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Speed influence on the recycled high-density polyethylene/HDPE handles, tested with a specific adapted industrial method

Influencia de la velocidad en las asas recicladas de polietileno de alta densidad probada con un método adaptado específico industrial

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Abstract

This article studies the influence of the tensile speed when testing plastic products used to transport containers that may contain various liquids (drinking water, windshield fluid, cleaning agents, etc.). This case study was conducted on certain parts, generally called "handles", which are basically plastic items obtained largely from recycled technological waste resulting from the injection process of various packaging related to the food industry polyethylene caps and lids more precisely. During the handling and transport process, these parts are subjected to various static stresses, therefore, a minimum mechanical resistance is required. Fatigue stress has not been performed due to a limited number of duty cycles. To determine these quality characteristics, multiple measurements of tensile strength and elongations were performed at different traction speeds, measurements that have been validated on the market for several years. We have observed that testing speed over 500 mm/min is not necessary because the tensile strength values do not vary significantly. These results are very important in determining the constructive form of these products and the methods for validating quality indicators. Also, we have proposed to identify a method able to assess the mechanical performance of the product used in nonstandard conditions. The study can be used for a much wider range of similar applications in the plastics industry.

Keywords: tensile strength; elongations; recycling; handles; polyethylene; testing speed.

Resumen

En este artículo se estudia la influencia de la velocidad de tracción a la hora de ensayar productos plásticos utilizados para transportar contenedores que pueden contener diversos líquidos (agua potable, líquido parabrisas, agentes limpiadores, etc.). Este caso de estudio se realizó sobre determinadas piezas, generalmente denominadas “asas”, que son básicamente artículos de plástico obtenidos en gran parte de residuos tecnológicos reciclados resultantes del

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proceso de inyección de diversos envases relacionados con la industria alimentaria como tapas y cubiertas de polietileno. Durante el proceso de manipulación y transporte, estas piezas están sujetas a diversos esfuerzos estáticos, por lo que se requiere una mínima resistencia mecánica. La tensión de fatiga no se ha realizado debido a un número limitado de ciclos de trabajo. Para determinar estas características de calidad, se realizaron múltiples mediciones de resistencia a tracción y alargamientos a diferentes velocidades de tracción; estas mediciones han sido validadas en el mercado durante varios años. Se observó que la velocidad de prueba superior a 500 mm/min no es necesaria porque los valores de resistencia a la tracción no varían significativamente. Estos resultados son muy importantes para determinar la forma constructiva de estos productos y los métodos para validar los indicadores de calidad. También se propuso identificar un método capaz de evaluar el rendimiento mecánico del producto utilizado en condiciones no estándar. El estudio se puede utilizar para una gama mucho más amplia de aplicaciones similares en la industria del plástico.

Palabras clave: fuerza de tensión; alargamientos; reciclaje; manijas; polietileno; velocidad de prueba.

1. Introduction

Plastic materials are cheap, light, and durable and they can be used in a wide variety of industrial products and applications. As a result, plastic production has grown exponentially over the past 70 years. Rapid research and development in the field of petro-chemistry has led to an increasing number of polymeric materials that are available for a variety of applications [1].

Plastics can bring significant benefits in terms of lightweight, durability, and lower costs compared to many other types of materials. Unfortunately, the use and disposal of these products are causing more and more environmental problems.

Consequently, the International Regulatory Agencies have issued several directives [2], [3] which promote the concept of the Circular Economy and prioritize sustainable and non-toxic reusable products. The directives promote systems for reusing and reducing the amount of waste generated by them. The main regulations refer precisely to plastic products concerning this article which are summarized below:

-Plastic packaging, lids, and plastic closure systems [4], which are used for beverage containers, are among the most used plastic items on beaches. Therefore, beverage containers that are single-use plastic products should only be allowed to be placed on the market if they meet specific product design requirements that significantly reduce the impact on the environment. Mainly, technical solutions that do not allow the detachment of these components from the containers are searched out–the products used in this case study (handles) match well the provisions of this directive because they remain firmly attached to the containers they serve.

