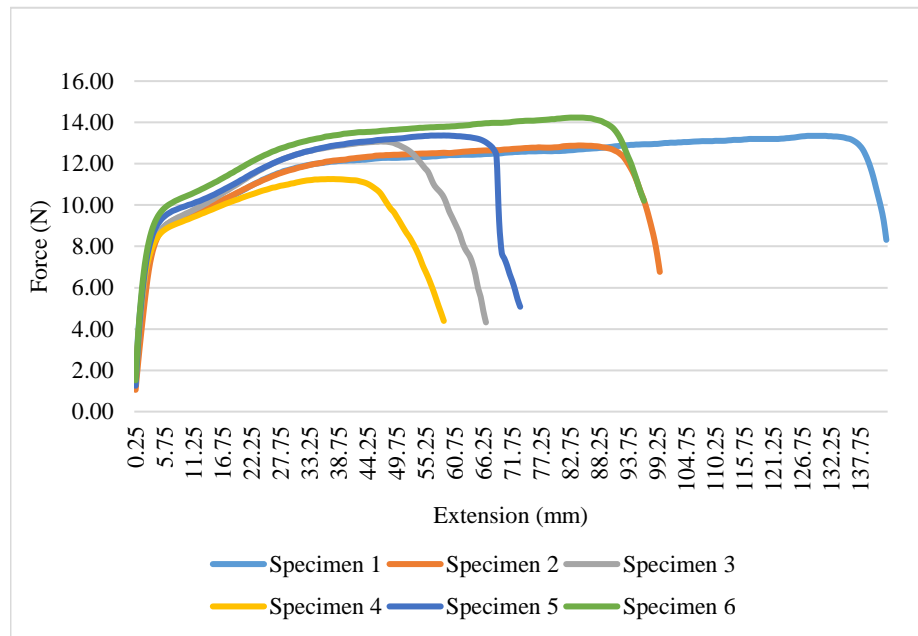


Fig. 48. Force v/s extension graph of RHDPE A50

Table 10. Results of RHDPE A50 tensile strength, Maximum Force, Elongation

Specimen No	Max Force N	Elongation at Max %	Elongation %	Stress at break MPa	Force at break N
1	13.35	255.2	286.0	10.68	8.01
2	12.89	167.8	199.8	8.60	6.45
3	13.08	93.0	133.1	5.76	4.320
4	11.26	72.6	117.8	5.55	4.163
5	13.38	115.8	146.3	6.74	5.06
6	14.24	164.6	193.4	13.48	10.11
Mean	13.03	144.8	179.4	8.47	6.35
Std. Dev	0.982	66.1	61.7	3.126	2.345

The average force of each material was calculated, and the graphs were plotted for force and extension. Fig. 49 shows the graph of materials HDPE, HDPE A15, HDPE A30, HDPE A50. Fig. 50 shows the graph of materials RHDPE, RHDPE A15, RHDPE A30, RHDPE A50. Comparing the results of HDPE materials, it is observed that virgin HDPE has a more elastic region than HDPE A15, HDPE A30, HDPE A50. In the case of recycled HDPE materials, RHDPE A50 has a more elastic region than RHDPE, RHDPE A15, and RHDPE A50.

