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Study of Ethylene 1-Hexene Addition on Elongation, Tensile Strength and Cling Values of Stretch Wrap Plastics

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ABSTRACT

Stretch wrap plastic is a very important packaging material on a variety of scales. It provides flexibility, strength, and transparency that make it indispensable for packaging goods efficiently. This research aims to investigate the effect of stretch wrap plastic thickness on its mechanical properties and analyze the impact of ethylene 1-hexene addition on these properties. The research was conducted using stretch wrap plastic samples made from linear low-density polyethylene (LLDPE) with varying thickness and percentage of ethylene 1-hexene addition. The test method involved elongation, tensile strength, and cling testing using a Universal Testing Machine (UTM). The results showed that the thickness of stretch wrap plastic affects its mechanical properties. The thicker the plastic, the higher the elongation and tensile strength values, while the stickiness tends to decrease. The optimal thickness of stretch wrap plastic is 20 µm. The addition of ethylene 1-hexene also has a positive effect on the elongation and tensile strength properties, with the optimal percentage of addition at 55% with respect to components such as density and melt index.

1. Introduction

Plastic is one of the materials that we can find in almost every item [1]. Plastics are made from hydrocarbons, which go through a refining process into ethane and propane, then ethane and propane are broken down or cracked in a hot furnace, then ethylene and propylene will be formed in this process. After that, it is further processed with additional catalysts into plastic polymers until it becomes small pellets called plastic ore. The plastic ore is then further processed into plastic finished products. One of the plastic finished products that is currently widely used is plastic stretch film [2].

Stretch wrap plastic has become a very important packaging material ranging from household scale to industrial scale. Used to wrap food on a plate to avoid insect bites. While on an industrial scale, this plastic is used to wrap industrial goods on pallets for shipping using cargo so that they are not dirty, damaged, or easily collapsed while traveling, and so on [3]. The advantages of flexibility, strength, and transparency make stretch wrap plastic a top choice for protecting and packaging goods efficiently. However, to meet the demands of increasingly complex and diverse applications, research continues to improve the mechanical properties and performance of stretch wrap plastics [4]. The raw material for plastic finished products, plastic ore, is available in a wide variety of types in the market. These include plastic ores such as PE/polyethylene, PP/polypropylene, ABS/Acrylonitrile butadiene styrene, etc. Some types such as PE/polyethylene have further variations such as LD

PE/low-density polyethylene, HD PE/high-density polyethylene, and LLDPE/linear low-density polyethylene. These various types are known to have different characteristics [5].

Polyethylene, as a type of thermoplastic polymer, has various variants that stand out based on their molecular structure and physical properties. First, High-Density Polyethylene (HDPE) stands out with its tight and uniform molecular structure, providing high strength and hardness as well as chemical resistance, making it ideal for drinking water bottles and pipes. Meanwhile, Low-Density Polyethylene (LDPE), with a looser molecular structure, offers elastic and flexible properties, suitable for shopping bags and bottle caps. Linear Low-Density Polyethylene (LLDPE), having a linear molecular structure and short branches, provides good strength and elasticity, making it a superior choice for stretch films and plastic bags. Finally, Medium-Density Polyethylene (MDPE) occupies the middle position with medium strength and hardness, suitable for water and gas pipes, as well as applications that require a compromise between HDPE and LDPE. These four types of polyethylene provide diverse solutions depending on the specific needs of various industries and applications [6].

One interesting approach is the combination of plastic ores, such as the addition of ethylene 1-hexene, which can modify the mechanical properties of plastics. Ethylene 1-hexene is a compound that can add flexibility and elasticity to plastic materials. Previous research has shown that the addition of this kind of material can produce significant changes in the mechanical properties of plastics, affecting tensile strength, strain, and tear strength [7].

In this context, this study aims to investigate the effect of stretch wrap plastic thickness and the addition of ethylene-1-hexene additive on the elongation, tensile strength, and cling values of stretch wrap plastic. An in-depth analysis of these changes is expected to provide valuable insights in the development of superior stretch-wrap plastic materials. Further understanding of how these materials interact with the plastic matrix may open the door for the application of this technology in the development of more effective and environmentally friendly packaging products.