-Recycling is currently one of the most important actions that reduce the impact of waste offering opportunities to reduce the consumption of crude oil, carbon dioxide emissions, and the amount of waste that needs removal or neutralization [5], [6], [7], [8]. Consequently, recycling is a pillar in the circular economy, i. e. the treatment of post-consumer plastics. Colombia has also produced regulations for one-time plastic usage [6]. Moreover, according to Euromap [5] in 2020 (estimate), each person in Colombia uses about 28,4 kg of plastics every year, whereas in Brazil 33,4 kg and Argentina 38,7 kg.

Due to the wide range of recycling activities, it is recommended to use common terminology. In this respect, several International Standards can be used (ASTM D5033, ISO 15270).

Finally, according to ASTM D-7611 [9], polymers are labeled as shown in Figure 1. This is done this way to ease the post-consumer treatment and recycling.

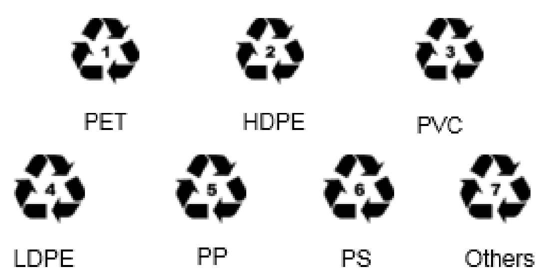
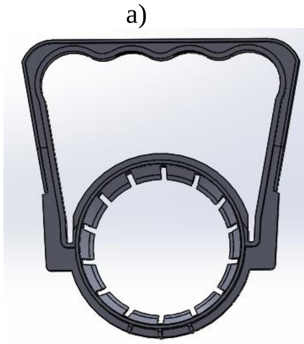


Figure 1. Polymers labeling according to ASTM D-7611

2. General considerations

An application often found in the food industry and not only is represented by products that facilitate the transport and handling of PET containers with volumes from 5 to 10 liters (Figure 2a) containing various liquids (drinking water, food oil, cleaning solutions, washable paint, various consumables in the automotive industry, etc.). These products are generally called "handles" (Figure 2b).

a)



b)

Figure 2. Handles: a) on PET bottles, b) Handle design in flat configuration.

These handles must meet certain quality, mechanical resistance, and ergonomic requirements. Cost criteria, environmental requirements, and new legislative requirements in the field of plastic product usage and recycling are important elements that determine the design, materials used, and the product manufacturing and testing process. These handles can be applied manually but in recent years, bottling companies have been equipped with automatic applicators [10] which require a compatible design with the operating system of these applicators (center of gravity position, geometric symmetries, easy orientation, correct application, etc.).

Currently, there are such handles on the market in different constructive variations and their weights differ between 5,5 and 11 grams [10], [11]. The most important technical parameter in the design of these handles is the *maximum Load* when this product is going to break. Broken handles are continuously observed on the market.

The handles are injection molded products, manufactured from HDPE material that might come from:

- Virgin resin
- Post-Industrial Resin (PIR): trash from production (trimming and cut-off, colour changes, process setup, quality rejects, samplings, etc.),
- Post- Consumer Resin (PCR): the resin has been used by end-consumers and is coming back to the production chain (so-called circular economy)
- Mixtures of virgin and recycled resins (PIR or PCR)

This article is related to Post Industrial Resin. In the cases when mixtures of different re-grinded materials are used, the physical-mechanical properties resulting from these blends might be affected [12], [13], [14], [15], [16].

It is generally recommended to sort out this waste by material type with the same melting temperature, [12], [16].

After the selective collection phase, the high-density polyethylene (HDPE) waste can be ground (in flakes) or re-granulated (in pellets) and stored in sealed containers. As there is not yet a defined universal protocol to assess the handles' performance, several methods to determine the tensile strength performance for this kind of product are employed by the bottlers, and we can mention even the "*Drop Test*" (Figure 3). For the bottlers the most important requirement is to have no broken handles.

Figure 3. Drop test method for handles resistance.

This is a very fast and simple method but for handle producers, it involves a lot of limitations in product design optimisation and recycled material usage. It is not considered a fully reliable method.

3. Materials and methods

In the first instance, it is important to know some of the Rheological and Mechanical Properties of the HDPE virgin material (ELTEX Superstress CAP 602) as reference. The specified values collected from the producer Material Data Sheet are presented in Table 1.