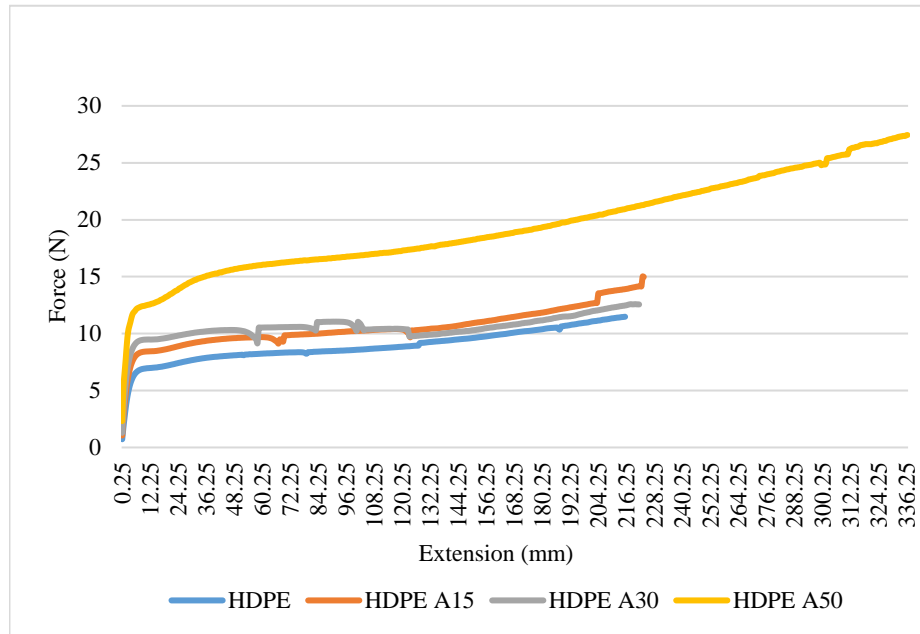


Fig. 49. Force v/s extension graph for HDPE

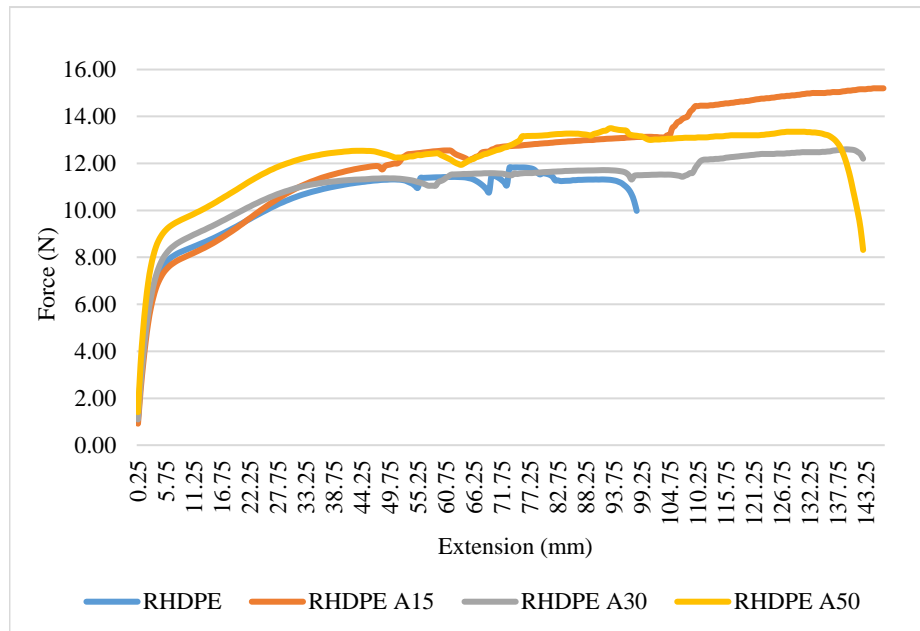


Fig. 50. Force v/s extension graph of RHDPE

4. Managerial points

From the last decades, there is an increase in the population of the world; eventually, there is an increase in the consumption of plastics [28]. Plastics have numerous benefits which have widened their use and these involve breakage and leakage resistance, flexibility in shapes and sizes, and reusing of plastics for other purposes. Nevertheless, the durability of plastic which is an advantage has also become its drawback because when it is disposed of much of them is not biodegradable and prevail in the environment for a long time [29]. Most of the plastics like HDPE are non-biodegradable and they take centuries to decompose, so it will be good if the bags and containers like items should be recycled and used again.

The markets are limited but growing for recycled plastics, the applications of the recycled material change and will influence the overall environmental benefits and economics of recycling [30]. Recycling of plastics reduces the landfill space, recycling 1 ton of plastic will save 7.4 cubic yards of landfill space. It is known that huge amount of plastic ends up straight in the environment, that breaks down into smaller pieces, pollutes soil and water, and adds to the ocean's Great Garbage Patches [31].

4.1. Environmental aspects of HDPE

The global production of waste generated from different plastics is displayed in Fig. 51. It is observed from the figure that HDPE is the third-largest plastic waste produced in the packaging sector and hold significant shares in the other sectors. It also describes, in a way, the global benefit different plastics have produced as waste also describes the different use of the plastics. HDPE is used as the largest material (in terms of mass) used for packing and other applications. Therefore, it has found its use in different areas such as plastic bags, packing of food, chemicals, goods, and clothing and have contributed tremendously to the growth of the society.