Through careful experimentation and detailed analysis, this research is expected to contribute significantly to our understanding of the role of ethylene-1-hexene as an additive in improving the mechanical properties of stretch wrap plastics. The results of this research are expected to provide practical guidance for the packaging industry in selecting optimal raw materials and production processes, as the demand for better packaging performance continues to grow.

2. Research Methodology

2.1. Materials

The plastic stretch wrap samples used in this study are processed from plastic ore materials of the type LLDPE (Linear Low-Density Polyethylene), Ethylene-1-Hexene (EH), and additional adhesive additives of the type polyisobutylene / PIB. Raw material characteristics are shown in Table 1. The plastic ore material is processed using a Cast-line extruder type machine into plastic stretch wrap which will then be tested and the results will be analyzed in this study.

Table 1. Characteristics of raw materials

Parameters	LLDPE	EH 1	EH 2	Polyisobutylene
Density/Specific Gravity (g/cm^3)	0.92	0.92	0.92	-
Melting Temperatur (°C)	121.0	114.0	114.00	-
Melt Index (190°C/2.16 kg)	2.00	3.50	1.00	-

2.2. Preparation of Stretch Wrap Plastic

The following are the stages of making and testing the stretch wrap plastic used in this study:

a) Stretch wrap plastic, which is the sample in this study, is processed from several types of plastic ores. Some samples were processed from one type of plastic ore, namely LLDPE with added adhesive additives, and some samples were processed from LLDPE plus Ethylene-1-Hexene with added adhesive additives. The plastic mixture is blended in the extruder system section of the cast extruder line machine. The percentage of plastic ore mixture in each sample is presented in Table 2. Sample code A is a sample without a mixture of ethylene-1-hexene, while sample code B is a sample with a mixture of ethylene-1-hexene. Meanwhile, the code number next to the letter is a variation in the percentage of ingredients.

Table 2. Composition of research material

Sample	Thickness (μm)	Polyisobutylene (%)	LLDPE (%)	Ethylene -1-Hexene (%)
A1	17.00	1.50	98.50	0.00
A2	20.00	1.50	98.50	0.00
B1	15.00	1.50	56.38	42.10
B2	20.00	1.50	43.50	42.00 (EH1) ; 13.00 (EH2)
B3	20.00	1.50	20.18	78.32

b) The plastic ore material is processed using a Cast-line extruder type machine into plastic stretch wrap as shown in Fig. 1, which will then be used as a sample in this study. The plastic ore is placed in the hopper on the machine and then enters the extruder system on the machine where several types of plastic are mixed at high temperatures. The next stage is molding the melted plastic mixture into thin sheets of stretch film on the dies of the machine. The settings on the machine when making samples for this research include, the melting temperature in the extruder is 318^{o} C, while the cooling roll temperature in chill roll is 20^{o} C. The speed of the extruder screw rotates at 150 rpm with extruder torque is 80.4 nm. The primary roll speed is 315.4 rpm.


(a)


(b)

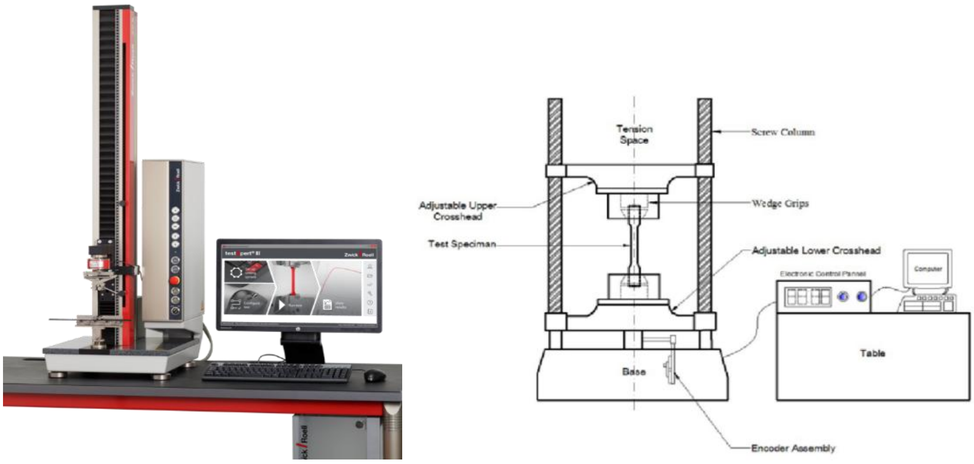
Fig. 1. Plastic ore as stretch film material: (a) before and (b) after the production process [1]

c) Each sample was then cut into 15 x 15 mm specimens. The specimen was then inserted into a UTM (Universal Testing Machine) machine which in this study used the Zwick Roell brand. The machine is connected to a computer to see the value of the test results (Fig. 2).
d) After the number of results on the PC monitor layer comes out, it is then recorded for further analysis in this study. This research focuses on the analysis of the 3 indicators tested, namely the tensile strength test, elongation, and cling. All three were tested with a UTM machine.