Table 1. Properties of the material tested (HDPE – ELTEX Superstress CAP 602)

Property	Conditions	Test Method	Value	Unit
Melt Flow Rate (MFR)	190°C/2.16 kg	ISO 1133-1	0.8 ±10%	g/10min
Tensile Strength at Yield	23°C, 50 mm/min	ISO 527/1, - 2	26	MPa
Elongation*	23° C 50 mm/min	ASTM D638-14	3-80	%

Source: Matweb: HDPE general data sheet.

As can be seen in Table 1, the speed of testing used to determine the Tensile Strength at Yield is *50 mm/min.*

3.1. Polymer samples

HDPE reground material, Eltex Superstress Cap 602, in flakes, has been used (Figure 4a).

As described in the article regarding "Influence of recycled material on the tensile strength of HDPE products", the most important condition to mix HDPE grades is the melting temperature [12], [13], [14], [15], [16]. For our case study, it is allowed to mix various colours as the colour of the final product is dark. Up to 100% of reground HDPE materials with different MFR can be used without compromising the product specifications.

Melt Flow Rate measurements for the reground material have been performed using a Gottfert MI-3 Plastometer (Figure 4b).

A total of 28 measurements of the MFR of reground material were performed, as seen in Figure 5 with an average MFR of 0.76.

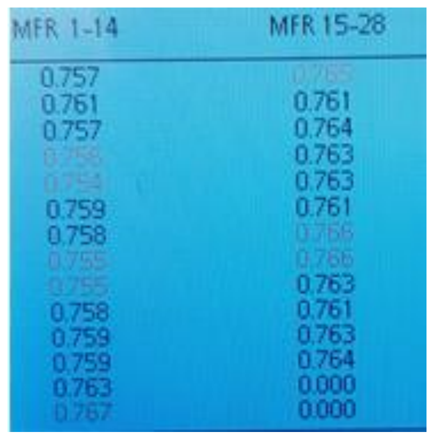


Figure 5. Screenshot of MFR measurements.

As can be observed, the measured values are well within specification.

a) b)

Figure 4. a) Reground flakes of HDPE material, b) Plastometer for MFR measurement.

3.2. Polymer samples

Five sets of handles are injected in the same mould, with the same design, and with the same material: 100% recycled (flakes) of HDPE Eltex Superstress Cap 602.

The process parameters are described below.

Mold data:

- Number of cavities: 16 (4x4)
- Single tip control
- Hot runner type, no sprue
- Cycle time: 13 seconds
- Clamping force: 220 KN
- Mold cooling temperature: 13-14 °C

Injection molding machine data:

- Producer: Klockner-Ferromatik
- Machine type: FM 250.
- Melt temperature: 240-245 °C
- Number of injection stages: 4
- Injection pressure: 150/130/80 bar
- Injection hold on pressure: 55 bar
- Injection speed: 300/200/170/50 [mm/s]

3.3. Mechanical testing

For material performance testing, the standards ASTM D 638-14 have been considered as benchmarking [17], [18], [19].

A Tinius Olsen H25KT universal testing machine was used to measure the tensile strength performance (Figure 6).

Figure 6. Tinius Olsen tensile testing machine.

The environmental conditions in the laboratory were set as follows:

- temperature: 22.6 °C
- humidity: 47.50 %

For the testing speed of 50 mm/s, given by the resin producer, the proposed reference for the resistance to breakage (max Load force) was defined at 500 N and the minimum allowed breaking force must be no less than 400 N. The maximum value of the load force is less important, but it can be roughly estimated at 700 N.

To test the handle's resistance, a dedicated device was built, as shown in Figure 7, to reproduce the grip and the real stress as accurately as possible.

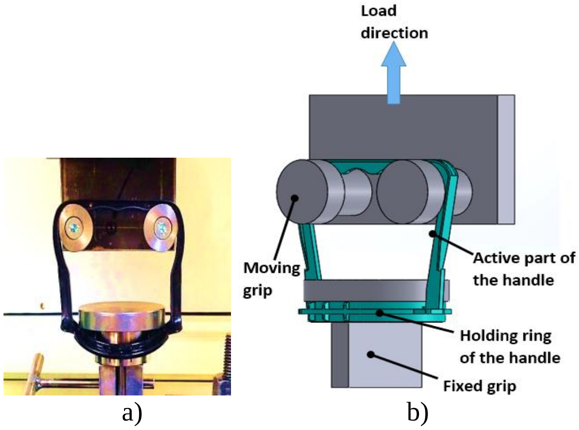


Figure 7. Experimental set up showing a handle mounted in the universal testing machine grips: a) Photo, b) Schematic.