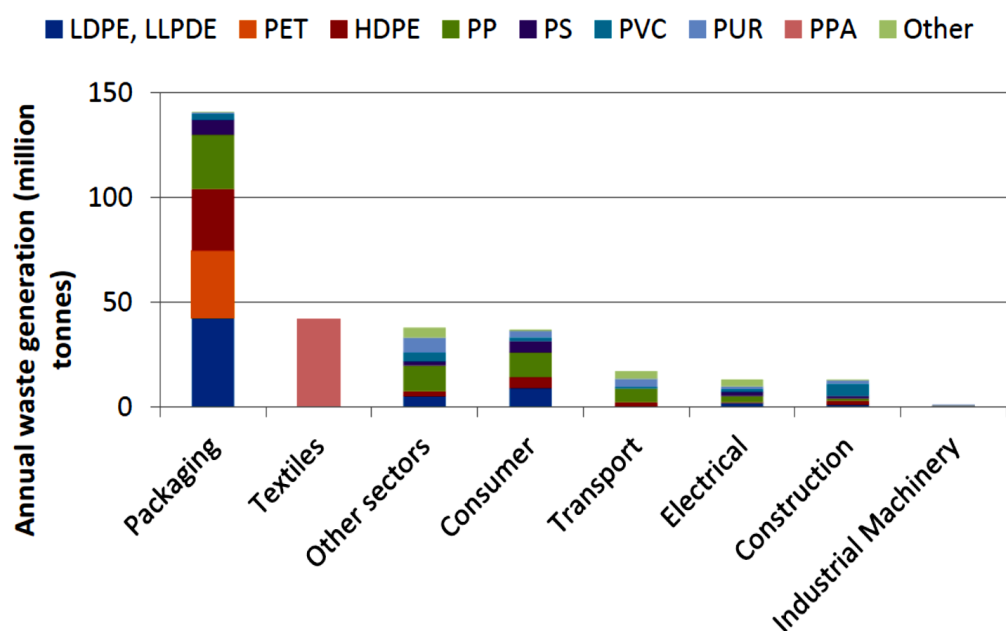


Fig. 51. Share of different plastic wastes generated globally [32]

This growth has come at a price, which is the environmental side effects of the production of HDPE. Therefore, the emission of greenhouse gases, particulate matter, and microplastics to the water bodies are some of the environmental harms caused by the HDPE, There is a contribution of the production, processing, and transportation of HDPE to the different forms of environmental damage [33]. For example, in the contribution towards carbon dioxide production, the percentage contribution of raw material production, blow moulding manufacturing process, and the transportation of different forms of HDPE contribute to different percentage. Similarly, the contribution of same factors are chlorofluorocarbon production (which depletes ozone layer), photochemical ozone creation (which is harmful for environment), sulphur dioxide production (which results in acid rain), and discharge of nitrogenous substances to the environment (which contributes to unnecessary algae and weed production in water bodies).

4.2. Environmental effects of recycled HDPE (RHDPE)

HDPE is an easy polymer to recycle, so it is accepted by many recycling centres in the world. To process HDPE products, most of the recycling companies collect them and take them to larger facilities. HDPE is converted back into pellets, which can be then used in manufacturing. As there are chances of contamination of other types of plastics during recycling, sink float separation, and Near-Infrared Radiation (NIR) techniques are used for separation. The specific density of HDPE ranges from 0.93 to 0.97 g/cm³. This density is much lower than that of PET, which is 1.43 to 1.45 g/cm³, so these polymers HDPE and PET can be differentiated by sink-float separation but, HDPE has density similar to polypropylene (PP), so the sink-float separation is difficult to use but to separate these polymers Near-Infrared Radiation (NIR) techniques can be used.

Though recycling is a cost-effective and process to manage waste, the quantity of the recyclable material can be reduced as there is financial, energy, and environmental cost involved in recycling a quantity of HDPE, which can be saved by managing the waste and taking simple steps. For example, if the milk bottles are washed out thoroughly, they can be reused. Similarly, carrier bags can also be reused during shopping. Some of the supermarkets also have collecting areas to recycle the used carrier bags. An identification code is given to different polymers to help in the separation process of plastics at the recycling stage. This code is known as a resin code and 2 is the code of high-density polyethylene is '2'.

HDPE has a huge worldwide market with its volume around 30million tons per year. Amount of plastic used in plastic bags is lessen by almost 70 percent from last twenty years, the amount of plastic used in plastic bags has been reduced by almost 70 %. Such reduction has been made possible by the introduction to the use of recycled bags or reusable bags. However, HDPE is used to produce most of the bags. Besides, there is a huge market for HDPE products in China and India caused by the improved standards of living and a higher demand for HDPE cables and pipes owing to fast-growing industries.

HDPE can take hundreds of years to decompose, as they are not biodegradable. So, it is vitally important to recycle these bags and containers, so they are used again. It is more economical to manufacture a product from recycled HDPE than 'virgin' plastic. Like numerous polymers, HDPE is made by using a substantial amount of fossil fuels. To manufacture 1 kg of HDPE, 1.75 kg of oil is used.