2.3 Measurement Method

2.3.1 Elongation Test

In this study, the Elongation test was conducted under the ASTM D882 method with a Universal Testing Machine (UTM). The elongation test, is done by taking a specimen from plastic stretch wrap with a width of 15 mm x 15 mm the plastic specimen is pulled until stretched, and calculated how much the plastic can stretch to the point where the plastic is torn (elongation at break). Meanwhile, the test where the plastic is pulled until it stretches, and calculated how much the plastic can stretch until the point where the plastic can no longer return to the shape as before it was stretched (elongation at yield). In this research, the elongation test uses % (percent), namely the percentage of plastic elongation from the initial plastic length.



(a) (b)

Fig. 2. Universal Testing Machine: (a) machine (b) Scheme [8]

2.3.2 Tensile Strength Test

In this investigation, the tensile strength evaluation adhered to the ASTM D882 methodology and was conducted utilizing a state-of-the-art Universal Testing Machine (UTM) from the renowned brand Zwick & Roell. The UTM apparatus is intricately linked to a sensor device that interfaces with a computer program, facilitating precise control over the machine's operations. The mechanical components, particularly the grips used for clamping and pressing the sample during testing, are driven by a motor integrated into the UTM. The test procedure involves measuring the force applied against the elongation or change in length of a stretch wrap plastic specimen. A sample, measuring 15mm x 15mm in width, is carefully positioned within the grips of the UTM machine. Subsequently, the motorized grips initiate the pulling process, gradually exerting force until the plastic undergoes a tensile break. The exerted force, quantifying the pulling effort, is then calculated, and the value is expressed in mega Pascals (MPa) in this study.

2.3.3 Cling test

The cling test in this study is under ASTM method D5458. It is a relevant measurement because two or more layers of stretch wrap are usually in contact with each other. In this study, this test was carried out using a UTM (universal test machine) brand Zwick & Roell. In this research, the cling test uses units of milli newtons (Mn).

3. Results and Discussion

3.1. Effect of Thickness on Elongation, Tensile Strength and cling properties of stretch wrap plastic

3.1.1. Effect of Thickness on Elongation Properties of Stretch Wrap Plastic

Elongation is a key parameter that reflects the flexibility and elasticity of stretch wrap materials [9]. Fig. 3 shows the effect of thickness on the elongation of stretch wrap plastic (Sample A1; A2 and sample B1; B2) for each type of elongation MD elongation and TD elongation. Machine Direction (MD) elongation refers to how much the plastic can stretch along its machine direction. It is measured by pulling the plastic sample in its machine direction and recording how much the plastic stretches before breaking. A high MD elongation indicates that the plastic is stronger and more resistant to tearing. Transverse Direction (TD) elongation refers to how much the plastic can stretch perpendicular to its machine direction. It is measured by pulling a plastic sample perpendicular to the direction of the machine and recording how much the plastic stretches before breaking. A high TD elongation indicates that the plastic is more flexible and easier to mold .

Sample A1 has an MD elongation of 410%, which means that the stretch wrap plastic produced can be pulled until its length increases by 410% from its original length. Samples A1 and A2 are stretch wrap plastic products whose raw materials do not contain ethylene-1-hexene, with differences in thickness. Sample A1 has a thickness of less than 20 µm (17 µm), while sample A2 has a thickness of 20 µm. From Fig. 3, it can be observed that for each type of elongation, the sample having a thickness of 20 µm shows lower elongation values (MD from 410 to 380 and TD from 690 to 650). This indicates that the thickness of the stretch wrap plastic has an influence on the elongation value. The thicker the plastic, the lower the elongation value. However, the most optimal result for stretch wrap plastic products is the longer one [10].