Furthermore, the grips were designed and built to mimic the force exerted by a hand when picking up just one PET bottle.

The handles were subjected to tensile stress with a force (Load) set to a progressive increase between the minimum limit of 0 N and the maximum limit of 700 N, with different values of traction speed (between 50 and 50,000 mm / min) until the complete break was achieved. (Figure 8).

Figure 8. Handle breakage.

The handle in the flat configuration, shown in Figure 1b, is moving to the spatial configuration by applying the load force along the vertical axis. The active parts are staying now perpendicular to the holding ring.

Thus, in addition to the longitudinal tensile stress, the material is subjected to transversal stress also leading to the bending effect (Figure 9).

a) b)

Figure 9. Detail of handle: a) working in the vertical position, b) showing loading status.

In this way, the longitudinal tensile strength performance of the handle is affected, and the stress should be estimated.

The stress, σ, in an axially loaded component is estimated by equation (1).

$$\sigma = \frac{P}{A} \tag{1}$$

σ – Tensile strength in N/mm²
P – Load, in N
A – Original cross-section area (Figure 10)

Cross sectional area can be determined according to the equation (2):

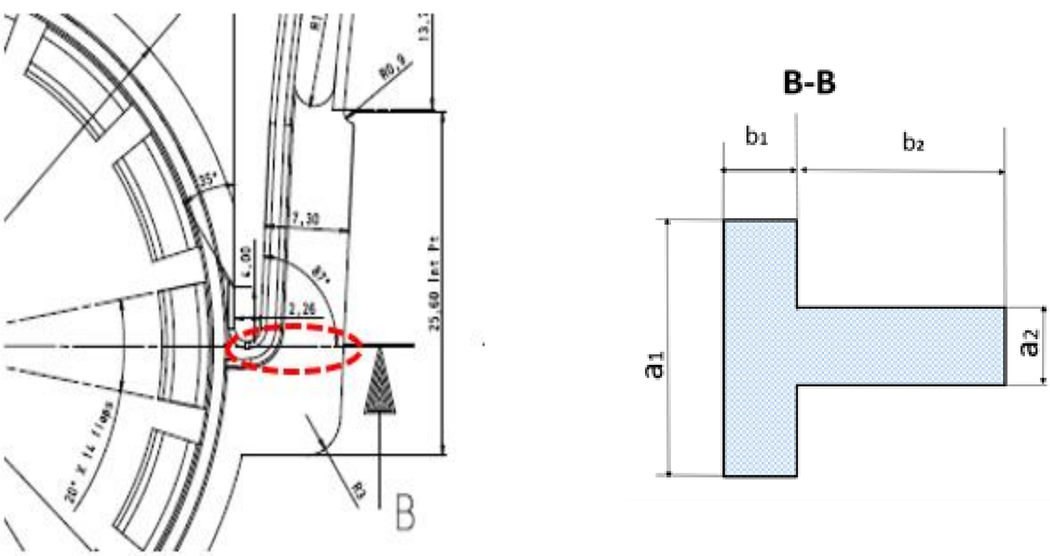
$$A = a_1 \cdot b_1 + a_2 \cdot b_2 \tag{2}$$

The critical area has the value: A = 22.7 mm²

If there is also an applied bending moment M, such as the case of an eccentrically applied force, the normal stress is computed through equation (3).

$$\sigma = \frac{P}{A} + \frac{Mc}{I} \tag{3}$$

where I am the second area moment and c the distance from the neutral axis to the evaluation point. In case c represents the furthest away point, the stress is then the maximum on the cross-section.



a) b)

Figure 10. Details of critical Cross-sectional area a) Position of rupture area, b) Original Cross section dimensions for the critical area.

The acting loads and the geometry for the top part of the handle are depicted in Figure 11 in a free body diagram (FBD). The handle has a 3º inclination. The acting force P is exerted by the universal testing machine, which is decomposed in the forces Fx and Fa. Therefore, in interest, Fx produces a bending moment (named M_1) and Fx produces axial tensile stress.