When the plastic products are produced from recycled HDPE, there are clear benefits as compared to plastic production using virgin polymers. The leading environmental benefit is that much of the energy is saved by avoiding the processes of oil refining and polymerization of monomers. Approximately, they account for over 95% of the total energy consumed in HDPE production. Recycling also saves CO₂. On average, it saves 1.5 tons of CO₂ equivalent per ton of HDPE films. However, the environmental gains from recycling compared with landfill and incineration are dependent on the level of contamination of the recovered films to a high degree. Mainly, the process of removing contamination through hot washing of HDPE films can be energy-intensive, although some lifecycle assessment analysis suggests that net CO₂ benefits remain.

4.3. Economic aspects of HDPE and RHDPE production

An estimated order of the magnitude of energy per unit mass required to produce virgin and recycled plastics is shown in Fig. 52. The energy (which is the main elements constituting the cost of production) required to produce RHDPE is far less (around one-eighth) than the virgin HDPE. As the raw material needs to be transported to respective facilities for recycling, so there is a cost of transportation involved, which is shown in the recycled plastic bar in Fig. 52.

There are two main economic drivers that affect the practical benefits of HDPE recycling. Firstly, the recycled HDPE cost comparing with a virgin HDPE and secondly, the recycling cost as compared to the alternatives of disposal. There are some other issues too, which are related to variations in the quality and quantity of recycled HDPE compared with virgin HDPE. Insufficient information about the recycled HDPE availability, its quality and fitness for applications, can also discourage the use of recycled material.

In the past, landfill or incineration were the main methods of waste disposal. Costs of landfill vary greatly among the regions according to the fundamental geology and land-use patterns and can affect the growth of recycling as an alternative disposal way. For example, In Japan, because of the hard nature of the underlying volcanic bedrock the excavation required for landfill is expensive, while in the Netherlands, it is expensive because of permeability from the sea. High costs of disposal are an economic motivation towards either recycling or energy recovery.

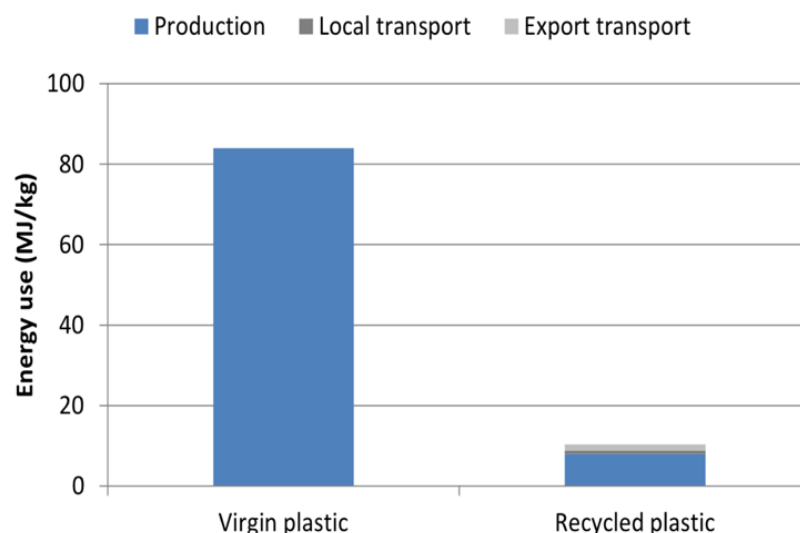


Fig. 52. Comparison of energy required to produce virgin and recycled plastic per unit mass [34]

Eight samples of HDPE and RHDPE were studied in different compositions. As both chemicals are mostly the same, they present similar environmental challenges. Recycling is a preferred way of handling and reusing the HDPE, which saves energy and cost by replacing the need for virgin HDPE for a given product. Therefore, according to environmental and cost perspective, the use of RHDPE is preferred over virgin HDPE.

Conclusions

In this paper, the influence of additives in HDPE and RHDPE surface tension and ink adhesion was observed by performing some tasks. One of the reasons to use additives is to increase the impact on the environment and use more recycled material.