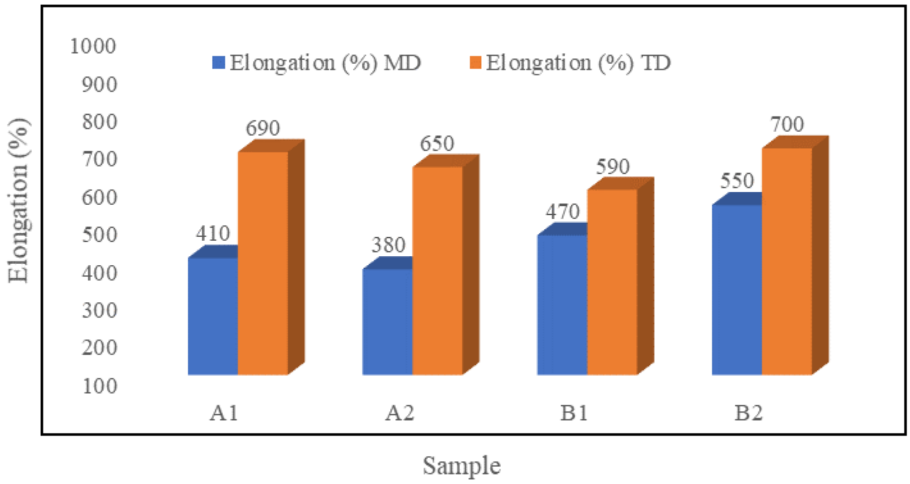


Fig. 3 Effect of Thickness on Elongation Properties of stretch wrap plastic

Furthermore, the elongation test was conducted on samples B1 and B2, where these samples are stretch wrap plastic products with the addition of ethylene-1-hexene. Sample B1 has a thickness of less than 20 µm (15 µm) and sample B2 has a thickness of 20 µm. Fig. 3 shows the percentage elongation of sample B2 is better than B1 (700% :590%). Furthermore, the elongation value of sample B2 is compared with the elongation value of sample A2, where each has the same thickness of 20 µm but a different composition (A2 no addition of ethylene-1-hexene). From Fig. 2, it is known that the value of B2 has a better elongation than A2 (700%: 690%).

3.1.2. Effect Thickness on the Tensile Strength Properties of stretch wrap plastic

Tensile strength gauges the force required to pull a material until it fractures. In the realm of plastic stretch wrap, tensile strength manifests in two primary directions: Machine Direction (MD) and Transverse Direction (TD). MD represents the strength along the machine's course, measured by guiding a distinctive plastic sample through the machine and meticulously documenting specifications for precise cutting. A heightened MD tensile strength signifies greater resilience and resistance to tearing. On the other hand, TD denotes the strength perpendicular to the machine direction. Measuring this involves positioning an intriguing plastic sample upright in line with the machine's direction, adhering to a specified note-taking style essential for subsequent precision cutting. Elevated TD tensile strength signals increased durability against tearing and delamination.

In Fig. 4, the impact of thickness on the robust pulling force of plastic stretch wrap is evident. Samples A1 and A2, with thicknesses of 17 µm and 20 µm and lacking the addition of ethylene-1-hexene, demonstrate a noticeable decline in the marked pulling force towards the Machine Direction (MD), decreasing from 32 MPa to 29 MPa. Conversely, there is an increase in the pulling force towards the Transverse Direction (TD), rising from 13.8 MPa to 16 MPa. In a thicker plastic stretch wrap, a heightened thickness results in a more substantial pull towards MD. This is attributed to the increased interlocking of polymer chains, with numerous chains aligning parallel to each other.

Additionally, molecules in thicker plastic stretch wrap exhibit a more linear orientation, leading to a stronger withdrawal moment parallel to the production direction. This observation suggests that plastics with greater thickness yield a significantly higher tensile strength, particularly in the MD.