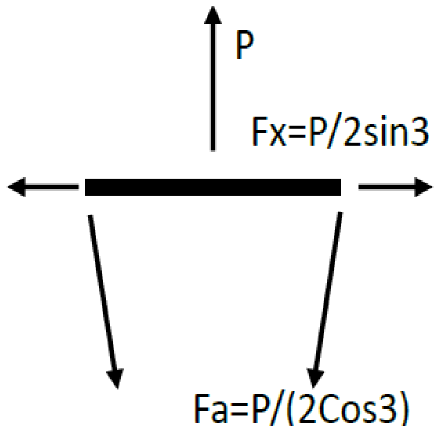


Figure 11. Free body diagram for the top handle.

Besides that, the handle is normally flat, so bending the handle to turn it vertically induces a moment, named M_2. The directions of bending moments, acting around interest, are shown in Figure 12 and all loads produce normal stress. One can see the stresses act simultaneously, so they can be superimposed using Equation (1).

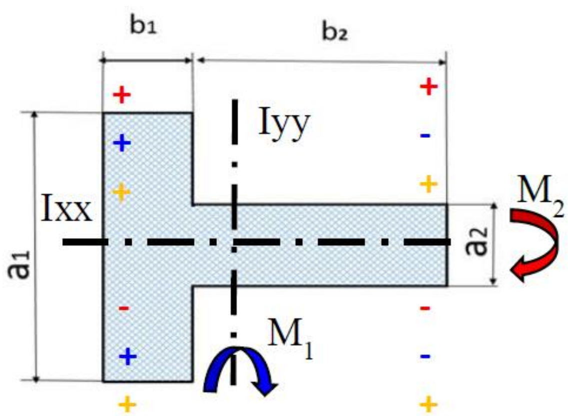


Figure 12. Schematics of stress state at the broken section.

Figure 12 are also shown the signs of the acting normal stresses. In the notation used, tensile is positive and compression is negative. Fa is always positive (shown in yellow), M_1 (shown in blue) produces tension on the left side of the neutral plane and compression on the right side, whereas M_2 (shown in red) produces tension at the top of the neutral plane and compression at the bottom of it. Furthermore, M_2 produces a constant stress value whereas the stress produced by M_1 is proportional to the applied load. However, it fades when the handle is aligned with the load, as shown in Figure 4, which happens before rupture. Therefore, in the end, only axial normal stress is in play.

4. Outcome

The average values of the load and elongation for each set of measurements are presented in Table 2.

Table 2. Average values of load and elongations

Test Speed [mm/min]	Load [N] Avg(min/max)	Elongation [mm] Avg
50	564(451/631)	36,2
500	473(410/585)	18,9
1,000	466(403/541)	17,7
10,000	460(385/546)	15,1
50,000	456(390/505)	11,8

The evolution of the Loads and Elongations until the moment the breaking occurs can be seen as an example, in Figure 13.

Figure 13 depicts the product comportments along with the tensile test:

- In the first region, the load and elongation are increasing up to the point YP.
- The points YP, usually called *yield point*, is the first point at which an increase of elongation (strain) occurs without an increase of the load (stress). The handle still does not break. At this point, the maximum *Load* has been recorded.
-After the YP, the material continues to elongate up to point C, the cross-section continues to reduce but without any fatal rupture.
- At the BP point, called *rupture point*, the complete rupture of material occurs, and the handle is breaking. At this point, the total/maximum deformations (elongations) have been recorded.

The distribution of measured values of Load force (tensile strength) and elongation, are shown in Figure 14 and Figure 15, respectively [20].