1. The contact angle for all the eight materials of HDPE and RHDPE was measured. It is observed that for both HDPE materials contact angle for printing sides is around 28° to 33° and non-printing sides are around 39° to 51° , comparing all the HDPE materials HDPE A15 has a lower contact angle of 28° for printing side and 39° for the non-printing side. RHDPE materials contact angle for printing sides is around 29° to 37° and non-printing sides are 40° to 44° , comparing all the RHDPE materials RHDPE A50 has a lower contact angle of 29° for printing side and 40° for the non-printing side.
2. In the adhesion test with a measured force, it is observed that RHDPE has good adhesion property than HDPE. The range of RHDPE materials is from 1.9 N/cm to 2.19 N/cm, and HDPE materials are 1 N/cm to 1.5 N/cm. RHDPE A50 requires the force of 2.19 N/cm which is highest among all the materials.
3. In the adhesion test with the visual inspection, which was done by Tesa 4965 tape, there was a delamination of ink on some materials. Comparing HDPE and RHDPE materials, it is seen that flaking/delamination of ink is twice greater in HDPE materials than in RHDPE materials so it can be inferred that RHDPE materials have good adhesion property.
4. SEM images of materials were taken to clearly understand the delamination of ink from the materials. Images show that RHDPE materials have less delamination/removal of ink than HDPE materials. Some images of HDPE and RHDPE show uneven surfaces that might happen while manufacturing.
5. FTIR analysis was performed to confirm all the materials, their functional group and wavenumbers with the HDPE IR spectrum. All the materials HDPE, HDPE A15, HDPE A30, HDPE A50 including RHDPE, RHDPE A15, RHDPE A30, RHDPE A50 IR spectrums show the same functional groups as HDPE without any major differences. The additives present in the materials did not affect the functional groups of the materials.
6. The tensile test of all the eight materials was done, and the maximum force of each material with the extension was calculated. In the HDPE materials, it is seen that HDPE A50 has maximum elastic region and the maximum force it can withstand is 25.02 N. In RHDPE materials RHDPE A50 material has maximum elastic region and the maximum force it can withstand is 13.03 N.

List of References

1. CHARLES, J. Qualitative Analysis of High-Density Polyethylene using FTIR Spectroscopy. *Asian Journal of Chemistry*, 2009, vol. 21, no. 6. pp. 4477.
2. REIS, J.M.L., PACHECO, L.J. and DA COSTA MATTOS, H.S. *Tensile Behavior of Post-Consumer Recycled High-Density Polyethylene At different Strain Rates.* , April 2013, 2013 Available from: <http://www.sciencedirect.com/science/article/pii/S0142941812002231> ISBN 0142-9418. DOI <https://doi.org/10.1016/j.polymertesting.2012.11.007>.
3. OBLAK, P., et al. *RETRACTED: Mechanical Properties of Extensively Recycled High Density Polyethylene (HDPE).* , 2016, 2016 Available from: <http://www.sciencedirect.com/science/article/pii/S2214785316002601> ISBN 2214-7853. DOI <https://doi.org/10.1016/j.matpr.2016.03.055>.
4. MILIŪNAS, V., et al. Detection of the Surface Defects in Thin Polymeric Films using Projection Moiré. *Journal of Measurements in Engineering*, 2017, vol. 5, no. 2. pp. 106-114 ISSN 2335-2124.
5. FÁVARO, S.L., RUBIRA, A.F., MUNIZ, E.C. and RADOVANOVIC, E. *Surface Modification of HDPE, PP, and PET Films with KMnO4/HCl Solutions.* , July 2007, 2007 Available from: <http://www.sciencedirect.com/science/article/pii/S014139100700136X> ISBN 0141-3910. DOI <https://doi.org/10.1016/j.polymdegradstab.2007.04.005>.
6. HAHLADAKIS, J.N., et al. *An Overview of Chemical Additives Present in Plastics: Migration, Release, Fate and Environmental Impact during their use, Disposal and Recycling.* , 15 February 2018, 2018 Available from: <http://www.sciencedirect.com/science/article/pii/S030438941730763X> ISBN 0304-3894. DOI <https://doi.org/10.1016/j.jhazmat.2017.10.014>.
7. SHAMIRI, A., et al. The Influence of Ziegler-Natta and Metallocene Catalysts on Polyolefin Structure, Properties, and Processing Ability. *Materials*, 2014, vol. 7, no. 7. pp. 5069-5108.
8. KAMINSKY, W. and LABAN, A. *Metallocene Catalysis.* , 20 December 2001, 2001 Available from: <http://www.sciencedirect.com/science/article/pii/S0926860X01008298> ISBN 0926-860X. DOI [https://doi.org/10.1016/S0926-860X\(01\)00829-8](https://doi.org/10.1016/S0926-860X(01)00829-8).
9. SIDDIQUE, R., KHATIB, J. and KAUR, I. *Use of Recycled Plastic in Concrete: A Review.* , 2008, 2008 Available from: <http://www.sciencedirect.com/science/article/pii/S0956053X07003054> ISBN 0956-053X. DOI <https://doi.org/10.1016/j.wasman.2007.09.011>.
10. MIU, E.V., FOX, A.J., JUBB, S.H. and WAKABAYASHI, K. Morphology and Toughness Enhancements in Recycled High-density Polyethylene (rHDPE) Via Solid-state Shear Pulverization (SSSP) and Solid-state/Melt Extrusion (SSME). *Journal of Applied Polymer Science*, 2016, vol. 133, no. 10. pp. n/a-n/a ISSN 0021-8995.
11. A. RANOWSKY.CSC Scientific Company,Ic. 04-04, 2016 Available from:<https://www.cscscientific.com/csc-scientific-blog/how-does-contact-angle-relate-to-surface-tension>.
12. [Flexo Surface Tension, Surface Energy, and Wettability]: Luminite. 25-04, 2017 [viewed 05-04-2019]. Available from: <https://blog.luminite.com/blog/flexo-surface-tension-surface-energy-and-wettability>.