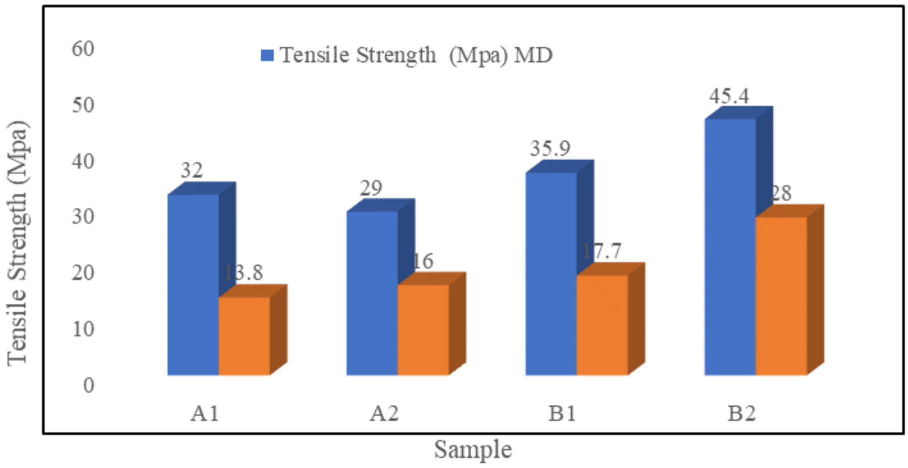


Fig. 4 Effect Thickness on the Tensile Strength Properties of stretch wrap plastic

The observed decline, evident in samples A1 to A2, is attributed to variations in LLDPE density. Notably, the lower density of LLDPE in sample A2 exerts a significant influence, resulting in a pronounced pull towards the machine direction (MD). On the other hand, samples B1 and B2, with thicknesses of 15 µm and 20 µm, exhibit a substantial increase in MD tensile strength, escalating from 35.9 MPa to 45.4 MPa. Additionally, a marked rise in transverse direction (TD) pull strength is observed, climbing from 17.7 MPa to 28 MPa. Notably, thicker samples demonstrate a higher pull strength. Fig. 4 underscores that the 20 µm thickness is optimal for both A2 and B2 samples, highlighting it as the ideal characteristic for enhancing pull strength.

3.1.3. Effect of Thickness on The Cling of Stretch Wrap Plastic

The cling of plastic *stretch wrap* is measured in milliNewtons (mN) and refers to the strength of the bond between the plastic and another surface. The higher the cling value, the stronger the bond. Fig. 5 shows the effect of thickness on the cling of plastic stretch wrap. Samples A1 and A2 are stretch-wrap plastic products without the addition of ethylene-1-hexene, with a thickness ratio of 17 µ m: 20 µ m. From Fig. 5, it is known that the highest cling is possessed by the A1 stretch wrap plastic product with a thickness of 17 µ m with an A1:A2 cling ratio of 10.4 mN: 10.2 mN. Next, samples B1 and B2 are stretch-wrap plastic products with the addition of ethylene-1-hexene with a thickness ratio of 15 µ m: 20 µ m. From Fig. 5, it is known that the sample with a lower thickness, namely B1, has a higher cling than the sample with a higher thickness, namely B2, with a bond ratio of 10.2 mN: 9.62 mN. This shows that thinner plastic stretch wrap generally has higher cling because thinner plastic sticks more easily to uneven surfaces and more easily follows surface contours.