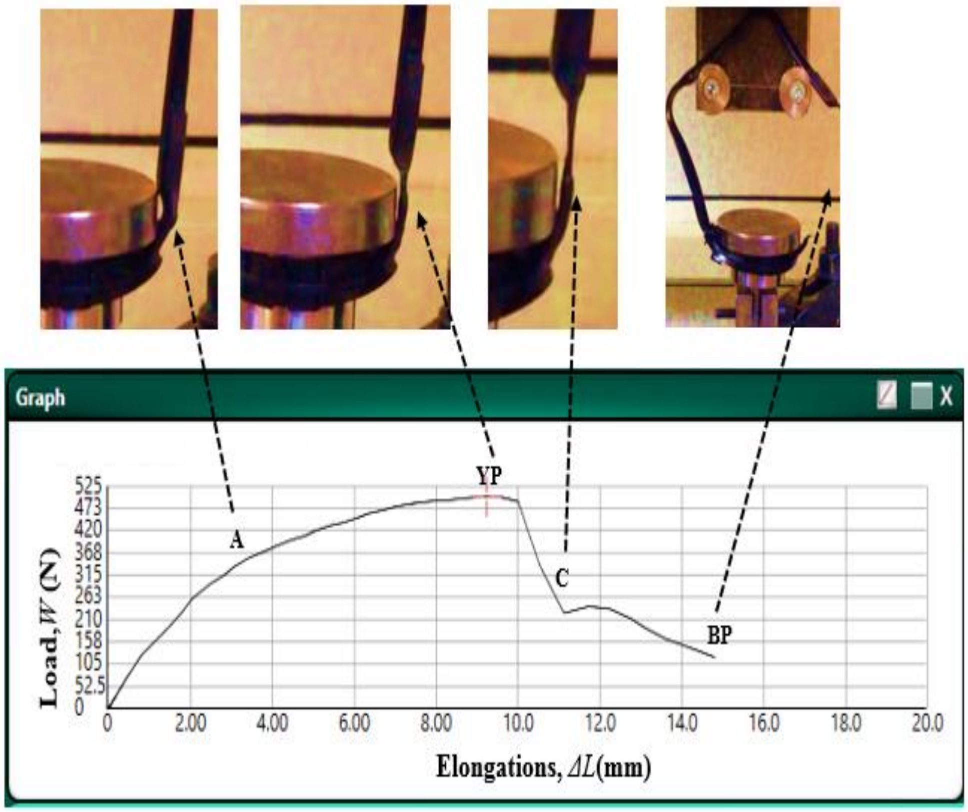


Figure 13. Evolution of the Load and Elongation until the moment of breaking.

It must be emphasized that the calculated stress is tensile strength, as shown in Equation (1) and the elongation is the value given by the universal testing machine.

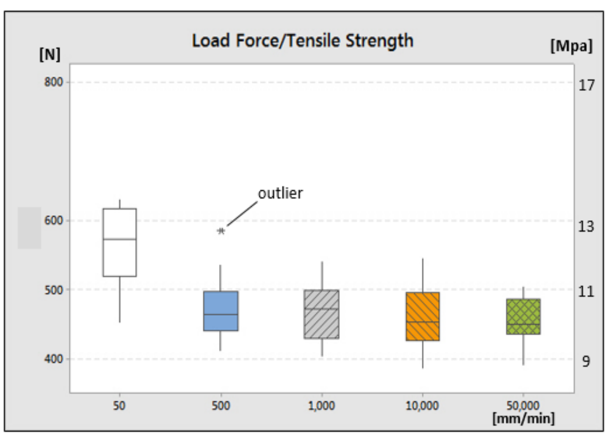


Figure 14. Load force and Tensile Strength for different testing speeds.

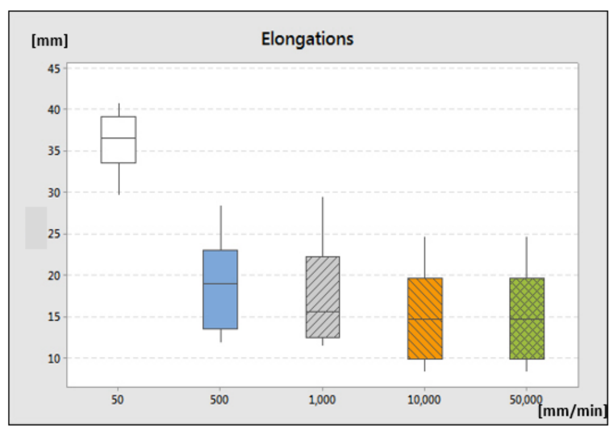


Figure 15. Measured elongation for different testing speeds.

From Figure 14 and Figure 15 we can observe:

• The best results of the Load force (tensile strength) were obtained at the speed of 50 mm/min which is the reference value of the tensile strength, in the material specification sheet.