13. PG2 / PG3 User's Manual 3.1a /ENG. [The Pocket Goniometer].Sweden: Copyright FIBRO System AB. , 2005-2007.
14. RYCOBEL, N. *Pocketgoniometer PG-3*. Belgium: Rycobel group. , 2013.
15. UVPS. [Ink and Coating Handling].Chicago: U V PROCESS SUPPLY, INC. , 2019 Available from:<https://www.uvprocess.com/>.
16. GULMINE, J.V., JANISSEK, P.R., HEISE, H.M. and AKCELRUD, L. Polyethylene Characterization by FTIR. *Polymer Testing*, 2002, vol. 21, no. 5. pp. 557-563 ISSN 0142-9418.
17. BERGSTRÖM, J. *Mechanics of Solid Polymers* 1st ed. Amsterdam: William Andrew Publishing, 2015 2 - *Experimental Characterization Techniques*, pp. 19-114.
18. CRAN, M.J. and BIGGER, S.W. Effect of Metallocene-Catalyzed Polyethylene on the Physicomechanical Properties of Blends with High-Density Polyethylene Or Low-Density Polyethylene. *Polymer-Plastics Technology and Engineering*, 2009, vol. 48, no. 3. pp. 272-279.
19. ANDREW, J. *FINAT Technical Handbook*. [Ink Adhesion].6th ed. Netherlands: Dow Corning Ltd., 2001 September.
20. *Plastics -- Determination of Tensile Properties Test Conditions for Films and Sheets (Elektroninis Išteklius)*. 2018-11-05. ed. Vilnius: Lietuvos standartizacijos departamentas, 2018.
21. Adhesives.org and Sealants.org, 2008 [viewed 21/05/2019]. Available from: <https://www.adhesives.org/adhesives-sealants/adhesives-sealants-overview/structural-design/joint-testing/non-destructive-evaluation#visual>.
22. MORAIS, J.A.d., GADIOLI, R. and DE PAOLI, M. Curaua Fiber Reinforced High-Density Polyethylene Composites: Effect of Impact Modifier and Fiber Loading. *Polímeros*, 2016, vol. 26, no. 2. pp. 115-122 ISSN 1678-5169; 01041428.
23. PETROVICH, J. FTIR and DSC of Polymer Films used for Packaging: LLDPE, PP and PVDC. *SHAPE American High School*, 2015. pp. 1-13.
24. D'AMELIA, R.P., GENTILE, S., NIRODE, W.F. and HUANG, L. Quantitative Analysis of Copolymers and Blends of Polyvinyl Acetate (PVAc) using Fourier Transform Infrared Spectroscopy (FTIR) and Elemental Analysis (EA). *World Journal of Chemical Education*, 2016, vol. 4, no. 2. pp. 25-31.
25. JUNG, M.R., et al. Validation of ATR FT-IR to Identify Polymers of Plastic Marine Debris, Including those Ingested by Marine Organisms. *Marine Pollution Bulletin*, 2018, vol. 127. pp. 704-716 ISSN 0025-326X.
26. Eman Mousa Alhajji. *Fourier Transform Infrared Spectroscopy: Low Density Polyethylene, High Density Polyethylene, Polypropylene and Polystyrene*. North Carolina State University: 3/13, 2016.
27. CHARLES, J. Qualitative Analysis of High Density Polyethylene using FTIR Spectroscopy. *Asian Journal of Chemistry*, 2009, vol. 21, no. 6. pp. 4477.