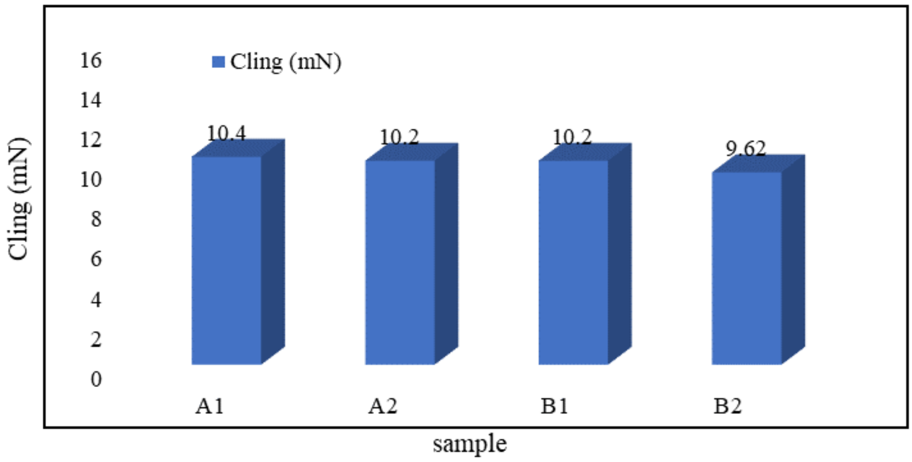


Fig. 5 Effect of thickness on the cling of stretch wrap plastic

The study results reveal that the thickness of plastic stretch wrap significantly influences its mechanical characteristics. Among the samples investigated, namely A2, B2, and B3, the most efficient thickness identified is 20 µm. This conclusion is drawn based on the optimal values observed for elongation, tensile strength, and cling at this particular thickness. However, to determine the overall optimal choice among samples A2, B2, and B3, it is essential to analyze the influence of other components present within them. Therefore, a comprehensive analysis is conducted to assess the impact of adding ethylene-1-hexene on the mechanical characteristics of plastic stretch wrap.

3.2. Effect of Ethylene 1 Hexene Addition Amount on Elongation, Tensile Strength and cling properties of stretch wrap plastic

As discussed earlier, the addition of ethylene-1-hexene significantly impacts the mechanical characteristics of the plastic stretch wrap product, influencing aspects such as elongation, tensile strength, and adhesiveness. This influence is evident in the subsequent section, where the percentage of ethylene-1-hexene addition is examined for A1 (0%), B1 (42.1%), B2 (55%), and B3 (78.32%) samples, revealing its effects on the mechanical characteristics. Detailed composition percentages of the standard material for each sample are provided in Table 1.

3.2.1. Effect of Ethylene 1 Hexene Addition Amount on Elongation properties of stretch wrap plastic

The introduction of ethylene-1-hexene into LLDPE stretch wrap plastic can yield varied effects on its elongation properties. Specifically, it tends to increase elongation in the Machine Direction (MD) due to the enhanced orientation of the polymer chain towards MD during manufacturing. Conversely, the addition of ethylene-1-hexene may decrease elongation in the Transverse Direction (TD) as it stiffens the plastic, limiting its ability to stretch in the TD.

Examining Fig. 6, it becomes evident that different percentages of ethylene-1-hexene can influence elongation in plastic stretch wrap. For instance, in sample A2 (0%), the MD and TD elongations are 380% and 650%, respectively, indicating a substantial elongation compared to the initial length. Notably, the addition of ethylene-1-hexene results in enhanced MD elongation but reduced TD elongation in samples B2 (55%) to B3 (78.32%), declining from 700% to 670%. This decline may be attributed to polymer degradation during the process, leading to shorter and more fragile polymer chains, thereby reducing TD elongation. However, the addition of ethylene-1-hexene can also improve the orientation of polymer chains, thereby increasing elongation in the MD direction. To address these considerations, it is recommended to use an ethylene-1-hexene addition percentage of around 55% for optimal results, balancing the enhancement of MD elongation while minimizing the decline in TD elongation.

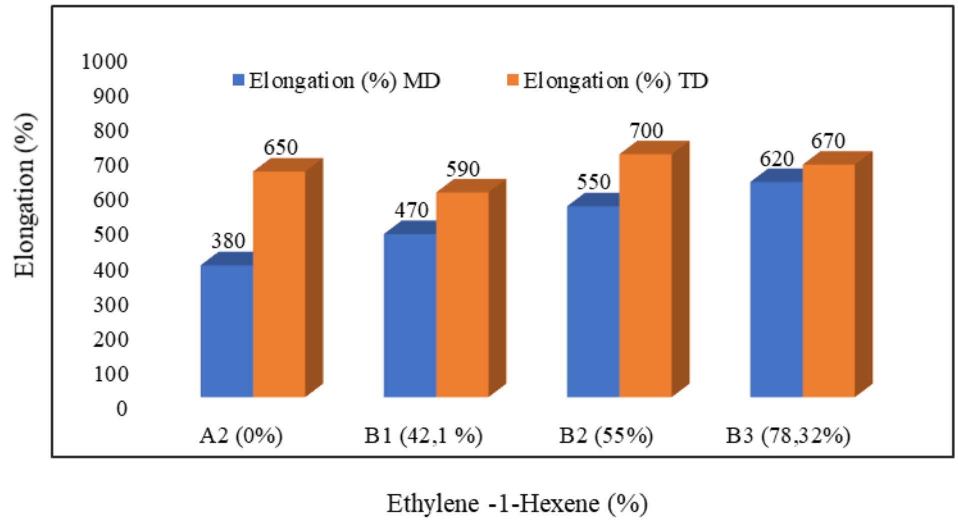


Fig. 6 Effect of Ethylene 1 Hexene Addition Amount on Elongation properties of stretch wrap plastic