• By increasing the speed from 50 to 500 mm/min, the tensile strength performance of the handles decreased.
• By increasing the speed over 500 mm/min, the tensile strength stabilizes at approximately the same value, until the speed of 50,000 mm/min is reached. These high-speed values correspond to a very hard stress regime and simulate the real "shaking" phenomenon happening on the market.
• The elongation decreases continuously by increasing the testing speed.
• The outlier observed in Figure 14 is defined as an unusual value, as long is over than upper whisker this might be ignored.
• The reference value of tensile strength σu which is given in the material specification with a value of 26 MPa. as seen in Table 1. We notice that in all cases, the measured tensile strength was far below this reference value. As already described above, this aspect can be explained by the fact that by bringing the handle into the working position, it suffers an additional bending stress.
• A slightly lower value on cavity no.6 at the test speeds over 10,000 mm/min has been observed. This is not leading to product rejection, but it might be a warning sign for the machine operator that the process capability starts to deteriorate. Mold filling and injection parameters should be investigated for this case (wearing on injection nozzle, injection pressure to low, dust on the injection gate of cavity 6, etc.).
• All handles break in the opposite side of the injection point, this is the area where each individual cavity of the mold, is filling last. The flow of melted material from different directions creates an effect of "welding" when the streams of material join (Figure 16).

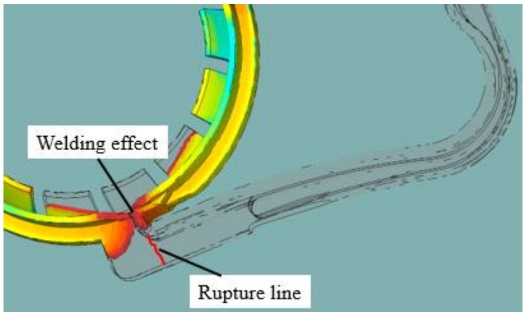


Figure 16. Welding effect on the injection process.

As observed, the part always breaks in the same place, this may be indicative of mold design issues since the flow lines would not be compensated concerning the geometry of the mold.

One possible solution is to relocate the injection point to improve the flow in the cavity (Figure 17).

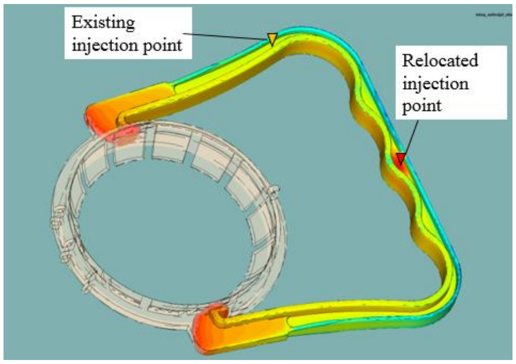


Figure 17. Relocated injection point option.

Two injection points simulated by CADMOULD software might be the best technical solution required by the complex geometry of the piece (Figure 18).

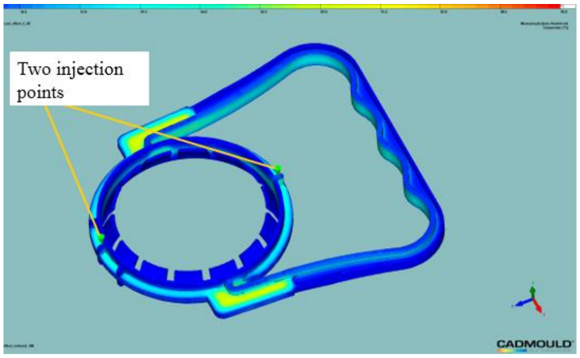


Figure 18. Two injection points option.

The flow lines are compensated, the material solidifies after filling the cavity completely and the cooling time is also improved. This improvement might solve also the issue detected at cavity 6. But this solution needs to be validated by economical study, as the costs for the new Hot Runner configuration will increase significantly.

It is difficult to compare handle behaviour with a standard test specimen comportment, but we found this method as the best available tool to evaluate the mechanical performance of these products.

5. Conclusions

For the qualitative determinations of the tensile strength performance, for this type of products, it is recommended to use the test speed of 500 mm/min. The use of this limit speed is since above this, the tensile strength values do not vary significantly. In this way, it will be easy to correctly perform a real benchmarking between similar products on the market.