28. ACHILIAS, D.S., et al. Chemical Recycling of Plastic Wastes made from Polyethylene (LDPE and HDPE) and Polypropylene (PP). *Journal of Hazardous Materials*, 2007, vol. 149, no. 3. pp. 536-542 ISSN 0304-3894.
29. *Solid Waste Recycling and Processing*. Elsevier Inc, 2014 ISBN 978-1-4557-3192-3; 978-0-323-22127-6.
30. SHEN, L. and WORRELL, E. *Handbook of Recycling*. Elsevier Inc, 2014 ISBN 978-0-12-396459-5; 978-0-12-396506-6.
31. L. WEST. *Why Recycle Plastics?* ThoughtCo. February 23, 2018 Available from: <https://www.thoughtco.com/benefits-of-plastic-recycling-1204142?print>.
32. OECD. *Improving Plastics Management IS 12.* , 2018 DOI <https://doi.org/https://doi.org/10.1787/c5f7c448-en>.
33. MERMERTAŞ, M. and BABUNA, F.G. Recycling and Reuse Approaches for Better Sustainability Springer, 2019 *Life Cycle Environmental Impact Analysis of HDPE Packaging Materials for Different Disposal Options*, pp. 55-61.
34. GEYER, R., JAMBECK, J.R. and LAW, K.L. Production, use, and Fate of all Plastics Ever Made. *Science Advances*, 2017, vol. 3, no. 7. pp. e1700782.

Appendices

Appendix 1. Certificate of participation in International Young Scientists Conference



Appendix 2. Abstract for participating in upcoming 7th International Conference IRF2020- INTEGRITY-RELIABILITY-FAILURE

An Evaluation of Adhesion and Surface Wettability of HDPE Films with Additives

Bhagyalaxmi Shivangouda Patil^{1(*)}, Vaidas Bivainis¹, Ramūnas Česnavičius¹, Nijolė Buškuvienė¹

¹KTU/MIDF, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Kaunas, Lithuania

(*) *Email*: bhagyalaxmi.patil@ktu.lt, bhagyalaxmi.patil6@gmail.com

ABSTRACT

High-Density Polyethylene is a lightweight and resistant to most factors, therefore it is very versatile and commonly used in worldwide industry. HDPE plastics are non-biodegradable, so recycling this type of plastics has gained a great attention. Manufacturing and using recycled plastic reduce landfills, pollution and save resources. The main objective of the work is to compare recycled (RHDPE) and not recycled HDPE films and evaluate the influence of additives (mix of plastic waste) on film's main printability properties such as surface wetting and adhesion strength.

Keywords: HDPE, Recycled HDPE, additives, wetting angle, ink adhesion, SEM images.

INTRODUCTION

The world's consumption of HDPE is increasing every year because of its inherent properties and wide range of applications. Due to special additives life of recycled polymers can be prolonged and properties can be enhanced (Shamiri et al., 2014). To determine the effects of the additives it becomes necessary to understand the main properties of films - printability, ink adhesion and wetting angle (Ramirez et al., 2018). Wettability becomes the main parameter to understand the interactions between the solid surface and liquid drop (Baba et al., 2015). Poor adhesion is a common problem of various polymers. In order to improve it - surface treatment is necessary. Materials used for the presented research are produced by a Lithuanian film extrusion and printing Company.

RESULTS AND CONCLUSIONS

HDPE (density – 0.976 g/cm³) and RHDPE (density – 0.952 g/cm³) were used in this research (Table 1). The printing side of the films was activated and for the flexographic printing the solvent black ink was used.

The film thickness was measured with thickness gauge IKG and ranges between 33.4-46.8 μm. To measure the wetting angle of the films - The Pocket Goniometer PG-2 was used. From the values, it is observed that the HDPE film wetting angle was about 26.15% higher (correspondingly lower adhesive strength) than the RHDPE. It can also be said that the effect of additives on the films, surface wetting angle is negligible.

For the basic manual ink adhesion test, Tesa 4965 tape was used with width 12 mm and initial adhesion to steel – 11.5 N/cm. For the advanced ink adhesion test (180° peeling at 300 mm/min. speed), Thwing-Albert 225-1 Friction/Peel Tester and Tesa 4104 tape were used. Tape width was 25 mm and the initial adhesion to steel – 3.6 N/cm. It was found that the adhesion strength of RHDPE was approximately 60.62% higher than HDPE.