3.2.2. Effect of Ethylene 1 Hexene Addition Amount on Tensile Strength properties of stretch wrap plastic

The introduction of ethylene-1-hexene (EH) enhances the elastic modulus of stretch wrap plastic, reinforcing the bond strength between molecules and imparting increased resilience against tearing. The tensile strength, a result of intricate interactions among various factors in material composition and production processes [11], is a crucial parameter reflecting the plastic's overall strength.

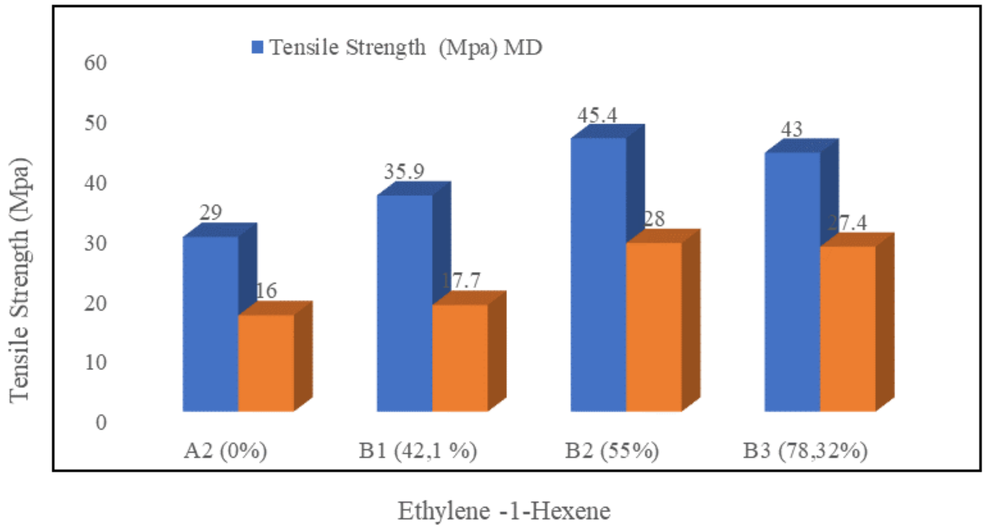


Fig. 7 Effect of Ethylene 1 Hexene Addition Amount on Tensile Strength properties of stretch wrap plastic

Examining Fig. 7, the influence of EH on the tensile strength of stretch wrap plastic is evident. Sample A2, devoid of EH, exhibits the lowest tensile strength value, while samples B1, B2, and B3, with added EH, demonstrate higher tensile strength values compared to sample A2. Interestingly, the percentage increase in EH does not proportionally correlate with the tensile strength value. Sample B2 stands out with the highest tensile strength, surpassing even the sample with the highest EH percentage, which is sample B3. The remarkable tensile strength of Sample B2, observed in the image, is attributed to its 43.5% LLDPE material composition, potentially representing an optimal balance between tensile strength and elasticity. This optimal LLDPE percentage contributes to resilience against strain and deformation. Sample B2 incorporates two ethylene-1-hexene fractions with distinct density and melt index (13% with Density: 0.918 MI: 1 and 42% with Density: 0.918 MI: 3.5). This combination may synergistically enhance the pull strength, exemplifying the intricate effects arising from the interplay between these two fractions.

3.2.3. Effect of Ethylene 1 Hexene Addition Amount on Cling properties of stretch wrap plastic

The incorporation of ethylene-1-hexene into the raw material for producing stretch wrap plastic induces increased adhesiveness through various mechanisms, such as bolstering intermolecular bonds, tensile strength, flexibility, heat and chemical resistance, and crystallinity [12]. Fig. 8 illustrates that, for a sample without the addition of ethylene-1-hexene, the obtained stickiness of the plastic is 10.2 mN. In contrast, samples with ethylene-1-hexene exhibit varying levels of stickiness: B1 (42.1%) with 10.2 mN, B2 (55%) with 9.62 mN, and B3 (78.32%) with 10.9 mN. A noteworthy observation is the decrease in stickiness in sample B2, despite sharing the same thickness as samples B1 and B3, which is 20 μm. This decrease is attributed to the composition of sample B2, as indicated in Table 1, where two types of ethylene-1-hexene are mixed, each with different melt index and density. This mixing lowers the overall melt index and density, resulting in decreased cling in the stretch wrap product.