The most important parameter is the Breaking Force referred to in this study as maximum Load. The nominal (target) value should be defined at 500 N and the minimum value at 400 N, at a testing speed of 500 mm/min.

Such models can be very useful in increasing the degree of recycling of plastic waste at the source, either by capitalizing on products with similar properties or by downgrading to different products where mechanical performance is less restrictive.

Depending on the specifications of the finished product, obtained from recycled materials, one can establish which are the mechanical properties and the necessary parameters to be tested. In this sense, the parameters tested in this study are not limitated.

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References

[1] MATWEB, "Overview of materials for High Density Polyethylene (HDPE), Injection molded," [Online]. Available: www.matweb.com/search/DataSheet.aspx?MatGUID=fce23f90005d4fbe8e12a1bce53ebdc8

[2] Directive 2019/904 of the European Parliament and of the Council, "Reduction of the impact of certain plastic products on the environment", 2019. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2019/904/oj

[3] California Legislative information, "AB-319 Recycling: single-use plastic beverage container caps,". 2017. [Online]. Available: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB319

[4] Marketsandmarkets, "Plastic Caps and Closures Market - Global Forecast to 2023," [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/plastic-caps-closure-market-132939537.html

[5] Euromap, "Plastics Resin Production and Consumption in 63 Countries Worldwide," 2016. [Online]. Available: https://www.pagder.org/images/files/euromappreview.pdf

[6] Ministerio del Medio Ambiente, "Plan Nacional para la Gestión Sostenible de los Plásticos de un solo uso," Bogotá, Septiembre 2019.

[7] Green Alliance Annual Report, [En línea]. Available: https://green-alliance.org.uk/resources/AnnualReports/Annual_Review_2019-20

[8] M. G. S. Bicket, M. Hestin, C. Hudson, P. Razzini, A. Tan, P. ten Brink, E. van Dijl, R. Vanner, E. Watkins, "Scoping study to identify potential circular economy actions, priority sectors, material flows and value chains," Office of the European Union, Luxembourg, 2014, doi: 10.2779/29525.

[9] ASTM, "ASTM D7611. Standard Practice for Coding Plastic Manufactured Articles for Resin Identification," West Conshohocken, PA, 2020.

[10] And & Or, "Handle aplicator systems," [Online]. Available: https://andyor.com/en/handle-applicators/#neck

[11] Vieira Araujo, "handles products," 2020. [Online]. Available: https://www.vieiraaraujo.pt/en/highlights

[12] J. Hopewell, R. Dvorak, E. Kosior, "Plastics recycling: challenges and opportunities," *Phil. Trans. R. Soc. B*, vol. 364, p. 2115–2126, 2009, doi: 10.1098%2Frstb.2008.0311.

[13] M. K. Akkapeddi, B. V. Buskirk, C. D. Mason, S. S. Chung, X. Swamikannu, "Performance blends based on recycled polymers," P*olymer Engineering and Science*, vol. 35, pp. 72-78, 1995, doi: 10.1002/pen.760350110.

[14] M. R. Shishesaz, A. A. Donatelli, "Tensile properties of PE Blends," *Polymer Engineering and Science*, vol. 21, no. 13, pp. 869-872, 1981.

[15] R. Brown, *Handbook of polymer testing*. Boca raton: CRC Press, 2020.

[16] D.F. Teusdea, V.D. Stan, M. Voda and E.C. Lovasz, "Study on the influence of recycled material on the tensile strength of HDPE products", *IOP Conf. Series: Materials Science and Engineering*, 916, 012119, 2020, doi: 10.1088/1757-899X/916/1/012119.

[17] ASTM, "D638-14. Standard Test Method for Tensile Properties of Plastics," 2014.

[18] ISO, "ISO 527-2. Plastics-Determination of Tensile Properties-Part 2: Test Conditions for Molding and Extrusion Plastics," Geneva, Switzerland, 2012.

[19] M. Amjadi, A. Fatemi, "Tensile behavior of high-density polyethylene including the effects of processing technique, thickness, temperature, and strain rate," Polymers (Basel), vol. 12, no. 9, 2020, doi: 10.3390/POLYM12091857.

[20] Minitab 18 "User Guide", [Online]. Available: https://support.minitab.com/en-us/minitab/18/