Table 1. Description of materials, thickness, wetting angle of printing side and ink adhesion strength

No.	Film description and abbreviation	Film thickness, μm	Film printing side wetting angle, degree	Ink adhesion strength, N/cm
1	High Density Polyethylene (HDPE)	33.4 \pm 1.02 ^{**}	39.22 \pm 0.88	1.35 \pm 0.22
2	High Density Polyethylene with 15% additive (HDPE A15)	44.4 \pm 1.68	38.04 \pm 1.64	1.14 \pm 0.09
3	High Density Polyethylene with 30% additive (HDPE A30)	46.8 \pm 2.61	44.61 \pm 2.01	1.02 \pm 0.09
4	High Density Polyethylene with 50% additive (HDPE A50)	43.0 \pm 2.64	38.56 \pm 1.74	1.50 \pm 0.11
5	Recycled High Density Polyethylene (RHDPE)	40.4 \pm 1.01	30.55 \pm 1.36	2.06 \pm 0.09
6	Recycled High Density Polyethylene with 15% additive (RHDPE A15)	34.6 \pm 1.22	33.20 \pm 1.47	1.93 \pm 0.12
7	Recycled High Density Polyethylene with 30% additive (RHDPE A30)	40.8 \pm 1.64	34.33 \pm 1.70	2.06 \pm 0.06
8	Recycled High Density Polyethylene with 50% additive (RHDPE A50)	38.9 \pm 1.96	29.28 \pm 1.88	2.19 \pm 0.14

**The average of minimum 6 specimen's measurements and the confidence level (95.0%)

SEM images presented in Figure 1 shows that HDPE materials have delamination/removal of flexographic inks of nearly 50% and RHDPE materials show the removal of inks nearly 5%.

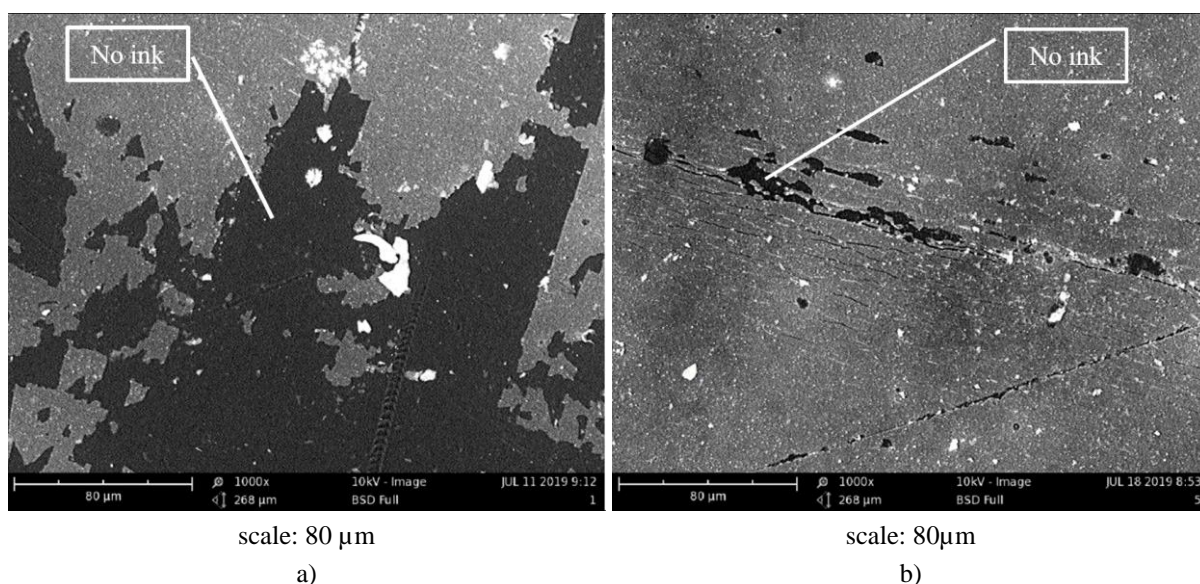


Fig. 1 – Comparison of HDPE (a) and RHDPE (a) printed with solvent flexographic inks surface view after hand delamination test. Black areas represent ink delamination areas

Also, the investigation of FTIR analysis by Nicolet iS10 device gives the IR spectrum by which the materials can be confirmed that they belong to polyethylene.

REFERENCES

- [1]-Shamiri A, Chakrabarti MH, Jahan S, Hussain MA, Kaminsky W, Aravind PV, Yehye WA. The Influence of Ziegler-Natta and Metallocene Catalysts on Polyolefin Structure, Properties, and Processing Ability. *Materials*, 2014, 7, p.5069-5108.
- [2]-Ramirez C, and Tumolva TP. Analysis and Optimization of Water-Based Printing Ink Formulations for Polyethylene Films. *Applied Adhesion Science*, 2018, 6, p.1-21.
- [3]-Baba E, Cansoy C, and Zayim E. Optical and Wettability Properties of Polymers with Varying Surface Energies. *Applied Surface Science*, 2015, 350, p.115-120.