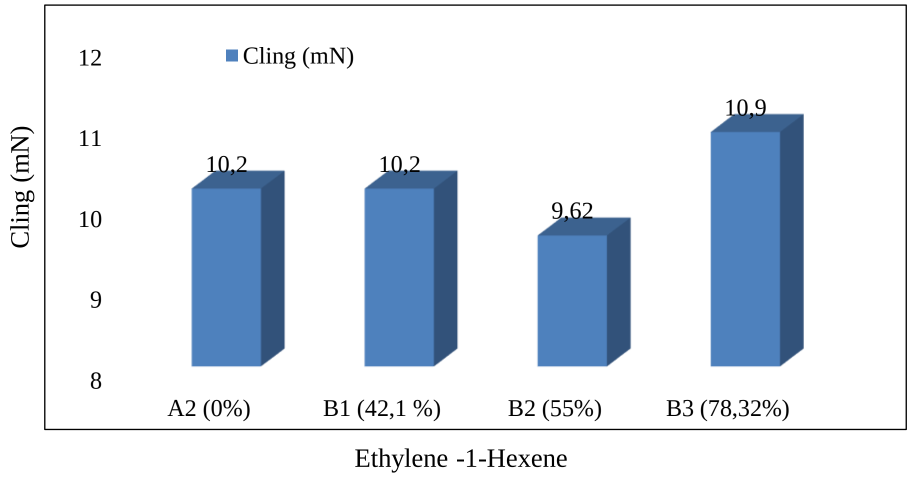


Fig. 8 Effect of Ethylene 1 Hexene Addition Amount on Cling properties of stretch wrap plastic

Samples B1 (42.1%) and B3 (78.32%), both possessing a substantial percentage of ethylene-1-hexene, exhibit high adhesiveness. This emphasizes that the addition of ethylene-1-hexene contributes to increased stickiness. Surprisingly, sample B2 (55%) displays lower stickiness despite its unique combination of two ethylene-1-hexene factions with distinct density and melt index, as well as different percentages of LLDPE and ethylene-1-hexene. This highlights the influential role of the combined percentage of ingredients. The addition of ethylene-1-hexene generally enhances stickiness, but its effects can be influenced by other factors such as density, melt index, and LLDPE percentage.

The results of the analysis indicate that the addition of ethylene-1-hexene in varying percentages (A1: 0%, B1: 42.1%, B2: 55%, and B3: 78.32%) has a notable effect on the mechanical characteristics of plastic stretch wrap. In general, the addition of ethylene-1-hexene renders the plastic stretch wrap more flexible by promoting a more uniform distribution of copolymer structures, thus enhancing its tensile strength. Additionally, copolymerizing ethylene with olefins, such as hexene, imparts greater elasticity to the material, increasing its elongation. While enhanced elasticity is desirable for achieving good elongation and recovery in plastic stretch wrap, excessive elasticity can render the material prone to tearing or breaking under stress. This loss of tensile strength, combined with reduced stiffness, compromises the material's ability to withstand mechanical stress, potentially leading to permanent deformation or structural failure. Therefore, the most efficient ethylene-1-hexene addition percentage identified in this research is B2 (55%).

4. Conclusion

The thickness of stretch wrap plastic affects its mechanical properties, namely: the thicker the plastic, the higher the elongation and tensile strength values will be. In addition, the thickness of streatch wrap will cause the stickiness to decrease, so the thinner the stretch wrap plastic, the higher the stickiness. The most efficient thickness is owned by samples A2, B2 and B3 which is 20 µm.

The addition of ethylene-1-hexene has the effect of increasing the elongation and tensile strength properties of stretch wrap plastic, but with a balanced percentage. The most efficient percentage of ethylene-1-hexene addition is 55%. The best stretch wrap plastic sample is sample B2 with a plastic thickness of 20 µm and a percentage of ethylene-1-hexene addition of 55%.

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